# LABORATOIRE TRAITEMENT ET COMMUNICATION DE L'INFORMATION

**Bilan 2008-2013 et perspectives 2015–2019**


Ce document regroupe tous les éléments du dossier d'évaluation du **Laboratoire Traitement et Communication de l'Information** (LTCI – UMR5141) pour la période 2008–2013 :

1. **Présentation de l'unité** Cette partie rédigée en anglais correspond à la partie I du document ; l'ensemble des données factuelles ayant été rassemblées dans le chapitre B.
2. **Réalisations de l'unité de recherche** Cette partie rédigée elle aussi en anglais est **structurée par équipes**, numérotées de 1 à 14 et présentées dans les parties II à IV qui matérialisent la structuration intermédiaire du laboratoire en *départements*. Pour faciliter la lecture, **chaque rapport d'équipe comporte l'ensemble des annexes qui sont pertinentes à ce niveau : présentation synthétique (annexe 1), liste des réalisations (annexe 6) et liste des thèses (annexe 7) ; la présentation synthétique figure en tête du rapport de chacune des équipes**. En ce qui concerne les publications communes à plusieurs équipes, celles-ci apparaissent dans les rapports de chaque équipe mais sous une numérotation unique à l'échelle de l'unité.
3. **Implication de l'unité dans la formation par la recherche** Cet aspect est traité au sein des chapitres consacrés aux équipes (contribution aux master listées en fin de la présentation synthétique et liste des thèse dans la section finale de chaque chapitre).
4. **Stratégie et perspectives scientifiques de l'unité** La partie stratégique, rédigée en français, correspond à la partie V du document.

**Annexes**

**Annexe 1 : Présentation synthétique** Comme indiqué ci-dessus, cette présentation synthétique a été préparée au niveau des équipes et figure en tête des chapitres 1 à 14 (section *Executive summary*).

**Annexe 2 : Lettre de mission contractuelle** NA

**Annexe 3 : Équipements lourds** NA

**Annexe 4 : Organigramme fonctionnel** Figure en page 18 dans le chapitre B

**Annexe 5 : Règlement intérieur** Celui-ci est reproduit dans le chapitre E avec la composition actuelle du conseil de laboratoire.

**Annexe 6 : Liste des réalisations** Elle est présentée au niveau de chaque équipe, dans la section *Achievements*.

**Annexe 7 : Liste des thèses** Elle est présentée au niveau de chaque équipe, dans la section *PhDs*.

**Annexe 8 : Document unique d'évaluation des risque** NA

**Annexe 9 : Liste des personnels** Elle figure dans le chapitre F.

# Table des matières

# Part I

# Presentation of the LTCI lab

# Chapter A

# Overview

This chapter provides a global vision of the LTCI lab for the period 2008 – mid 2013. All figures and facts have been gathered in Chapter B for easier reference.

## A.1 Context and Scope of the Report

LTCI *(Laboratoire Traitement et Communication de l'Information)* is a joint laboratory (*Unité Mixte de Recherche*) between the CNRS *(Centre National de la Recherche Scientifique)* and the engineering school Télécom ParisTech (formerly known as Télécom Paris or ENST). Since 2003, all the research activities of Télécom ParisTech are encompassed within LTCI which thus gathers researchers both from fields related to Information and Communication Technologies (ICT), for about 80% of them, and from Social and Economic Sciences (SES). This positioning is quite unique within French academic research labs. The research activities of LTCI range from the hardware layer (microwaves, antennae, electronics, opto-electronics, SoC, ...), to the econonomic and social issues of new communication technologies. They cover protocol and standardization aspects as well as mathematical ones (graph theory, optimization, probabilities, statistics). They encompass studies on audio, video and images as well as works on network performance and services, or quantum cryptography issues.

In the next five year period (starting from 2015) the SES component of LTCI will evolve to become part of a new joint lab centered on the study of Innovation (*Institut Interdisciplinaire de l'Innovation*) from the point of view of social sciences at large (management, economy, sociology, design) and involving external partners (Mines-ParisTech and Ecole Polytechnique). In this perspective, **the current report focuses on the sole activity of the part of LTCI that is relevant to ICT for the period ranging from 2008 to mid 2013**[1]. In the following, *mentions of the LTCI lab should thus be interpreted as pertaining to the ICT component of the LTCI only*.

Moreover, the structure and the management of the lab has evolved in early 2013 with the retirement of Henri Maître who has been managing the LTCI lab since 2003 and was simultaneously director for research of Télécom ParisTech. The LTCI lab is now headed by Olivier Cappé, who has been deputy director with Henri Maître since 2009, and Patrick Duvaut (formerly professor at ENSEA in Cergy) has been appointed as director for research of Télécom ParisTech. In the following, *the structure of the LTCI lab is presented in its current form*, which has been adopted since March 2013.

The next paragraphs of this section briefly present some further relevant elements of the context of the LTCI lab.

1. The detailed assessment of our activity in SES for the same period is available in a separate report

### A.1.1 The Lab's Funding Institutions

Télécom ParisTech is a leading French higher education institution in the domain of ICT. Its ambition summarized by its motto " innovating in a digital world" is to train students either during their initial engineering studies or through life-long learning to develop a high-level of both technical and entrepreneurial skills. Télécom ParisTech hosts about 800 engineering students, 70 Master students and 300 PhD. students

Télécom ParisTech belongs to the Institut Mines-Télécom group (formerly known as Institut Télécom or GET) of French higher education institutions. The Institut Mines-Télécom is the leading group of engineering schools in France, with a network of twelve schools [2] located throughout the national territory. Among those schools, Eurecom, located in Nice Sophia Antipolis, has strong connections with Télécom ParisTech as it hosts students from Télécom ParisTech as well as a limited number of its faculty members (six faculty members in total, in the domains of SoC and sociology, who are also member of the LTCI). The Institut Mines-Télécom plays an important role in the scientific strategy of the LTCI, notably through it yearly funding program *Futur et Ruptures* which provides funding of PhD theses and postdocs that serves all the schools affiliated to the Institut, with a significant fraction of them being awarded to LTCI (the call funds between ten and twenty PhDs and postdocs and about a third of them are attributed to the LTCI lab).

Télécom ParisTech is also a member of the ParisTech alliance of Parisian *Grandes Ecoles*. The role of ParisTech has evolved through the period: initially conceived as a PRES (*Pôle de recherche et d'enseignement supérieur*) in 2007, it is now mostly active in the fields of industrial and international partnerships. In 2013, ParisTech opened a school on the Shanghai Jiao Tong campus (China) as well as the Institut Villebon-Georges Charpak (in Palaiseau), both projects in which Télécom ParisTech plays a major role.

The LTCI lab was founded jointly by Télécom ParisTech and the CNRS in 2003 as a successor to a former joint lab (called URA820) which was started in the 1990's around the themes of signal processing and communications. The CNRS (*Centre National de la Recherche Scientifique*) is the major public organization for research that is present in all research fields. The CNRS contributes to the scientific management of LTCI and allocates several full-time researchers (21 as of mid 2013) to the lab. Within the CNRS, LTCI is managed by the Institute for Information Sciences and Technologies (INS2I) but also conducts some research that is relevant to the domains of the Institutes for Engineering and Systems Sciences (INSIS) and Mathematical Sciences (INSMI).

### A.1.2 The *Université Paris Saclay (UPSay)* Project

Both the CNRS and the Institut Mines-Télécom are founding members of the Université Paris Saclay (UPSay) project which is poised to become a world-class campus by gathering several higher education institutions physically located in the south-west of Paris (within a triangle which goes from Palaiseau to Gif-sur-Yvette and St Quentin en Yvelines). The campus will not only be limited to research and education centers as several major French companies (including, among others, Thales, EDF and Danone) are also currently migrating (or have already installed) their research activities on the campus.

The UPSay project was funded though the *Investissements d'Avenir* program in 2012 and a new public organization called *Université Paris Saclay* will be created (as a *Communauté scientifique d'universités et d'établissements*) in early 2014. For Télécom ParisTech, the project also implies to move to a new location in Palaiseau in a building to be constructed. The construction process in underway (with an architectural project that has been revealed during the fall 2013) and the move is planned to occur for the academic year 2017–2018.

Télécom ParisTech, as part of the Institut Télécom, joined the RTRA (*Réseau Thématique de Recherche Avancée*) Digiteo in 2009. At the time of its creation Digiteo was the only Excellence cluster in information science and technology in France, situated in the Paris-Saclay Campus.

2. Mines Albi, Mines Alès, Mines Douai, Mines Nantes, Mines ParisTech, Mines Saint-Etienne, Télécom ParisTech, Télécom Bretagne, Télécom SudParis, Télécom Business School, Télécom Lille1, Eurecom.

Digieto is expected to evolve in 2014 into the ICT department of UPSay as an instrument of coordination between the main research labs of the field present in the Paris-Saclay site. More generally, Télécom ParisTech has been instrumental in the definition of the main instruments of UPSay in the domain of ICT: the Engineering and Information Sciences and Technologies School which coordinates engineering studies, the PhD program on ICT (scheduled to start in 2015) and the ICT department mentioned previously.

## A.2 Organization

The organogram of LTCI is shown on Figure B.1 (in Chapter B) together with supporting staff (in the administrative and management domains) from Télécom ParisTech. The lab follows Télécom ParisTech organization into three research and teaching departments. From an organizational point of view, each departement is managed by the department head who is also responsible for the adminsitrative staff of the department and the relationships with Télécom ParisTech's supporting services (human ressources, financial accouting, partnership and development). Ressources (human and financial) managed by the CNRS are under the direct responsibility of the director of the LTCI lab (in terms of permanent personnel CNRS is providing 15% of the lab's staff and about 10% of the grants and contracts are managed by CNRS).

The **Communications and Electronics (COMELEC)** department headed by B. Thedrez focuses on the communication and networking tasks with researches that range from the physical layer of ICT (electromagnetism, optical components) to performance evaluation of large-scale communication systems, including works on mixed (analog and digital) signals or safety against physical attacks or digital systems. The department consists of five groups [3]:

1. **Radio Frequency and Microwave (RFM)**, headed by Xavier Begaud
2. **Optical Communications (GTO)**, headed by Didier Erasme
3. **Circuits and Communication Systems (C2S)**, headed by Patricia Desgreys
4. **Complex Digital Electronics Systems (SEN-LabSoC)**, headed by Jean-Luc Danger and Renaud Pacalet
5. **Digital Communications (ComNum)**, headed by Philippe Ciblat

The SEN-LabSoC group merges two sub-groups working on related topics (Systems on Chip, safety and reliability of digital communication systems) with the SEN component being located in Paris while the LabSoC is hosted on Eurecom's campus in Sophia Antipolis. The RFM group has been reinforced in 2009 with the arrival of two staff members from ENSTA ParisTech working on propagation channels, antennae, and electromagnetic propagation. This coordination of effort between Télécom ParisTech and ENSTA ParisTech also led to the transfer of the technical means of the anechoïc room of ENSTA ParisTech to the LTCI. Since 2008, the ComNum and GTO groups have been jointly developing a new scientific project to develop very high rate optical communications, taking benefit of their complementary expertise in coding and signal processing and the one hand and optical transmission on the other hand.

The **Networks and Computer Science (INFRES)** department is headed by Gérard Memmi (since 2009) and focuses, as the name suggests, on various aspects of computer science (embedded and real time systems, information retrieval and web mining, cryptography, ...) with a strong emphasis on networks (performance evaluation, network control and monitoring, design of innovative network services). The department is organized in five groups:

6. **Network, Mobility and Services (RMS)**, headed by Jean-Louis Rougier
7. **Software, Systems and Services (S3)**, headed by Elie Najm
8. **Interaction, Cognition and Complexity (IC2)**, headed by Talel Abdessalem
9. **Network and Information Security (SR)**, headed by Jean Leneutre and Isabelle Zaquine

3. See table B.1 in Chapter B for the complete list of research groups with a summary of their staff and research themes.

10. **Mathematics of Information, Communications, and Computation (MIC2)**, headed by Olivier Hudry

The SR group is composed of two sub-groups focused on different topics within the domain of computer security: security of network communications and services on the one hand and information security of quantum communications on the other hand. This gathering of security-oriented researchers from several groups of the INFRES department took place in 2009 as a an answer to the growth of the network security activity (see detailed report of the group activities in Chapter 9). Other thematic evolutions during the 2008–2013 period include the strengthening of a sub-group of the IC2 group on data management and web mining, with the recruitment of Pierre Senellart in 2008 and Mauro Sozio in 2011 as associate professors. The sub-group, called DBWeb, now includes five permanent researchers working on the foundations of databases, information retrieval and web data mining.

The **Signal and Image Processing (TSI)** department headed by Yves Grenier covers all aspects of signal and image processing (computer graphics and 3D images, video coding, audio applications, medical imaging, statistical signal processing...) with sub-groups specialized in further topics such as emotional aspects in human-agent interactions or statistical learning. The department is organized in four groups:

11. **Audio, Acoustics and Waves (AAO)**, headed by Gaël Richard
12. **Image Processing and Understanding (TII)**, headed by Isabelle Bloch
13. **Multimedia (MM)**, headed by Béatrice Pesquet-Popescu
14. **Statistics and Applications (STA)**, headed by Stephan Clémençon

During the period, major thematic evolutions include the creation of a sub-group of the TII group (started with the arrival of Tamy Boubekeur in 2009) focusing on selected aspects of Computer Graphics (geometrical modeling and rendering); a group which now incorporates two additional CNRS researchers (recruited in 2010 and 2011). Another evolution concerns the MM group and the theme of affective computing which has been developed by Catherine Pelachaud since her recruitment as a CNRS senior research scientist in 2008. The group, which has been joined by Chloé Clavel as associate professor in 2012, is in particular developing an open platform called GRETA which makes it possible to control a 3D embodied conversational agent by specifying communicative intentions and behaviors. Recently, the STA group, which has seen an important turnover (with the departure of four CNRS research scientists in 2012 and two professors in 2013 and the arrival of one associate professor in 2012) has evolved towards large scale machine learning applications. Likewise the AAO group, whose size has been reduced during the period (with the departures of two professors and one research scientist), has recruited Alexandre Gramfort (in 2012) who is bringing a new research direction on brain signal analysis in collaboration with the CEA Neurospin.

Overall, the permanent staff of the LTCI consists of **21 researchers from CNRS** (13 junior research scientists and 8 senior research scientists) [4], **109 professors from Télécom ParisTech** (61 of them being associate professors and 48 full professors), **14 engineers and 3 technicians** and 19 people in the administrative staffs working primarily in the service of research. The detailed evolution of the staff of permanent researchers and professors is given in Table B.2. Figure B.2 displays the same numbers using the conventional notion of Equivalent Full-Time Researchers (in which Professors are counted for only half of their time, assuming that the other half is devoted to teaching). It can be observed that the main event of the period is a significant drop which occurred in the academic year 2011–2012 (mostly due to the departure of four CNRS researchers for external opportunities together with four additional retirements).

In mid 2013, the non-permanent staff includes **72 postdocs and non-permanent researchers** (65 of whom are Télécom ParisTech employees and 7 are CNRS employees) and **222 PhD students**, including 58 *CIFRE (Convention industrielle de formation par la recherche)* PhDs who

4. In the groups' reports we used the following acronyms: JRS for Junior Research Scientist *(Chargé de recherches)*, SRS for Senior Research Scientist *(Directeur de recherches)*, AP for Associate Professor *(Maître conférences)*, FP for Full Professor *(Professeur)*.

are employees of industrial partners of the lab and 8 PhDs in *co-tutelle* who are jointly supervised between members of the lab and foreign academic partners. The lab also benefits from the presence of 3 research associates and 8 emeritus professors and researchers who are actively contributing to our research. The lab has an important potential for supervising doctoral students as **72 of its members have an *Habilitation à diriger des recherches (HdR)*** (15 among the researchers and 57 among the professors). On average, 5 new HdR have been obtained by members of the lab every year in the period between 2008 and 2012. Table B.3 shows that the number of defended PhD theses is very stable over the period around 60 per year with an average duration slightly above 40 months. As of mid 2013, the large majority of PhD students are either CIFRE PhDs —for 25% of them— or employed directly by Télécom ParisTech (under a so-called *Contrat doctoral*), for 65% of them. The rest of the non permanent personnel mostly correspond to postdocs and research associates, as about 57% of them already have a PhD.

The lab's PhD students are affiliated (for all but a few exceptions) to the EDITE (ED130), *Ecole Doctorale Informatique, Télécommunications et Electronique*, doctoral school. The doctoral school is managed by Christian Queinnec (Université Pierre et Marie Curie) and Alain Sibille serves as deputy director, managing in particular PhD students of the LTCI lab. Members of the lab are actively involved in teaching at the M2 (2nd year of master) level in several Parisian, masters as shown by table B.4. Most of the PhD students from LTCI are recruited within the masters listed in table B.4.

A current diffculty for the lab is the complexity caused by the fact that Télécom ParisTech has premises in three different locations, located roughlty at a 20mn distance walking distance of each others: nearly all teams [5] of the COMELEC department are located in the historical buildings of Télécom ParisTech at 46 rue Barrault (Paris 13) together with Télécom ParisTech's students and administrative services; the staff of the INFRES departement is splitted between 46 rue Barrault and a second site in 23 avenue d'Italie (Paris 13); and finally, all groups of the TSI departement except the TII group (which is hosted in the Barrault site) are in a third site located at 37/39 rue Dareau (Paris 14). In terms of overall capacity these premises are appropriate for the lab but their dispersion hinders communications within the lab or with students of Télécom ParisTech.

## A.3 Achievements

The scientific production of LTCI in the period 2008–2012 can be gauged from Table B.5 in Chapter B. Note that the very last year of the period is often atypical due to a number of publications not properly registered, being for instance only submitted an not yet accepted. Here, this effect is combined with a peak in the scientific production in 2011 which can be explained by the important number of departures of researchers that occurred the next year (see Figure B.2): between 2008 and 2011, the scientific potential of the lab has been increasing steadily (by nearly ten percent) and then dropped significantly in 2012, a decrease that has been only partly compensated since then. Globally, the production is stable over the period at an average of **175 journal papers and a little more than 400 conference publications per year**, which is a significant production given our permanent research staff of 109 professors and 21 researchers (see Table B.2 for evolutions over the period).

On a more qualitative level, each research group has highlighted in its report (in the executive summary) five publications that are considered by the group as the most significant of the period, considering the publication standards of its research field. Although we do not provide systematic bibliometric data at the lab level, let us simply note that **according to Google Scholar,** there are 44 publications from members of the lab in the period (ie. published since 2008) that have been cited at least 50 times. And among those, **the ten most cited publications have been cited at least 90 times**. Interestingly these highly cited publications can be found both in flagship ICT journals and conferences (IEEE Transactions on Speech and Audio Processing, Multimedia or

5. Some PhD students of the SEN-LabSoC group are at the 37/39 rue Dareau and the LabSoC subgroup is hosted on Eurecom's campus in Nice Sophia-Antipolis.

Information Theory, IEEE INFOCOM Conference on Computer Communications...) but also in journals that lie outside of the scope of ICT in domains such as Physics (Physical Review Letters, New Journal of Physics) or Statistics (Annals of Statistics, Journal of the Royal Statistical Society) as well as in very specialized venues such as, to name but a few, the journal Fuzzy Sets and Systems or the ACM CHI Conference on Human Factors in Computing Systems.

These numbers suggest a very good visibility which is corroborated by Table B.6 that confirms that the research carried at LTCI enjoys a high reputation with several members of the lab having been distinguished by awards and distinctions since 2008. In addition to those, other markers of scientific recognition such as paper awards in conferences, membership of editorial boards of journals or of program committees of major conferences are listed in the groups' detailed reports.

This academic production is accompanied by an average of 13 patent applications per year with co-inventors from LTCI, 72% of which are directly filed by the lab (see details in Table B.7). During the last semester of 2012, Télécom ParisTech introduced a new internal process to speed up registering of patents and avoid delaying scientific publication (by using provisional patents), which is expected to increase our production in this domain. Several research groups are also contributing to software as documented in the groups' reports. Three of the patents mentioned in Table B.7 have been transferred to spin-off companies that have been created during the period (see Table B.8).

Table B.9 shows that the resources obtained from contracts and grants are very significant (of the same order as the total cost of personnel directly in the service of research) and have been increasing regularly over the period, progressing of more than 30% between 2008 and 2012. These amounts correspond to public funding (French and European funding agencies, direct funding from ministers, etc.) for about 74% of them, the rest corresponding to direct bipartite contracts with industrial partners. The significance of these relations with industrial partners is also enhanced by the lab's affiliation to the Institut Carnot *Télécom & Société numérique*.

Regular industrial partners of the lab are also involved in two different sorts of long-lasting actions : joint research labs and chairs. Join research labs typically involve a single industrial partner who wants to secure the involvement of the LTCI on a specific theme (usually during three to five five years). In most cases, the industrial partner also delegates some of its engineers who become part-time research associates within the joint lab. In contrast, chairs are usually backed by several industrial partners and do not involve any sort of intellectual property agreement. Chairs are also not limited to the funding of research-related actions and most often involve educational aspects, such as the creation of a specific master on the topic of the chair. Tables B.10 and B.11 list the joint labs and chairs of the 2008-2013 period.

The LTCI lab is also involved in several larger scale collaborative projects funded by the *Investissements d'Avenir* program, essentially in projects (DigiCosme, LMH, Digiscope, SystemX) affiliated to the Paris-Saclay initiative, which has itself been endowed with a 950 M€ fund in the context of the *Initiatives d'Excellence* (Idex) call. The complete list of these projects is given in Table B.12.

## Chapter B

# Key Figures and Facts: the LTCI at a Glance

## B.1 Organization and Human Ressources

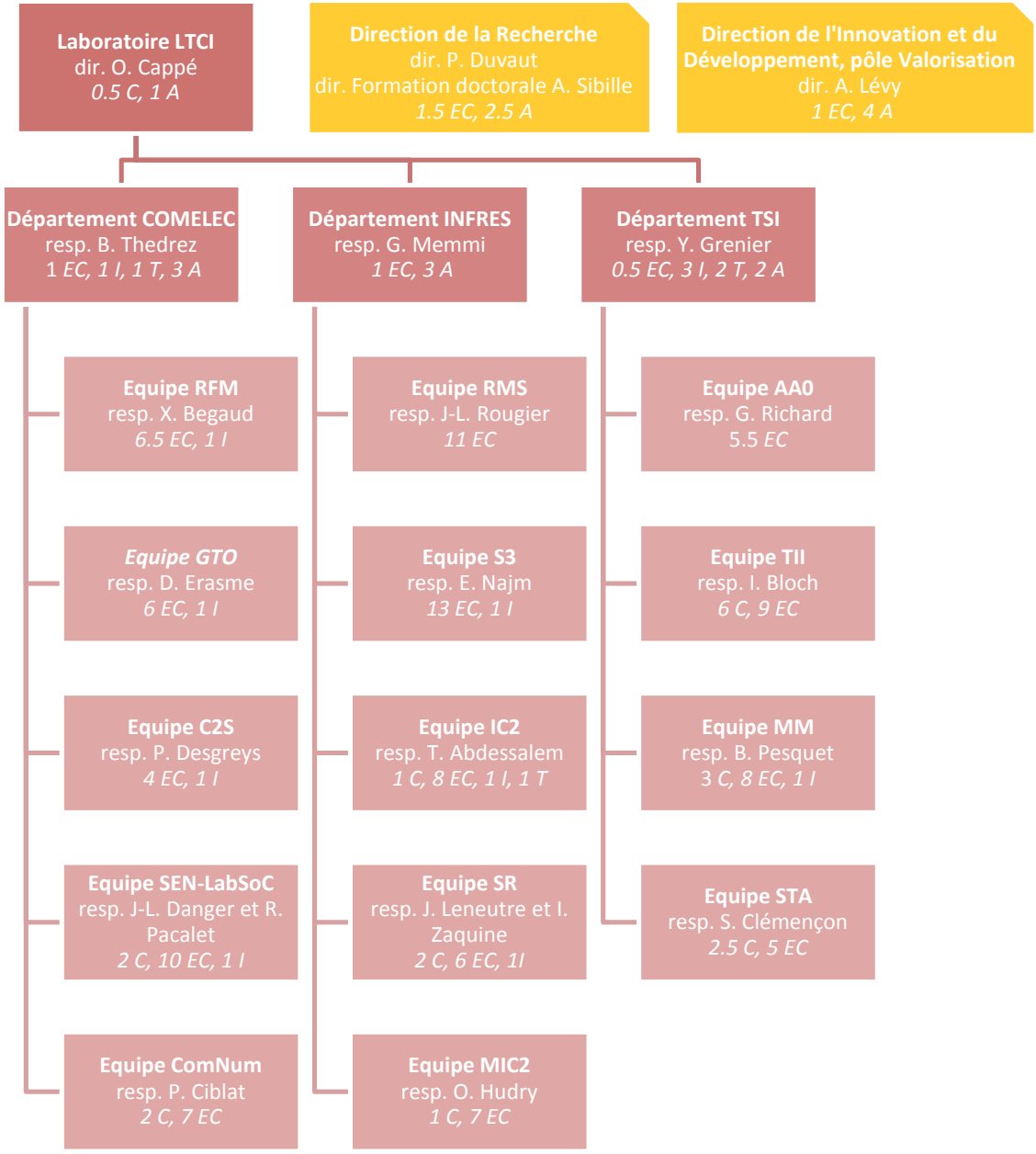


Figure B.1: Organogram of the LTCI. Yellow boxes correspond to administrative and management staff of Telecom ParisTech in the service of research.

| | |
|---|---|
| **Communications and Electronics (COMELEC)** | |
| **1 RFM** | **Radio Frequency and Microwave** Leader: Xavier Begaud; Staff: 6.5 professors, 1 engineer; *Keywords: antennas, radiofrequencies, propagation, electromagnetism.* |
| **2 GTO** | **Optical Communications** Leader: Didier Erasme; Staff 6 professors, 1 engineer *Keywords: optical transmissions, optoelectronic and photonic components, optival functions, digital communication.* |
| **3 C2S** | **Circuits and Communication Systems** Leader Patricia Desgreys; Staff: 4 professors, 1 engineer; *Keywords: mixed signals, system on chip, circuits and systems, sofware radio.* |
| **4 SEN-LabSoC** | **Complex Digital Electronics Systems** Leaders: Jean-Luc Danger and Renaud Pacalet; Staff: 2 researchers, 10 professors, 1 engineer *Keywords: system on chip, safety and reliability, security, circuit architecture.* |
| **5 ComNum** | **Digital Communications** Leader: Philippe Ciblat; Staff: 2 researchers, 7 professors; *Keywords: digital communications, information theory, coding.* |
| **Networks and Computer Science (INFRES)** | |
| **6 RMS** | **Network, Mobility and Services** Leader: Jean-Louis Rougier; Staff 11 professors; *Keywords: networks, distributed systems, future internet.* |
| **7 S3** | **Software, Systems and Services** Leader: Elie Najm; Staff: 13 professors, 1 engineer; *Keywords: embedded systems, real-time systems, software design.* |
| **8 IC2** | **Interaction, Cognition and Complexity** Leader: Talel Abdessalem; Staff: 1 researcher, 8 professors, 1 engineer, 1 technician; *Keywords: databases, web mining, knowledge management, human-computer interaction.* |
| **9 SR** | **Network and Information Security** Leaders: Jean Leneutre and Isabelle Zaquine; Staff: 2 researchers, 6 professors, 1 engineer; *Keywords: network security, quantum information.* |
| **10 MIC2** | **Mathematics of Information, Communications, and Computation** Leader: Olivier Hudry; Staff: 1 researcher, 7 professors *Keywords: operations research, performance evaluation, cryptography.* |
| **Signal and Image Processing (TSI)** | |
| **11 AAO** | **Audio, Acoustics and Waves** Leader: Gaël Richard; Staff: 5.5 professors; *Keywords: signal processing, speech and audio processing, biomedical signals.* |
| **12 TII** | **Image Processing and Understanding** Leader: Isabelle Bloch; Staff: 6 researchers, 9 professors; *Keywords: image processing, computer graphics, radar and medical imaging, data fusion.* |
| **13 MM** | **Multimedia** Leader: Béatrice Pesquet; Staff: 3 researchers, 8 professors, 1 engineers; *Keywords: multimedia signal processing, video coding, human-computer interaction.* |
| **14 STA** | **Statistics and Applications** Leader: Stéphan Clémençon; Staff: 2.5 researchers, 5 professors *Keywords: statistics, statistical signal processing, machine learning.* |

Table B.1: List of research groups with their permanent staff as of mid 2013.

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|
| Researchers | 23 | 23 | 24 | 26 | 20 | 21 |
| COMELEC | 3 | 3 | 4 | 4 | 4 | 4 |
| INFRES | 5 | 5 | 5 | 5 | 4 | 4 |
| TSI | 15 | 15 | 15 | 17 | 12 | 13 |
| | | | | | | |
| Professors | 103 | 105 | 108 | 110 | 108 | 109 |
| COMELEC | 32 | 33 | 34 | 35 | 35 | 35 |
| INFRES | 41 | 42 | 44 | 45 | 45 | 46 |
| TSI | 28 | 30 | 30 | 30 | 28 | 28 |

Table B.2: LTCI staff (researchers and professors only) in the period 2008–2013.

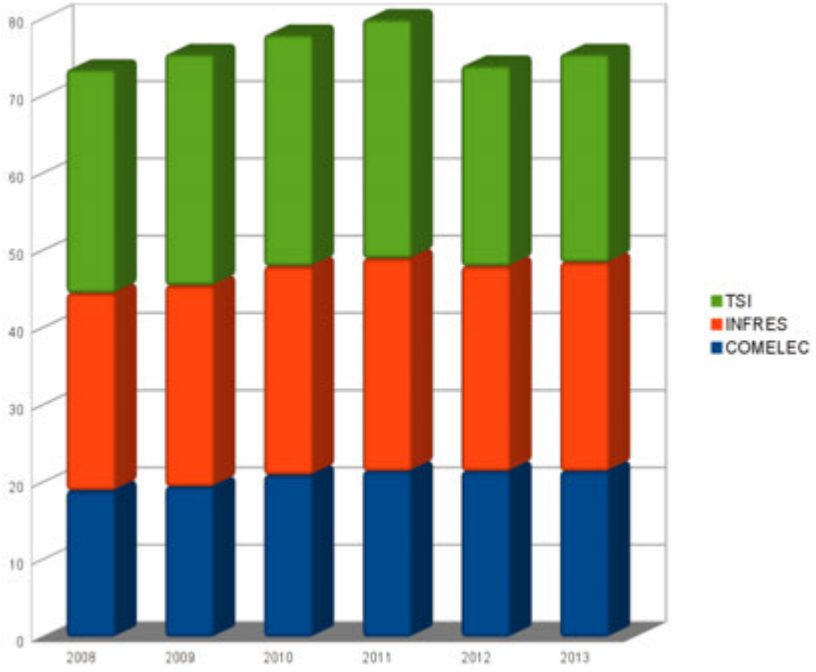


Figure B.2: LTCI staff measured in Equivalent Full-Time Researchers and its repartition in the three departments.

| | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|
| LTCI | 59 | 61 | 79 | 45 | 57 |
| COMELEC | 17 | 20 | 24 | 15 | 18 |
| INFRES | 22 | 18 | 24 | 11 | 26 |
| TSI | 20 | 23 | 30 | 19 | 13 |
| | | | | | |
| Average duration (months) | 42 | 44 | 45 | 39 | 40 |

Table B.3: Number of defended PhD theses per year.

| | |
|---|---|
| **SYSCOM STN Systèmes de Télécommunications Numériques** | Phillipe Gallion, Philippe Ciblat, Ghaya Rekaya, Jean Claude Belfiore, Aslan Tchamkerten, Michéle Wigger, Georges Rodriguez, Anne Claire Lepage, Xavier Begaud, Bernard Huyart, Houda Labiod, Ahmed Serhrouchni, Patrick Loumeau |
| **COMASIC Conception & Management des Systèmes Informatiques Complexes** | Isabelle Demeure, Talel Abdessalem, Mauro Sozio, Ada Diaconescu, Sylvie Vignes, Pierre Senellart |
| **RES Réseaux** | Jean Leneutre, Ahmed Serhrouchni, Houda Labiod, Pascal Urien |
| **SAR Systèmes et Applications Réparties** | Laurent Pautet, Etienne Borde, Thomas Robert |
| **MPRI Master Parisien de Recherche en Informatique** | Jacques Sakarovitch, Pierre Senellart, Petr Kuznetsov |
| **MPRO Master Parisien en Recherche Opérationnelle** | Olivier Hudry, Laurent Deucresefond |
| **IAD Intelligence Artificielle et Décision** | Isabelle Bloch, Eric Lecolinet, Yves Grenier, Gaël Richard |
| **IFL Ingénierie de la Formation en Ligne** | Catherine Pélachaud |
| **IMA Imagerie** | Isabelle Bloch, Alexandre Gramfort, Florence Tupin , Said Ladjal, Jean Marie Nicolas, Tamy Boubekeur, Michel Roux |
| **ATIAM Acoustique, Traitement du Signal et Informatique Appliqués à la Musique** | Bertrand David, Roland Badeau, Gaël Richard |
| **MVA Mathématique, Vision, Apprentissage** | Yann Gousseau, Gael Richard, Yves Grenier , Eric Moulines, Gersende Fort, Stephan Clémençon, Jean Marie Nicolas, Florence Tupin, Andres Almansa, Said Ladjal |
| **Probabilités et Applications** | Eric Moulines |
| **M2MO Modélisation Aléatoire** | Eric Moulines, Stéphan Clémençon, Joseph Salmon, Francois Roueff |
| **MPT Méthodes Physiques en Télédétection** | Michel Roux, Marc Sigelle, Florence Tupin, Jean Marie Nicolas |
| **OMP Optique, Matière, Plasmas** | Isabelle Zaquine |
| **BIM BioMedical Engineering** | Elsa Angelini, Isabelle Bloch, Alexandre Gramfort |

Table B.4: M2 (2nd years of master) with implications from members of the LTCI lab.

## B.2 Achievements

| | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|
| Peer reviewed journals | 165 | 162 | 183 | 198 | 167 |
| COMELEC | 37 | 41 | 40 | 46 | 56 |
| INFRES | 54 | 45 | 65 | 48 | 39 |
| TSI | 74 | 76 | 78 | 104 | 72 |
| Peer reviewed conferences | 405 | 391 | 426 | 454 | 360 |
| COMELEC | 109 | 101 | 131 | 158 | 116 |
| INFRES | 128 | 117 | 122 | 119 | 106 |
| TSI | 168 | 173 | 173 | 177 | 138 |
| Books and book chapters | 31 | 40 | 39 | 48 | 18 |
| COMELEC | 3 | 7 | 6 | 6 | 6 |
| INFRES | 13 | 14 | 10 | 15 | 5 |
| TSI | 16 | 19 | 23 | 27 | 7 |

Table B.5: Scientific production

| | | |
|---|---|---|
| **2008** | **Isabelle Bloch** (TII group), professor in the TSI dept. | **Médaille Blondel of the SEE** |
| **2009** | **Aslan Tchamkerten** (ComNum group), associate professor in the COMELEC dept. | **ANR Junior Excellence Chair** |
| **2010** | **Eric Moulines** (STA group), professor in the TSI dept. | **CNRS Silver Medal** |
| | **Nancy Bertin**, PhD in the AAO group | **Gretsi / Club EEA PhD Award** |
| | **Antony Leverrier**, PhD in the SR group | **ParisTech PhD Award** |
| **2011** | **Eric Moulines** (STA group) | **Grand Prix France Télécom de l'Académie des Sciences** |
| | **Julien Cornebise**, PhD in the STA group | **Savage PhD Award from the International Society for Bayesian Analysis** |
| | **Elmar Eisemann** (TII group), associate professor in the TSI dept. | **Eurographics Young Researcher Award from the Eurographics Society** |
| **2012** | **Marc Kaplan**, postdoct in the SR group | Laureate of the **ANR *Retour Postdoc* Program** |
| | **Guilhem de Valicourt**, former PhD in the GTO group | **Paul Baran Young Scholar Award from Marconi Society** |
| | **Mathieu Feuillet**, co-advised by Thomas Bonald, professor in the INFRES dept. | **Gilles Kahn PhD Award from SPECIF** |
| **2013** | **Jacques Sakarovitch** (MIC2 group), emeritus CNRS researcher in the INFRES dept. | Elected as **Chairman of the IFIP Technical Committee 1** (Foundations of Computer Science) |
| | **Béatrice Pesquet-Popescu** (MM group), professor in the TSI dept. | Nominated **IEEE Fellow** |
| | **Gérard Cohen** (MIC2 group), professor in the INFRES dept. | Nominated **IEEE Fellow** |
| | **Philippe Gallion** (GTO group), professor in the COMELEC dept. | Elected as **Chairman of the French Chapter of the IEEE Photonics Society** |
| | **Charles-Alban Deledalle**, PhD student in the TII GROUP | **Gretsi / Club EEA PhD Award** |
| | **Jean-François Cardoso** (STA group), senior CNRS research scientist in the TSI dept. | **Prix Paul Doistau – Emile Blutet de l'Académie des Sciences** |
| | **Olivier Cappé** (STA group), senior CNRS research scientist in the STA group | **Grand prix de la fondation d'entreprise EADS de l'Académie des sciences** |

Table B.6: Awards: personnal distinctions receveived by members of the LTCI in the period 2008–2013.

| | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|
| LTCI | 18 (17) | 18 (14) | 12 (6) | 14 (8) | 7 (5) |
| COMELEC | 15 (14) | 11 (8) | 6 (2) | 7 (4) | 3 (2) |
| INFRES | 3 (3) | 3 (3) | 2 (2) | 3 (1) | 3 (2) |
| TSI | | 4 (3) | 4 (2) | 4 (3) | 1 (1) |

Table B.7: Number of patents with co-inventors from LTCI; in parentheses the number of patent applications filed by Telecom ParisTech (the remaining ones have been filed by partners of LTCI).

| Spin-off | Domain | Involved groups |
|---|---|---|
| STREAMEZZO (2004–) | Mobile Rich Media mobile | MM |
| ETHERTRUST (2007–) | Software security | SR |
| SEQURENET (2008–) | Quantum security | SR |
| SECURE-IC (2010–) | Secuity of circuits and critical components | SEN-LabSoc |

Table B.8: Spin-offs created by members of the LTCI lab.

| | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|
| Total ressources | 7 423 | 7 614 | 9 011 | 9 806 | 11 239 |
| COMELEC | 1 745 | 1 686 | 1 975 | 2 473 | 2 765 |
| INFRES | 3 020 | 3 152 | 2 945 | 2 965 | 4 099 |
| TSI | 2 018 | 2 116 | 3 301 | 3 558 | 3 365 |
| CNRS | 640 | 660 | 790 | 810 | 1 010 |

Table B.9: Financial ressources from grants and contracts in k€ by management entity: the three departments for contracts managed by Telecom ParisTech and the part managed by CNRS.

| Partners | Research theme | Involved groups |
|---|---|---|
| **CNES, DLR** | **Centre de compétence *Imagerie pour l'observation de la Terre*** (2005–2011) | TII |
| **EDF** | **BILab: Business Intelligence Lab** (2007–2011) | IC2 |
| **Altran** | **Digital communications** | ComNum |
| **Alcatel Lucent** | **Ubiquity in medias** (2008–2013), with Telecom Sud Paris | MM, IC2 |
| **Orange** | **WHIST: Wave Human Interactions and Telecommunications** (2009–), with Télécom Bretagne | TII, STA |
| **Morpho (Safran)** | **ISA: Identity & Security Alliance** (2011–) | SEN-LabSoC, MIC2, TII |
| **Alcatel Lucent** | **LINCS: Laboratory for Information, Networking and Communication Sciences** (2010–), with INRIA, Université Pierre et Marie Curie and IRT SystemX | RMS |
| **EDF** | **SEIDO: Security of the Internet of Things** (2012–) | RMS, S3, SR |

Table B.10: Joint research labs

| Parters | Title | Involved groups |
|---|---|---|
| **Dassault Systèmes, Ubisoft, Orange, PSA** | **Modélisations des Imaginaires, Innovation et Création** (2009–), with Université de Rennes 2 | TII, IC2, MM |
| **Thales, Dassault Aviation, DCNS, DGA** | **Ingénierie des Systèmes complexes** (2011–), with ENSTA ParisTech and Ecole Polytechnique | S3 |
| **BNP Paribas, Criteo, PSA, Safran** | **Machine Learning for Big Data** (2013–) | STA, IC2 |

Table B.11: Chairs (the *Modélisations des Imaginaires* chair is a project orginiating from the SES component Telecom ParisTech, which is at the origin of several other chair projet omitted here).

| | |
|---|---|
| ***Laboratoires d'Excellence*** **(Labex)** | |
| **DigiCosme** | Digital worlds: distributed data, programs and architectures (Idex Paris-Saclay) focused on Computer Science |
| **LMH** | *Labex Mathématique Hadamard* (Idex Paris-Saclay) on Mathematics, both theoretical and applied to Biology, Engineering, ICT and Physics |
| **SMART** | Smart human/machine/human interactions in the digital society (Idex Sorbonne Universités) on advanced Man-Machine Interaction in the society (modelling of human, human between real and virtual worlds, etc.) |
| **UCN@SOPHIA** | User-centric networking (in Nice Sophia-Antipolis) |
| ***Equipements d'Excellence*** **(Equipex)** | |
| **Digiscope** | Collaborative interaction with complex data and computation (Idex Paris-Saclay) |
| **FIT** | Future Internet of Things (national network involving five partners) |
| ***Technological research institutes*** **(IRT and IEED)** | |
| **SystemX** | IRT on systems enginering for tranportation, communications, security and energy systems (Idex Paris-Saclay) |
| **VeDeCom** | IEED on communicating and carbonless vehicles and their mobility (in Satory); the LTCI lab is mostly concerned by aspects related to vehicular networks and impact of the new technologies on the users |
| **Internal projects of the Idex Paris-Saclay** | |
| **ISN** | *Institut de la Société Numérique* for an interdicisciplinary approach of the digital society (between social sciences and computer science) |
| **Nanodesign** | Platform in natotechnology and design |

Table B.12: List of projects funded in the context of the *Investissements d'avenir* program in which LTCI is involved.

# Part II

# Detailed activities: Communications and Electronic

# Chapter 1

# Radio Frequency and Microwave (RFM)

## 1.1 Executive Summary (Appendix 1)

**Team Leader** Bernard Huyart (FP,-Dec. 2012), Xavier Begaud (FP, Jan. 2013-)

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**Initial Staff** 2 Professors, 3 Associate Professors , 7 PhD students

**Staff who Left** 17 PhD students (624 months), 2 Post-docs (71 months), 3 Sabbaticals (15 months), 2 Engineers (57 months) and 21 Internships (82 months)

**Staff who Were Hired** 1 Full Professor (former FP at ENSTA ParisTech), 1 Associate Professor (former AP at ENSTA ParisTech), 1 Engineer, 24 PhD students and 5 Post-docs

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**Scientific Highlights**

- RFM team has developed modulation/demodulations schemes as well as automatic matching impedance circuits for antennas, dedicated to several wireless communication standards from 450 MHz to 40 GHz.
- Such matching circuits enable to achieve improved operating conditions for power amplifiers and since 2009 our efforts have been focused on the design and implementation of a load-pull and source-pull measurement setup in the 40-60 GHz frequency band.
- Metamaterials associated with a radiating element can produce innovative antennas. These materials are inherently narrow band and we have proposed and validated the development of innovative solutions to realize wideband reflector used to reduce the size/thickness of wideband devices.
- Small antennas interacting with their close environment, furthermore require dedicated design approaches, such as de-sensitization, which have been demonstrated to improve the overall performance of antennas on the human body.
- A statistical approach has been developed to take into account the numerous sources of variabilities of wireless terminals and antennas jointly or not with the propagation channel. Models have been derived to asses wireless networks performance in realistic environments, for different types of RF transceivers and physical layer schemes.

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**Scientific Production** 40 Journals; 3 Books; 7 Book chapters; 159 Articles in Proceedings; 3 Invited talks; 8 Patents.

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**Major Publications**


- X. Begaud, A. Sibille, C. Roblin and al., (2010), UWB Antennas, Iste/Wiley.
- C. de la Morena Álvarez Palencia, K. Mabrouk, B. Huyart, A. Mbaye and M. Burgos Garcia, (2012), "Direct Baseband I Q Regeneration Method for Five Port Receivers Improving DC offset and Second Order Intermodulation Distortion Rejection", IEEE Trans. on Microwave Theory and Techniques, vol. 60, n° 8, pp. 2634 2643.
- A. Sibille, (2012), "Statistical Modeling of the Radioelectric Properties of Wireless Terminals in their environment", IEEE Antennas and Propagation Magazine, vol. 54, n° 6, pp. 117 129.

- M. Grelier, M. Jousset, S. Mallegol, A. C. Lepage, X. Begaud and J. M. Le Mener, (2011), "Wideband QAMC reflector's antenna for low profile applications", Applied Physics A: Materials Science and Processing, vol. 102, n° 2.
- R. Mohellebi, E. Bergeault, G. Idir Abib and B. Huyart, (2010), A Millimeter Wave Six port Reflectometer for Active Load Pull Characterization, "EUMC 2010 ", Paris.

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**Impact and Attractivity**

- Three members served as Associate Editor in Journal of Communications and Networks (Wireless Communications), Journal of Communications and Networks (Korea), International Journal of Microwave Science and Technology, Advanced ElectroMagnetics (AEM).
- Organisation with Paris-Sud University of two international scientific events at Telecom ParisTech: META'12, the 3rd International conference on Metamaterials, Photonic Crystals and Plasmonics and AES 2012, Advanced Electromagnetics Symposium.
- Invited conference of A. Sibille at EuCAP2012 [172].
- Management of the ANR SAFAS project.
- PhD student Q. Chu is the recipient of the Best Student Paper Award in IEEE VTC [71]

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**Interaction with Economic and Social Spheres**

- Four FP7 projects (SACRA, SELECT, LEXNET, PHYLAWS), one EDA (European Defense agency) project (MIMiCRA) and one CELTIC (SPECTRA).
- Two ANR projects (ANR-Smartvision, ANR-SAFAS).
- Four FUI projects (FUI- CONRAHD/OPTIMUM, FUI-PUMA, FUI-URC FUI-RECOSS).
- Many Cifre and bi-lateral collaborations including SMEs (CNES, LNE, Orange, Thales Airborne Systems, Thales AirSys, Bluwan).
- A. Sibille is involved in URSI-France as Secretary General and Vice Chair of Commission C 'Radio communication and Signal Processing Systems'.

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**Contributions to Higher Education**

- Organization of the set of courses (parcours) Microwave Engineering and of the set of courses (parcours) Aerospace Communications at Telecom ParisTech (180h).
- Organization of the 'Master Spécialisé' SCHD (Systèmes de Communications Haut Débit), the Master of Sciences Digital Radio (ParisTech).
- Lectures in the framework of Master Syscom STN (jointly accredited with UPMC), at ENSTA and at Université Paris-Sud (M2 IST).
- Life-long education courses (4 programs).
- Since 2013, A. Sibille holds the position of Deputy Director of the Doctoral School (EDITE).

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## 1.2 People

**Team leader** Bernard Huyart (FP,-12/12), Xavier Begaud (FP, 01/13-)

**Faculty** X. Begaud (FP), E. Bergeault (FP), J.C. Cousin (AP), B. Huyart (FP), A. Khy (Ing,06/12-), A.C. Lepage (AP), C. Roblin (AP,09/10-), A. Sibille (FP,09/10-).

**PhD students** M. Bahouche (02/06-12/10), A. Beniss (10/12-), D. B. Brito (10/08-12/10), M. Clemente (09/11-), Q. Chu (11/08-12/11), L. Damaj (09/09-03/13), C. Djoma (07/10-), H. El Arja (11/06-09/10), J. Enriquez Gonzalez (12/11-), M. Grelier (10/07-01/11), F. Guidi (10/10-05/13), A. Kaissoine (03/12-), S. Kammoun (06/13-), A. Krayni (12/12-), R. Kumar (12/11-), L. Leggio (11/12-), F. Linot (02/08-04/11), I. Maaz (11/12-), K. Mabrouk (12/05-12/08), S. Martinez Lopez (09/05-09/08), T. Mazloum (10/12-), Z. Mhanna (10/10-), C. Mohamed (01/05-09/08), R. Mohellebi (10/08-09/12), L. Mouffok (10/09-02/13), T. N. Mai (11/11-), A. Thior (10/08-10/12), Y. Wei (10/10-), M.A. Yousuf (10/10-10/11), X. Zeng (02/11-), F. Ziade (06/04-04/08).

**Post-docs, engineers and sabbaticals** J.P. Barbot (11/11-09/12), A. D'assuncao (10/09-10/09), L. Damaj (04/13-), J. Enriquez Gonzalez (03/10-11/11), A. Khy (09/06-05/12), F. Mani (09/12-), R. Planas (07/09-09/10), Y. Pinto (09/12-), J. Sarrazin (02/11-08/12), S. Varrault (05/13-), F. Rangel De Souza (12/11-02/12).

## 1.3 Overview

Universal connection between humans and machines is a global trend, which requires wireless RF systems, either mobile or embedded, with sensing mechanism to adapt to their environment applications. RFM focuses on wireless technologies, to provide optimal connectivity with respect to cost, energy efficiency, performance, flexibility for any type of environment. The aim of the research is to investigate new concepts/models/techniques with innovation at several levels: components (antenna), characterization and modelling (power amplifier, radio channel, localization and radar) and communication schemes (modulation) for wireless communication systems.

**Preliminary remark** It is important to note that the dimension of the group has changed since the previous evaluation. The RFM team has increased from five to eight full-time researchers, which led to an extended expertise: the team has been enriched with the arrival of A. Sibille and C. Roblin from ENSTA ParisTech with their RF equipments and with A. Khy as tenured research engineer. The research is now distributed on three main topics, summarized below.

**Energy efficient RF front-ends and systems** This activity concentrates on the so-called 'RF front-end', which is one of the most sensitive parts of communicating objects in terms of QoS and power consumption. It involves improved modulation/demodulations schemes as well as the study of automatic matching impedance circuits for antennas, dedicated to several wireless communication standards from 450 MHz to 40 GHz. Such matching circuits enable to achieve improved operating conditions for power amplifiers, owing to developed advanced load and source pull techniques. Other works address the design of active radar front-ends intended for indoor detection of persons for security (airports, embassies...) and the development of a multi-antenna radio channel sounder based on 5-ports RF circuits.

**Smart and small antenna design** Smart antennas have the potential to significantly increase the efficient use of the spectrum in wireless communication applications and to reduce antenna size, which is a must for nomadic terminals as well as for airborne systems. This flexibility concept has been developed through the design of the antenna itself, in the frequency/angular/polarization domains (wideband /multiband, dual polarized antennas) and by integration of RF functions directly on the radiating elements. A particular attention has been paid to metamaterials, which

provide extra degrees of freedom in the design optimization, owing to novel physical properties. Small antennas being disturbed by their close environment, furthermore require dedicated design approaches, such as de-sensitization, which improve the overall performance of antennas on the human body.

**Radio channel modeling and localization** The increasing complexity of wireless access networks requires more and more sophisticated radio channel models for a variety of environments and use cases. System optimization needs to consider jointly the propagation and the antennas in wireless networks performance evaluation, given the realistic characteristics of RF transceivers and of the physical layer schemes. In particular, a novel approach, based on the statistical modeling of antennas and channel separately or jointly, has been developed and applied to a variety of contexts such as wireless local or cellular networks, body area networks and RFID systems. A new topic related to the enhancement of the security of wireless communications at the physical layer level, based on the random variation of the propagation channel characteristics has started in 2013 in the framework of the EC project PHYLAWS. Finally, another focus of the team concerns the development of a FMCW signal based localization technique for remote monitoring in indoor environments.

The RFM team has a strong policy of dissemination and valorisation of its results which translates into the following indicators: 40 Journals, 3 Books, 7 Book chapters, 159 Articles in Proceedings, 3 Invited talks, 8 Patents.
The team has relevant international and national editorial activities: we take part in the technical committee of flagship conferences (Eucap, EUMW, Meta, JNM) and in the editorial board of four journals (Journal of Communications and Networks (Wireless Communications), Journal of Communications and Networks (Korea), International Journal of Microwave Science and Technology, Advanced Electromagnetics (AEM)).
All our research activities are supported by national, European, or industrial funding. RFM maintains close links (joint works, double Ph.D. program, co-advisorship, sabbaticals and visits) with various international laboratories, including Università di Bologna (Italy), ETSI de Telecomunicación UPM (Madrid and Malaga, Spain) Universidade Federal de Santa Catarina (Brazil), Universidade Federal do Rio Grande Natal (Brazil), University of Calgary (Canada).
Finaly our group is deeply implied in teaching for the Engineering school as well as for various Masters programs.

## 1.4 Research Themes

### 1.4.1 Energy efficient front-ends and systems

**Faculty** X. Begaud, E.Bergeault, J.C. Cousin, B.Huyart, A. Khy, A.C. Lepage
**Highlights: Scientific Production** [8] [40] [23] [14] [71]
**Highlights: Impact**

- One CELTIC project (SPECTRA) and one ANR (Smartvision) are linked with this topic as well as one FUI System@TIC (CONRAHD/OPTIMUM). Innovation project 'DEMODU' from Institut Mines-Telecom.
- E. Bergeault has been an invited Professor at XLIM, University of Limoges (sept 2011-sept. 2012).
- Q. Chu is the recipient of the Best Paper Award in Vehicular Technology Conference [71].
- Grant of program 'Research in Paris' from Mairie de Paris for a senior researcher of UFSC (Universidade Federal de Santa Catarina, Brazil).
- Participation in PhD examining committees (ETSI Telecomunicación Madrid and Malaga, Spain).

**Highlights: Interactions with Society**

- Bilateral projects (3 cifre) with LNE and Orange.
- 3 patents [178] [180] [179].

**MMIC design for RF front-end** Our research activity has been focused on the design of demodulator dedicated to software defined radio applications. Two three-phase demodulators using MMIC technology have been designed in the 1-24 GHz bandwidth [23] and Q band (33-45 GHz) [108], [109]. This demodulator architecture shows a better rejection of adjacent channels [19] than classical IQ structure but requires one more Low Frequency (LF) outputs. In order to reduce the number of LF components, a new design based on symmetry was tested [8] and patented [178]. The reduction of the number of RF and LF components involved is a first approach to make the front-end energy efficient. Another way is the insertion of an Automatic Matching Impedance Circuit (AMIC) between the antenna and the power amplifier (PAs) to keep the best operating conditions for the PAs. Indeed compact antennas are sensitive to their variable electromagnetic environment. First studies were conducted on the design of a compact antenna and a variable matching circuit [148]. As the Three Phase Demodulator (TPD) may act as a mismatch detector, the next step will be the design of the AMIC including the TPD and the variable matching circuit.

**Power probes and PAs** Our research in fundamental metrology with the LNE have yielded significant results for the realization of original RF power sensors that could be used as reference power standards instead of conventional bolometer mounts [14], [40], [107], [39], [158]. This work aims at the feasibility of a calculable HF power standard. Since a calculable power standard is only based on physical and mathematical principles, a calibrating procedure is no more necessary. A power standard has been realized in coplanar (CPW) technology operating up to 8 GHz. Probe measurements techniques of MMIC components have been also investigated with the LNE over a wide frequency band (few kHz-40 GHz) [55], [56], [158]. We have studied and defined the traceability and the accuracy of the Line-Attenuator-Reflect calibration technique up to millimeter wave frequencies. An original calibration kit has been realized on GaAs substrate. The power amplifier is one of the most critical circuits responsible for most of the system's power consumption and distortion. Consequently, the optimization of the power amplifier requires a trade-off between output power, efficiency and spectral range. It is then important to provide large signal measurements under real operating mode conditions, ie, under complex modulated signals. We have designed different measurement systems for different frequency bands. It should be noted that we have also published with the University of Calgary, Canada, new techniques for non-linear measurements [64]. Since 2009, our efforts have focused on the design and implementation of a load-pull and source-pull measurement setup in the 40-60 GHz frequency band. Numerical predistortion techniques have been also used to fight the distorsion of the RF signal [1], [51]. The originality of our setup concerns the generation of modulated signals up to 1GS/s in the 40-60 GHz frequency band realized by means of an Arbitrary Wave Generator to provide high data rate modulation schemes with an intermediate frequency carrier taken in the [1 5 GHz] frequency range. This signal is up-converted in the [40 60 GHz] frequency band by means of a double side band mixer [123].

**Radio communications channel sounding** Two channel sounders have been designed and realized for non stationary MIMO channel in the Wi-Fi and UWB frequency bands. Our studies have been focused on the simultaneous determination of the angles of departure and arrival of transmitted and received signals [20] and the measurement of arrival time [87], [88]. Comparisons between measurement and models were made from a 3D ray tracing [121]. Another aspect of channel sounding has been led with Orange Labs to estimate the contribution of relays in a multi link propagation channel modeling for the 4G systems. To this end, a multi link measurement campaign with relays has been carried out in realistic urban environments. This campaign has allowed the assessment of the relaying aspects with a focus on the path loss models developed

for the 4G systems [69], on the shadow fading correlation [71],[70] and on the impact of the relay antenna height [67]. A particular attention has been paid for the Base station-Relay Station link which had not been studied yet.

**RF front-end for Radar** The team was involved in the French ANR Smartvision, dealing with the development of a smart corridor or of an electronic gate dedicated to scan people without physical searches insecure area such as airports, embassies and so on [159] [132]. In this project, we have participated to the design of the RF front-end of a 77 GHz bi-static radar. This radar is mounted at 30 cm from the center of a rotative disk turning at 1500 rpm (rounds per minute). This bi-static radar includes the Transmitter (Tx) and the Receiver (Rx) and 2 antennas linked respectively to Tx and Rx. Tx provides a Continuous Wave source as a sinusoid signal at 77 GHz. Rx is an IQ demodulator allowing to compare the Doppler response of a scanned body to reference Doppler responses given by the presence of hazardous objects (gun, explosive and so on).

### 1.4.2 Smart and small antennas design

**Faculty** X. Begaud, A.C. Lepage, C. Roblin, A. Sibille

**Highlights: Scientific Production** [42] [9] [156] [11] [5]

**Highlights: Impact**

- Three FP7 projects (SACRA, SELECT, LEXNET), one EDA project (MIMiCRA) and one ANR project (SAFAS) are linked with this thematic as well as one FUI project (PUMA).
- European COST Action (IC0803) RF/Microwave Communication Subsystems for Emerging Wireless Technologies.
- Co-chair with Paris-Sud University of two international scientific events at Télécom ParisTech: META'12, the 3rd International conference on Metamaterials, Photonic Crystals and Plasmonics and AES 2012, Advanced Electromagnetics Symposium.
- Coordination with LEAT in the workgroup on very wideband antennas and arrays (GDR Ondes). Coordination with the Institut Fresnel and CEA in the workgroup on incertitudes (GDR Ondes).

**Highlights: Interactions with Society**

- Bilateral projects with: Thales Airborne Systems (4), Thales Air Systems (1), CNES (2).
- 4 patents on antenna with metamaterials [182], [176], [177], [181].
- 3 book chapters: Wideband antennas and Artificial Magnetic Conductors [48], Wideband antennas [47], Wideband directive antennas with High Impedance Surfaces [49].

**Antennas for cognitive radio** One of the main challenge in cognitive radio is to improve the overall efficiency of the system, ie. the energy efficiency, the spectrum efficiency and also the reduction of the number of components. The following topics aim at fulfilling these objectives. In the framework of the European project SACRA, our research is focused on compact dual band dual polarized antennas for the terminal side dedicated to future systems using LTE with also cognitive radio capabilities in the TVWS band (TV White Space) [25]. Studies on diversity performances are also performed for different environments. We are also studying co-design between antenna and filters: the objective of this topic is to develop an ultra wideband dual polarized antenna associated to a filter with non standard features in order to suppress any matching circuit between the antenna and the filter and thus to decrease the size. Moreover, to go further in the size reduction, we have developed more advanced solutions in which the filter has been integrated in the antenna element [5].

**Metamaterial inspired wideband antennas** A great part of our antenna design activities is devoted to wideband antennas and arrays. We initially focused our work on UWB (UltraWideBand) applications [37], [36], [42], [41] and are now exploring how to push antenna's limits. In this last decade a new area of research has emerged as a result of our ability to produce materials with entirely novel electromagnetic properties. On one hand, these metamaterials associated with a radiating element can produce innovative antennas. However, most of these materials are inherently narrow band and we are pioneer in the development of innovative solutions to realize wideband reflector [149], [11], [49] used to reduce the size/thickness of wideband antennas [47]. To improve the knowledge of such materials, we have developed analytical model [12], design strategies [177], [176], [182] and analysis tools [49]. All this experience has opened a new field of application on the design of ultra thin and light absorbers for space applications [131]. On the other hand, the extraordinary properties of Left Handed Materials has been exploited to develop miniaturized filters and directive antennas [3] and Leaky-wave antennas [150], [35].

**Robust antenna design for RFID tags and WBANs** Systems associating RFID and localization functionalities (RTLSs) are developed in the SELECT project. Thanks to its potential capabilities such as low power consumption, high ranging resolution and low sensitivity to interferences, UWB technology is a good candidate for RTLSs. Both active or passive tags architectures can be developed: the last, based on backscattering modulation has been considered in SELECT. Collocated UWB/UHF antennas for RFID tags have been developed in this project context. The novelty of the proposed antennas based on the integration of several 'functionalities' is threefold: 1. The integration of UWB and UHF radiators on a unique (credit card size) substrate, 2. The antenna robustness against proximity effects of nearby objects (such as metallic supports or human body), integrating a desensitization technique in a planar design, while maintaining a reasonable thickness (10 mm) compatible with use cases, and 3. The design of new UWB slot antennas (e.g. based on a pseudo-fractal geometry). This desensitization approach has been also applied to the design of body-worn UWB antennas for on-on WBANs [9], [50], [27].

### 1.4.3 Radio channel modeling and localization

**Faculty** J.C. Cousin, B Huyart, C. Roblin, A. Sibille

**Highlights: Scientific Production** [32] [175] [22] [6] [28]

**Highlights: Impact**

- Three FP7 projects (SELECT, LEXNET, PHYLAWS) and two FUI projects (URC, RECOSS) are linked with this topic.
- European COST 2100 Action and COST IC 1004 Action on mobile networks.

**Highlights: Interactions with Society**

- Two edited books : 'MIMO: From Theory to Implementation' (Elsevier 2010), co-edited by A. Sibille [43] and 'Les antennes Ultra Large Bande' (Hermes/Lavoisier 2010) [41] and 'Ultra Wide Band Antennas' (ISTE/Wiley 2011) [42] edited by X. Begaud (2 chapters respectively written by A. Sibille and Ch. Roblin).
- Chapters in 'Pervasive Mobile and Ambient Wireless Communications' (COST2100, Springer 2012), edited by R. Verdone and A. Zanella (3 chapters edition or contributions by A. Sibille and Ch. Roblin) [44], [50].
- Invited conferences of A. Sibille at EuCAP2012 ('How to simplify ultra wide band radio channel models?') and JNM2013 ('RFID ultra large bande semi-passifs : le projet Européen SELECT').

**Joint antennas and channels statistical modelling** Wireless networks need channel models in order to be able to test competing physical/link layer schemes and perform network level simulations. However there is an increasing complexity in the current and future communications

standards, which are multi-antennas, multi-frequency and where the behaviour of terminals in a use context is highly variable. The group has initiated and developed in the last few years a statistical approach of this behaviour [33], taking into account the variability of the terminals characteristics in their close environment. The method combines full antenna performance data to local propagation characteristics in order to arrive to an effective gain concept, seen as a stochastic quantity. It has been applied to the efficiency and effective gains of handsets in proximity to a user head and hand [143], [22] and to multiple antenna systems [171]. In body area networks, the influence of the human body on the behaviour of antennas is often of prime importance; the properties of the on-body propagation channel are very specific, and are notably sensitive to the subject movement for most scenarios. Both aspects, which are intricately related, have been studied with a statistical approach [137], [28], [171]. Joint space and frequency correlated path loss data have also been modelled through a simple semi-Kronecker approximation [31]. The latest works address the statistical analysis and modelling of UWB tag antennas employed in a backscattering based RFID system [145], [6], [7], [167].A related topic newly launched is focusing on physical based security. The project intends to address the improvement of the protection and confidentiality of information exchanged at physical interface through public wireless media by developing security techniques operating at the physical layer level or exploiting the characteristics of signals transmitted at the physical layer, accounting for realistic propagation channels characteristics.

**Parametric models for ultra wide band antennas** The full characterisation of the radiation of UWB antennas requires a significant amount of data arising from either measurement or electromagnetic simulations. It is therefore desirable to use "data compression" methods to handle them more easily. A complete (parametric) modelling of both frequency and time domain far field antenna responses (for any direction of radiation) with extremely high order reduction ("ultra compression") has been developed. It is based on both the singularity expansion and the spherical mode expansion methods. Theoretical properties of the model parameters and relationships with global indicators of performance of UWB antennas have been derived. The modelling has been applied to full 3D measurements of omni-directionnal or moderately directive UWB antennas with a good accuracy and high data compression rates of more than 97 percents (and up to more than 99.9 percents for some cases). These models can be efficiently used in simulations of the physical or radio link layers, or in deterministic propagation simulators based on asymptotic methods (UTD/GTD "ray tracing", etc.) Ch. 3 of [42] and [41], [138].

**Localization** Localization of human beings or objects is an active area of research with societal impact. For the wireless communications systems, this one allows a better management of the power reducing the consumption of devices. For medical applications, localization enhances the telemonitoring for the supervision of patients. For this purpose, the group develops a localization system for indoor environments based on a multistatic radar technique using FMCW (Frequency Modulation Continuous Wave) signals covering the European UWB frequency bandwidth. This system gives the localization of active tags in both range and angles of arrival. Compared to the other systems, it doesn't need an accurate synchronization clock, and the multipath effects are reduced by using jointly FMCW signals and circular polarization antennas. Initial efforts led to the design of 2 circular polarization antennas [112], [111], covering the [6-8.5 GHz] frequency bandwidth, and of different sizes matched to the tag and base station.

# 1.5 Achievements (Appendix 6)

## 1.5.1 Scientific Productions

### Articles in Journals


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T. Lamarque. Smartvision système multi-senseur de détection d'objets cachés pour une meilleure gestion du flux passager. In *Workshop interdisciplinaire sur la sécurité globale*, Troyes, Jan. 2010.

### Invited Talks

[160] X. Begaud and A. C. Lepage. Wideband low profile antennas and metamaterials. In *International Microwave and Optoelectronics Conference (IMOC 2011)*, Natal Brazil, Oct. 2011.

[172] A. Sibille. How to simplify ultra wide band radio channel models ? In *European Conference on Antennas & propagation (Invited talk)*, Prague, République Tchèque, Mar. 2012.

### Talks in Conferences Without Proceedings

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[173] A. Sibille. Statistical modeling of antennas in the radio channel context: a new impetus ? In *COST IC1004*, Malaga, Spain, Feb. 2013.

[174] A. Sibille and Y. Lostanlen. Spatial variability of cognitive radio channels. In *IWPCM*, Lyon, Mar. 2011.

### 1.5.2 Public Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2009-2011 | SMARTVISION - Système multi senseur de détection d'objets cachés pour une meilleure gestion du flux passager - conception du radar | ANR | J.C. Cousin | |
| 2009-2011 | PUMA - Produits Ultra haut débit sur bande Millimétrique Allouée - Millimeter wave antennas | FUI | X. Begaud | 531 |
| 2010-2013 | RECOSS - Réseau de Communication haut-débit pour les Services de Sécurité | DGCIS | A. Sibille | |
| 2010-2013 | BOURSE VINCI (F. Guidi)- Study of UWB modulated backscattering based RFID systems | Univ. | A. Sibille | 198 |
| 2011-2014 | MIMICRA - Metamaterial inspired microwave conformal radar antenna | EDA | X. Begaud | |
| 2011-2014 | SPECTRA - Spectrum and energy efficiency in 4G communication systems and beyond - Automatic impedance matching | Europe | A. C. Lepage | 500 |
| 2012-2015 | LEXNET - Low EMF Exposure Networks - dosimeter performance, statistical performance evaluation, low exposure antennas | Europe | A. Sibille | |
| 2012-2015 | PHYLAWS - PHYsical LAyer Wireless Security | Europe | A. Sibille | 677 |
| 2013-2015 | SAFAS - Structure Autocomplémentaire à FAible Signature - Absorber and antenna | ANR | X. Begaud (coord.) | 145 |

### 1.5.3 Private Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008 | Caractérisation de cables dans le cadre du protocole de mesure standard IEEE 1394 | SOPEMEA | J.C. Cousin | |
| 2008-2010 | CIFRE (R. Moghrani) - Modélisation hybride du canal de propagation | FT R&D | B. Huyart | 38 |
| 2009-2010 | TDF-Thales - Modélisation de l'exposition d'une personne se trouvant à l'intérieur d'un véhicule et soumise à des expositions induites par des antennes | TDF | X. Begaud | |
| 2009-2010 | Etude AMCA - Conception et réalisation d'un réseau de 5 antennes directives de faible épaisseur en bande VHF | CNES | X. Begaud | |
| 2009-2012 | CIFRE (Q. Chu) - A contribution to the multi-link propagation channel modeling for 4G radio mobile relaying systems | FT R&D | J.C. Cousin | |
| 2009-2012 | CIFRE (A. Thior) - Contribution à la conception d'antennes composées de structures CRLH | Thales Air Systems | X. Begaud | 128 |
| 2010-2011 | Antenne compacte pour application AIS | Thales Syst. Aero. | X. Begaud | |
| 2010-2013 | CIFRE (C. Djoma) - Conception de réflecteur quasi magnétique adapté aux antennes large bande | Thales Syst. Aero. | X. Begaud | 113 |
| 2011 | Mesure antennes en chambre anéchoïde | Thales Comm. | A. Sibille | |
| 2011 | Etude de système de localisation "indoor" | EADS | J.C. Cousin | |
| 2011-2012 | Modélisation statistique de canaux de communications | SIRADEL | A. Sibille | |
| 2011-2014 | CIFRE (J. E. Gonzales) - Antenne multi-lobes à 40 GHz | Bluwan | B. Huyart | 45 |
| 2012 | Etude de matériaux absorbants en bandes S/L | CNES | X. Begaud | |
| 2012-2013 | Etude de pions de jeux autoalimentés | EPAWN | B. Huyart | |
| 2012-2015 | Thèse Lucas Leggio - Modélisation des effets de l'environnement proche sur les caractéristiques d'antenne et du canal radio. | CEA | A. Sibille | 121 |

### 1.5.4 Patents and software


[175] R. D'Errico, A. Conti, D. Dardari, and A. Sibille. Localization method and system using non regenerative uwb relays. (11 352013.4):40, Dec. 2011.

[176] M. Grelier, S. Mallegol, M. Jousset, and X. Begaud. Réflecteur d'antenne large bande pour une antenne filaire plane a polarisation circulaire et procédé de réalisation du réflecteur d'antenne. (WO2012041770):31, Sept. 2011.

[177] M. Grelier, S. Mallegol, M. Jousset, A. C. Lepage, and X. Begaud. Dispositif d'antenne comportant une antenne plane et un reflecteur d'antenne large bande et procede de realisation du reflecteur d'antenne. (EP2365584 (A1)), Sept. 2011.

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[179] K. Mabrouk and B. Huyart. Dispositif analogique pour la calibration des récepteurs zéro-if cinq-port et triphasé. (FR: 08/04460), July 2008.

[180] K. Mabrouk and B. Huyart. Station d'emission et de reception comprenant une tete radio distribuee. (FR11/61859), Mar. 2012.
[181] L. Schreider, M. Soiron, B. Perpere, and X. Begaud. Dispositif de structure à bande interdite électromagnétique et dispositif d'émission et de réception d'ondes électromagnétiques. (FR2916308), Nov. 2008.
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## 1.6 PhDs (Appendix 7)

### 1.6.1 Defended PhDs

[183] M. Bahouche. *Etude et traçabilité du calibrage "Line-Attenuator-Reflect" pour des mesures sous pointes à l'aide de l'analyseur de réseau vectoriel*. PhD thesis, Telecom-Paristech, Dec. 2010.
[184] D. B. Brito. *Metamaterial inspired improved antennas and circuits*. PhD thesis, Télécom ParisTech, Dec. 2010.
[185] Q. Chu. *A contribution to the multi-link propagation channel modeling for 4G radio mobile relaying systems*. PhD thesis, Telecom Paristech, Dec. 2011.
[186] L. Damaj. *Antenne versatile intriquée*. PhD thesis, Telecom ParisTech, Mar. 2013.
[187] H. El Arja. *Sondeur de canal de propagation multi-capteurs appliqué à la mesure de canal de propagation pour l'Ultra Large Bande (6 GHz - 8.5 GHz) à l'intérieur des bâtiments*. PhD thesis, Telecom ParisTech, Sept. 2010.
[188] M. Grelier. *Miniaturisation des antennes large bande à l'aide de matériaux artificiels*. PhD thesis, Télécom ParisTech, Jan. 2011.
[189] F. Guidi. *Study of ultrawide band modulated backscattering based RFID systems*. PhD thesis, Ecole Polytechnique, May 2013.
[190] F. Linot. *Apport des Surfaces à Haute Impédance à la conception d'antennes réseaux compactes et d'antennes réseaux à très large bande passante*. PhD thesis, Télécom ParisTech, Apr. 2011.
[191] K. Mabrouk. *Conception et réalisation d'un système de Télécommunications MIMO avec Formation Numérique de Faisceaux en réception ; Calibrage aveugle du Démodulateur triphasé Zéro-IF et comparaison au démodulateur classique à 2 voies I et Q*. PhD thesis, Telecom ParisTech, Dec. 2008.
[192] S. Martinez Lopez. *Contributions au sondage de canal à l'intérieur des bâtiments : Direction de Départ, étalement Doppler, polarisation des ondes reçues et modélisation de canaux UWB*. PhD thesis, Telecom ParisTech, Sept. 2008.
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[195] L. Mouffok. *Conception de systèmes multi-antennes multi-bandes pour terminaux mobiles LTE*. PhD thesis, Telecom ParisTech, Feb. 2013.
[196] A. Thior. *Contribution à la conception d'antennes composées de structures CRLH (Composite Right Left-Handed)*. PhD thesis, Telecom ParisTech, Oct. 2012.
[197] M. Vahdani. *Low-profile, Ultra Wideband and Dual Polarized Antennas and Feeding Systems*. PhD thesis, TELECOM ParisTech, Oct. 2008.
[198] M. A. Yousuf. *Parametric Modeling of Small Terminals and Multiband or UWB Antennas*. PhD thesis, Ecole Polytechnique EDX, Sept. 2011.
[199] F. Ziadé. *Etude de faisabilité d'un étalon calculable de puissance haute fréquence (HF)*. PhD thesis, Ecole Nationale Supérieure des Télécommunications, Apr. 2008.

### 1.6.2 Ongoing PhDs

– A. Beniss (10/12-), Caractérisation de transistors de puissance dans le domaine des ondes millimétriques en présence de signaux modulés large bande.

- M. Clemente (09/11-), Application des transformations d'espace pour l'amélioration des performances des antennes planaires.
- C. Djoma (07/10-), Conception de réflecteur quasi-magnétique adapté aux antennes large bande.
- J. Enriquez Gonzalez (12/11-), Antenne multi-lobes à 40 GHz.
- A. Kaissoine (03/12-), Démodulation de signaux 4G (LTE advanced) agrégés en fréquence.
- S. Kammoun (06/13-), Géolocalisation à l'intérieur d'un bâtiment.
- A. Krayni (12/12-), Caractérisation statistique de l'esposition d'une population aux ondes émises.
- R. Kumar (12/11-), Système de localisation indoor pour l'aide à la Télésurveillance.
- L. Leggio (11/12-), Modélisation des effets de l'environnement proche sur les caractéristiques d'antenne et du canal radio.
- I. Maaz (11/12-), Impact du canal de propagation sur les performances des communications coopératives avec relais.
- T. Mazloum (10/12-), Analyse et modélisation conjointe antennes-canal radio pour les communications sans fil sécurisées.
- Z. Mhanna (10/10-), Etude statistique des propriétés électromagnétiques des RFID Ultra large bande.
- T. N. Mai (11/11-), Co-design antenne RF miniature et dispositif actif d'adaptation automatique d'impédance.
- Y. Wei (10/10-), Etude expérimentale et modélisation des antennes et du canal de propagation.
- X. Zeng (02/11-), Channel modeling for spectral sensing and cognitive radio networks.

# Chapter 2

# Optical Communications (GTO)

## 2.1 Executive Summary (Appendix 1)

**Team Leader** Didier Erasme

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**Initial Staff** Full Prof. = 3, Assoc. Prof. = 3 (1 HDR) ; Sabb. Prof. = 1, Postdocs = 2, PhD = 22.
**Staff who Left** Associate Prof. = 1 (HDR) ; Sabb. Prof. = 1, Postdocs = 6, PhD = 31.
**Staff who Were Hired** Assoc. Prof. = 1 (HDR) (previously AP, FOTON/INSA Rennes), (1 AP acquired HDR); Senior Research Engineer = 1 (previously postdoc), Postdocs = 5, PhD = 18

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**Scientific Highlights**

- In coherent optical systems, the unique capability for space-time coding to efficiently mitigate polarization dependent loss impairments and the performance discrepancy with respect to wireless transmission was demonstrated for the first time both theoretically and experimentally (in collaboration and in-house).
- Dispersion uncompensated transmission range records obtained at 10, 20 et 40Gb/s NRZ and 11.1Gb/s OFDM using a Dual Electro-absorption modulated laser (respectivelly 160, 40, 12 and 200km). This new integrated source allows single-side band modulation.
- Phase sensitive optical low coherence reflectometry proves to be an extremely powerful tool for advanced device characterization. Through collaborations the equipment allowed some elegant assessment in the field of photonics band-gap crystals and speciality fibers.
- Collaborating with the TU Denmark and the NIMS Japan, we demonstrated sub-clock recovery and full 1/64 OTDM demultiplexing at 640 Gbit/s, the second-ever demonstration of clock recovery at that high a bit rate, and the first involving a PPLN device.
- Implementation and security investigation of an all fiber one-way QPSK quantum key distribution system with conventional telecom equipment using balanced homodyne detection

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**Scientific Production** Journals = 70 (excluding invited papers); Book chapters = 3; Articles in Proceedings = 112; Invited talks and papers = 20; Patents = 4.

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**Major Publications**


- M. Selmi, Y. Jaouën, and P. Ciblat. Accurate digital frequency offset estimator for coherent polmux QAM transmission systems. In European Conference on Optical Communications (ECOC), page P3.08, Vienne, Autriche, Sept. 2009. [1070]
- L. K. Oxenløwe, F. Gómez Agis, C. Ware, S. Kurimura, H. C. Hansen Mulvad, M. Galili, K. Kitamura, H. Nakajima, J. Ichikawa, D. Erasme, A. T. Clausen, and P. Jeppesen. 640 Gbit/s data transmission and clock recovery using an ultra-fast periodically poled Lithium Niobate device. IEEE/OSA J. of Lightwave Technol., 27(3):205–213, Feb. 2009. Inv. paper. [411]
- Q. Xu, M. B. Costa E Silva, P. Gallion, and F. J. Mendieta. Auto-compensating quantum Cryptosystem using homodyne detection. In Optical Fiber Communication Conference, OFC 2008„ pages San Diego, California, Feb. 2008. [392]
- M. Patterson, S. Hughes, S. Combrié, N.-V.-Q. Tran, A. De Rossi, Y. Jaouën, and R. Gabet. Disorder-induced coherent scattering in slow-light photonic crystal waveguides. Physical Review Letters, 102(25):253903, June 2009. [256]

– J. Petit, D. Erasme, C. Kazmierski, C. Jany, J. Decobert, F. Alexandre, N. Dupuis, and R. Gabet. Enhanced 10-Gb/s NRZ Transmission Distance using Dual Modulation of an Integrated Electroabsorption Modulated Laser Transmitter. In Optical Fiber Communication Conference, number OThG2, San Diego, California, USA, Mar. 2009. [366]

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**Major Documents**

– 4 Patents [1133, 1126, 1125, 441]
– Edition by D. Erasme of 55 application notes produced by the EURO-FOS NoE Consortium. These AN can be downloaded from `http://www.euro-fos.eu/` (on demand)

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**Impact and Attractivity**

– Paul Baran Young Scholar Award from Marconi Society: G. de Valicourt, C. Ware's PhD st. (`http://www.marconisociety.org/youngscholars/recipients/devalicourt_guilhem.html`)
– Invitation by Emil Wolf to P. Gallion and F. Mendieta to write a review chapter in the prestigious series "Progress in Optics" [281]
– F. Gómez Agis, C. Ware and D. Erasme invited by IEEE/OSA J. Lightwave Technol. for a paper for a collaborative work with Denmark and Japan [411]
– Y. Jaouën guest editor "Académie des Sciences" special issue "Slow-light: Fascinating physics or potential applications?"
– P. Gallion chairperson of the French Chapter of the IEEE Photonics Society

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**Interaction with Economic and Social Spheres**

– GTO involved in many ANR and FUI projects (ANR: HQNet, SUPERCODE, ECOFRAME, TCHATER, AROME, MODULE, OCELOT, FUI : TRILOB, CHRONOS, 100GFlex), several Cifre and bi-lateral collaboration including SMEs (Orange, Mitsubishi, Yenista, Keopsys), in three European NoE (e-Photon/ONe$^+$, BONE, EURO-FOS) and one CELTIC (SASER).
– D. Erasme managed the ANR MODULE project and of a major work-package in the FP7-Network of Excellence EURO-FOS
– P. Gallion is active in dissemination to general public including "Cordées de la Réussite".
– Since 2010, D. Erasme is **Doyen des Enseignants-chercheurs de Télécom ParisTech**.

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**Contributions to Higher Education**

– Responsible for most of the teaching in applied physics for 1st year students of Télécom ParisTech(90h).
– Master level curriculum in the field of optical communications(150h).
– P. Gallion co-responsible of UPMC-Télécom ParisTech master "Systèmes de télécommunications numériques".
– Several life-long education courses

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## 2.2 People

**Team leader** Didier Erasme (FP).

**Faculty** Didier Erasme (FP), Renaud Gabet (AP), Philippe Gallion (FP), Christophe Gosset (I from 09/09), Frédéric Grillot (Adjunct Pr.(09/10–09/12) then AP), Yves Jaouën (FP), Cédric Ware (AP, Sabb. In Columbia Un. 8/11–7/12).

**PhD students** S. Jiang (10/04–02/08), F. Gómez Agis (02/05–10/08), J. Zhou (*/*–10/08), P. Hamel(10/05–03/09), Q. Xu (10/05–04/09), M. Sabban (11/05–04/09), V. Lanticq (07/06–06/09), E. Gueorguiev (10/01–07/09), A. Farhat (10/06–08/09), S. Hocquet (09/06–11/09), B.A. Bennai (09/06–01/10), F. Saliou (07/07–06/10), S. Cordette (12/06–08/10), O. Bertran Pardo (01/07–09/10), M. Gharaei (10/06–09/10), J. Petit (09/05–9/10), W. Akhtar (10/06–dem. 11/10), D. Fafchamps (10/05–12/10), C. Caillaud (09/07–12/10), S. Mumtaz (10/07–02/11), J.C. Antona (12/07–09/11), G. De Valicourt (10/08–10/11), M. Selmi (10/08–10/11), H. Brahmi (01/09– † 09/12), Y. Sikali Mamdem (09/09–10/12), K. Kechaou (11/09–11/12), A. Azarian (11/09–11/12), J. Karaki (10/09–04/13), P. Delesques (12/09–12/12), S. Tsyier (11/09–04/13), Q. Deniel Liu (10/10–), E. Lucas (01/11–), E. Awwad (10/11–), V. Henry (10/11–), M. Chaibi (09/12–), Xin You (09/12–), M. Song(10/12–), Ivan Aldaya, (visiting 07/12–07/13), Cheng Wang (co-supervision, registered at Foton).

**Post-docs, engineers and sabbaticals** F. J. Mendieta (Sabbatical until 03/08), postdoc: M. Costa E Silva (03/05–01/09), C. Gosset (09/08–08/09), Q. Xu (08/05–10/09), M.N. Ngo (09/10–02/12), H.T. Nguyen (11/10–02/13), E. Giacoumidis (11/11–03/13), I. Bertoldi Martins (05/12–07/13).

## 2.3 Overview

As part of LTCI, the Optical Communications Group focuses its research activities on topics related to optical transmission, processing of information and optical networking. Information refers primarily to communication data but also to sensors' inputs. During the first 5 to 8 years of the 2000's, the field of optical communications ran through a huge technical curve related to the co-development of advanced digital communication techniques associated and high-speed digital signal processing electronic devices. This evolution carries strong perspectives for enhancing the data transmission rate in the core network and for applications in access networks. Likewise, pulling the optical fibre all the way toward the end user while providing a significant step in services puts some very strong constraints on the devices' cost and power consumption. During that period, our group built a strong bedrock for embracing these evolutions, leading during the period of the report to a phase of consolidation and exploitation . Indeed, the 2008-2013 have been characterised by an extended set of national and international interactions as well as a large investment in equipment. Thanks to a state-of-the-art experimental platform for the evaluation of high rate transmission, we designed and developed original assessment procedures and tools for devices and signal characterisation. Following some efficient international experimental collaborations for the demonstration of new concepts developed by the GTO group, state-of-the-art experimental achievements were obtained. On an international ground, belonging to the EURO-FOS network of excellence (`http://www.euro-fos.eu/`), which involved the main European academic research groups in the field, provided a strategic position and a strong incentive for collaborative research. Our role as leader of a work package dedicated to joint experimental activities placed our group at the heart of the network. Collaboration with European groups have led to a large number of joint publications in the field of implementation of digital communication algorithms in experimental coherent systems, all optical packet switching, space-time coding e.g. [232, 207, 1034]. THis collaboration ended with the involvement in the large scale CELTIC project SASER. On national grounds, we have been involved in many collaborative research activities (one as leader) (7 ANR, 3 FUI) most of which involved several SMEs. Joint publications related to national initiative projects are many, eg. [232, 207, 233, 327, 339]. Bilateral industrial

relations continue to be very fruitful, one of them receiving “Paul Baran Young Scholar” award from the prestigious Marconi Society. In addition, GTO enjoys a strong position with respect to other optical communication groups in the world, being part of both the CNRS and the Institut Mines-Télécom with effective effective multidisciplinary collaboration. During the period, GTO recruited a new associate professor. Out of over 35 candidates, among which a number of advanced international researchers, Frédéric Grillot (HDR, previously in INSA-Rennes, H-index=16) was recruited.

## 2.4 Research Themes

### 2.4.1 Interfacing photonics, digital communication and signal processing, application to high rate communications and networking

**Faculty** D. Erasme, P. Gallion, C. Gosset, Y. Jaouën, C. Ware

**Highlights: Scientific Production** [223] [1034] [1070] [207] [232]

**Highlights: Impact** Four ANR (SUPERCODE, ECOFRAME, TCHATER, OCELOT) and one FUI (100GFlex) projects relate to this topic as well as the 3 NoEs and a CELTIC project. An Ile-de-France SESAME financial support was granted for platform investment. The publication record includes two led to invited papers. [411, 409]

**Highlights: Interactions with Society**

Most of the public funded projects above involve several industrial partners and co-supervising of PhD: Alcatel Lucent (Oriol-Pardo, Fafchamps, Antona), Orange Labs (Karaki), Mitsubishi Elect. (Delesques) International collaborations were conducted with TU Denmark, Henrich-Hertz Inst., Karlsruhe Inst. Technol., Nat. Techn. Un. Athens.

**Signal processing for optical time division multiplexing transmission** Clock recovery at transmission end or in routing nodes is an essential and yet challenging functionality in the case of high-bit-rate digital signals. A phase locked-loop can take advantage of ultrafast nonlinear optical devices (SOA or PPLN) as phase comparator. It allows clock recovery of RZ signals—and NRZ in some cases—as well as OTDM demultiplexing by recovering the “sub-clocks”. Collaborating with the Technical University of Denmark and the National Institute for Materials Sciences of Japan, we demonstrated sub-clock recovery [269] and full 1/64 OTDM demultiplexing at 640 Gbit/s. [223]. This was the second-ever demonstration of clock recovery at that high a bit rate, and the first involving a PPLN device, which was presented among record-setting postdeadline papers in OFC’2008. This activity, in the framework of e-Photon/ONe$^+$ and EURO-FOS was rewarded by an invited paper in the Journal of Lightwave Technology [411] and the “Letter of the Month” of Electronics Letters. Bit rate was pushed up to 0.87 Tbit/s [383], including phase modulation. Now that this level of performance and versatility has been shown, this activity is now reduced in favor of network-oriented functionalities.

**Coherent optical communication combined with Digital Signal Processing** Progress in digital signal processing and optical integration have enabled a new generation of optical transmission systems using complex modulation formats, coherent detection and digital algorithms to compensate for transmission impairments. Within ANR-TCHATER, we proposed more efficient coding/decoding forward error correcting (FEC) solutions suitable for high bit rates [1031, 915, 1035]. We investigated the unique properties of space-time codes for optical transmission systems. For the first time, we have shown that space-time coding could efficiently mitigate Polarization Dependent Loss impairments (PDL) [1032, 1033]. We have shown also that performances are very different from those in wireless transmission and explained why [951]. In collaboration with the Karlsruhe Institute of Technology, we proposed the first experimental implementation of Polarization-Time code (PT) for optical communications [1034]. The performance of Silver,

Golden and Alamouti PT codes for PDL mitigation were compared in reference to the uncoded case. A very-high-baud transmission platform is currently in development, including a 100 Gb/s transmitter/receiver and a 400 km recirculating loop. Its versatility and upgradability allows investigating different aspects of digital optical communications: Tx/Rx characterization, propagation impairments, new detection schemes, digital processing and coding techniques dedicated to the optical channel. As higher modulation formats are more sensitive to signal distortions, accurate estimators and more robust equalizers are still required for QAM formats. New adaptive blind and decision-directed equalizer based on Pseudo-Newton gradient-descent algorithm well matched to QAM and offering a better convergence speed with little extra computational load has been successfully introduced [1072]. The channel having very slow time variation (with respect to data rate), we proposed a block-wise implementation of the blind-time CMA equalizers [932]. Moreover, a new Carrier Frequency Oscillator (CFO) estimator well adapted to QAM modulation yields remarkable performance and allows penalty-less operation [1073].

**Cross-layer networks, network architecture and packet switching** Today's conventional OSI-layer-model networks face the critical challenge of unsustainable energy consumption growth. Solving it will require a drastic redesign, new network architectures optimised *globally*, beyond the artificial barriers imposed by network layers. Such *cross-layer networks* are already being developed to support mobile devices; in the case of fixed networks, optics has the potential to shine. Switching and routing, which is currently performed mostly in the electrical domain, entailing costly optical-to-electrical conversions is an emerging energy-cost driver. We have worked on the practical implementation of all-optical packet switching nodes at two occasions. An experimental proof of principle for a global all-optical node architecture based on serial-to-parallel conversion for header recognition concluded the first investigation [265]. Further work initiated with SUP'Com Tunis and supervised jointly whose objective used optical coding (OCDMA) to label the packets and performed all-optical routing using fiber Bragg grating coders/decoders and an optical flip-flop for routing. Experiments were performed in NTUA (Athens) thanks to the EURO-FOS NoE [207]. Another study led us estimate to the performance an optical ring WDM network architecture [312, 261] by providing the parameters of the statistical distribution $\chi^2$. However, contention is a major issue in all-optical switching: without practical buffering techniques, packets bound for the same destination must sometimes be dropped. Hybrid switching nodes aim to solve this problem by supplementing an optical switching matrix with an electronic memory. Our work on this architecture started with C. Ware's sabbatical in Columbia University (New York) [238, 414]; part of a Ph.D. was dedicated to a performance analysis of the hybrid node [1330] (in collaboration with other LTCI groups COMNUM, RMS, and with Mitsubishi El.).

**Complex signal analyses through pulsed coherent optical detection and optical sampling** Optical linear sampling uses the coherent optical mixing of the signal to be received, and statistically characterized, with a pulsed local oscillator (LO) providing simultaneously a temporal gating and a mixing gain. Oversampling, using several samples during symbol duration, takes benefit of improved modulation schemes and radiofrequency-based digital signal processing. Bandwidth related issues are solved afterward by using interleaved optical time bin and many fold detection. Synchronized linear optical sampling has been introduced, in real-time configuration, to overcome post detection electronics and analog-to-digital converter limitations as the bit rate increases [232]. We have derived a general theory for the optical transfer function and the signal-to-noise ratio of pulsed coherent detection, the results of which can be used in different applications [281]. On different grounds, a prototype based on asynchronous linear optical sampling was developed, especially for high frequency measurement (> 100GHz). We have derived and implemented digital blind signal processing techniques for digital clock recovery to display periodic signals and eye diagrams, for optical carrier recovery to display constellations, and for time resolved techniques to study frequency dynamic of optoelectronic devices [327]. This work is partially included in the ANR-OCELOT project.

**Related experimental means and novel characterisation concepts** Since 2008, we have defined a platform based programme, called “PENSER 100GIGA”, to implement both direct detection and coherent high-bit-rate optical techniques for the study of communication systems and related optoelectronic advanced devices. These new platforms allow the generation, detection and characterization of vectorial optical signals at 100 Gb/s. “PENSER 100GIGA” is ready to be upgraded up to 400 Gb/s, with a final target at 1 Tb/s. This investment project evaluated 500k€ has won a SESAME financing from region Ile-de-France (2010-2014). Within this programme we are developing a pulsed optical source, that now stands as a new field of investigation. It is a 1.5 µm widely tunable repetition rate, from 1 MHz to 10 GHz, femtosecond pulsed optical source, with frequency noise characteristics compatible with asynchronous linear optical sampling. The pulse duration allows THz bandwidth measurement.

### 2.4.2 Enhancement of optical devices and systems performance for context driven applications

**Faculty** D. Erasme, R. Gabet, P. Gallion, C. Gosset, F. Grillot, Y. Jaouën

**Highlights: Scientific Production** [201] [235] [216] [272] [275]

**Highlights: Impact** ANR projects HQNet, AROME, MODULE, and FUI projects TRILOB and CHRONOS are linked with this work.

**Highlights: Interactions with Society** All the projects mentioned above involve industrial partners. In addition a number of bi-lateral and CIFRE contracts have been running: Alcatel-Lucent 3-5 lab (Caillaud, de Valicourt laureate “Paul Baran Young Scholar”), Orange Labs (Saliou, Deniel), 3S-photonics (Tsyer), Yenista (Henry) and Thales. International cooperations include UPCatalunya, JiaoTong Shanghai, OFS.

**Cost effective high modulation bandwidth sources for access and metro networks** Providing higher bit rates, reaching longer distances and maintaining compatibility with the deployed standards are the main features of metro and specially access networks, which also have to cope with challenges related to the low cost, the small packaging and the reduced energy consumption of optical components. Optical sources for access, metro and radio-over-fiber networks must combine integration for both light generation and modulation. The ANR-MODULE project dealt with a novel integrated electro-absorption modulated laser (EML) with a dual-modulation access i.e. modulation on both the laser and the electro-absorption modulator acting jointly on the amplitude and the phase of the emitted optical signal. This technique allows single-side-band modulation and thus immunity to fiber dispersion impairment. Record transmission ranges have been achieved in NRZ at 10, 20, 25 and 40 Gbit/s [201, 340, 234] and in OFDM at 11 Gbit/s. Within the scope of the FUI-TRILOB project, we investigated another optical source consisting of an EML monolithically integrated with a semiconductor optical amplifier. Here again record transmissions were demonstrated at 10 Gbit/s [253]. In collaboration with 3-5 labs, we investigated the potentialities of reflective SOA (RSOA) mainly for access network applications [210]. Finally, novel device architectures including feed-back lasers and optically-injected laser and self-seeded cavities were studied showing widely enhanced bandwidth and reduced phase amplitude coupling [341, 235, 309]. A powerful new modelling tool for semiconductor lasers has been developped. Within our investigation of access network solutions, we have proposed a novel decentralized scheme supporting multiple optical Private Networking (PN) over ring-based Passive Optical Network (PON) taking benefit of asynchronous OCDMA technique. The network scalability and throughput performance of the proposed scheme have been analyzed in [322].

**Multi-Mode Interference coupler based switching and optical orthogonal transforms** We have analyzed the principle and the implementation of optical switching, Hadamard transform and discrete Fourier transform based on Multi Mode interference (MMI) devices in association with variable phase shifter array. The approach points out the possibility of achieving the higher

order Hadamard transform using simple 2D structures and provides a possible solution for all optical CDMA systems [273, 275].

**Advanced characterization techniques for photonic devices** Optical Low Coherence Reflectometry (OLCR) is a unique investigation tool for the study and the characterization of new photonic components. Over the past four years, we particularly studied the impact of disorder on the propagation of photonic crystal waveguide modes [255, 264]. In 2009 we produced an article displaying the many capabilities of OLCR for the characterization of specialty fibers [216]. For the FUI CHRONOS project devoted to the study of long Bragg grating manufacturing (1 m), the limits of OLCR set-up led us to develop a new characterization technique based on studying the emitted blue luminescence when the grating is irradiated by a UV beam [385]. Finally, we are currently looking on how to implement a new technology to measure precisely the PDL and the chromatic dispersion on ultra-fine filters (width about 50 pm, slope about 800 dB/nm) in relation with the SME Yenista through a CIFRE PhD.

**Associated experimental means and novel characterisation concepts** Testing optical device behaviour in communication system architectures requires high-bit-rate transmission platforms such as those mentioned in the previous paragraph (PENSER 100GIGA). In addition, measuring the complex (amplitude and phase) aspect of a modulated optical signal is crucial when one needs to assess its propagation in particular along length of dispersive optical fibers. Small-signal modulated waveform can be analysed using a dispersive element. Generalisation and analysis of this standard method was published [200]. On the other hand a new large signal measurement method has been designed and applied to test the optical sources mentioned above.

### 2.4.3 Quantum optics, non linear photonics and laser physics

**Faculty** P. Gallion, R. Gabet, F. Grillot, Y. Jaouën

**Highlights: Scientific Production** [395] [243] [219] [380] [267]

**Highlights: Impact** This topic has been supported by the ANR HQNet and several bi-lateral public or semi-public cooperations inculding PhDs with institution such as ONERA (Bennai, Azarian) and CEA-LASER MEGAJOULE (Hocquet)

**Highlights: Interactions with Society** The sensor research work has been carried out in collaboration with EDF and LCPC. (PhD: Lanticq, Sikali Mamdem), a long term collaboration with SME Keopsys has led to two consecutive PhD (Guiorguiev, Lucas). Expertise on slow-light has led to the co-edition by Y. Jaouën of a special issue of the “Comptes rendus de Physique” of the Académie des Sciences. International interactions include TU-Berlin, U. New-Mexico, CICESE (Mx).

**Space quantum communications, quantum key distribution (QKD) and quantum level detection** By using the quantum coherent state model of the signal field, we have compared different quantum receiver implementations and derived the minimum signal energy required to achieve a given bit error rate, or a given bit erasure rate, in high bit rate, quantum level communications [395]. We have implemented an optical Costas loop at 1550 nm based on polarization splitting of the laser field to detect I and Q quadratures simultaneously. We have obtained results on the performance in phase error and bit error rate and compared with the corresponding quantum limit in the quantum space communication context [395, 218, 219]. Using pulse coherent detection, we have implemented an all-fiber one-way QPSK quantum key distribution system at 1550 nm using a photon counting or a balanced homodyne detection (BHD) configuration. The security issues of the BHD QKD system have also been investigated under different attack protocols [271, 270]. As the use of decoy states improves the security level, coping against the photon

number splitting (PNS) attacks, we have generalized the standard QKD security analysis to our implemented system [251].

Finally, aiming at performing optical carrier recovery for weak optical signals, we implemented a receiver structure in which a sequential field quadrature measurement is achieved in association with digital Costas loop. We obtained results close to the uncertainty limit and to the standard quantum limit for low photon number reception [272, 245].

**Non linear fiber optics: Brillouin and Raman effects in optical fibre, assessment and application to sensing** A general formulation for the quantum macroscopic nonlinear optics has been derived [231] for application to fibre systems. A theoretical analysis on the PMD-assisted pump-to-signal noise transfer in distributed fiber Raman amplifiers (RA) allows to account for the high frequency noise transfer which is observed experimentally [334]. Raman amplifiers with time-division-multiplexed (TDM) pumps have been analyzed using a computational cost-effective Fourier series approach that allows the analysis and the optimization of the pumping mechanism [278]. An analytical approach of the forward and backward propagating configurations has allowed an explicit derivation for the Double Rayleigh Scattering (DRB) and Amplified Spontaneous Emission (ASE) noises [273].

Given its low power threshold, the Brillouin effect in optical fibres is one of the most promising nonlinear effects for designing new all-optical processing devices and optical sensors. A self-referenced technique for measuring the Brillouin gain in an optical fibre has been recently proposed, and the importance of the acousto-optic effective area in place of the optical effective area on the Brillouin efficiency has been confirmed for the first time [346, 203]. A 2 D FEM model has been proposed for accurate Brillouin gain spectrum (BGS) calculation in acoustic guiding and anti-guiding single mode optical fibres [405]. Particularly, the influence of the geometrical structure, the doping composition profile and the internal residual draw-induced stresses on BGS properties have been investigated [263]. An accurate determination of the strain dependence of the Brillouin frequency shift has been proposed for the first time and has been validated experimentally using different types of optical fibre [380].

**High power lasers** Our work is carried out mainly through collaborations with external laboratories (ONERA, CEA, PhLAM) and with the Keopsys SME. We have collaborated With ONERA on the analysis of the Brillouin spectrum doping dependence of doped fibres[405], as well as the combination of coherent fibre amplifiers in both continuous [407] and pulsed regimes [348, 243]. Numerical space-filling designs have been proposed to analyze the sensitivity of coherent beam combination in large fibre amplifier arrays. The most critical interactions have been investigated in details[282]. The collaboration with CEA on Laser Mégajoule focused on the spectral broadening properties through FM-AM conversion induced by non-sinusoidal phase modulation in comparison to the sinusoidal phase modulation case [227, 229]. The collaboration with PhLAM concerns the design of an Ytterbium-doped solid core photonic band-gap fiber for laser operation at 980 nm [258]. In collaboration with Keopsys Company and ONERA, we are presently developing advanced architectures of pulsed fiber Thulium laser at 2 µm.

**Nonlinear Photonics in Advanced Semiconductor Lasers** Investigating the field of semiconductor laser dynamic and microwave photonics, this topic investigates nonlinear dynamics and optical injection in diode oscillator especially quantum-well, quantum-dot and quantum-cascade lasers to prepere the next generation of photonic oscillators and semiconductor lasers. The applications range from mid-infrared ultra-low-noise oscillators, bandwidth enhancement for various engineering applications from optical communications up to defence and homeland security. To this end, recent studies have shown the potential of Q-Dot lasers operating under external control for free-chirp high-speed communications by linewidth enhancement factor engineering [410]. In addition, we have theoretically reported for the first time some unique properties of optically

injected Q-cascade lasers for free-space communications [226]. It was shown that the injection-locked quantum-cascade lasers exhibit a flat modulation response at zero detuning as well as bandwidth enhancement with injection level.

## 2.5 Achievements (Appendix 6)

Note: Christophe Minot (DE) is administratively part of the GTO group but does his research work in LPN-CNRS. His publications (9 journals, 1 conference and 1 patent) are listed below but not counted in this executive summary. Frédéric Grillot being adjunct professor before joining by GTO, his publications listed below correspond to research work performed with LTCI.

### 2.5.1 Scientific Productions

#### Articles in Journals


[200] L. Anet Neto, D. Erasme, N. Genay, P. Chanclou, Q. Deniel, F. Troare, T. Anfray, R. Hmadou, and C. Aupetit-Berthelemot. Simple estimation of fiber dispersion and laser chirp parameters using the downhill simplex fitting algorithm. *IEEE/OSA Journal of Lightwave Technology*, 31(2):334–342, Jan. 2013.

[201] T. Anfray, C. Aupetit-Berthelemot, K. Kechaou, D. Erasme, G. Aubin, C. Kazmierski, and P. Chanclou. Simulation of SSB-LC with D-EML for extended PON beyond the chromatic dispersion limit. *IEEE/OSA Journal of Lightwave Technology*, 30(19):3089–3095, July 2012.

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[203] C. Baskiotis, Y. Jaouën, R. Gabet, G. Bouwmans, Y. Quiquempois, M. Douay, and P. Sillard. Microbending behavior of large mode area bragg fibers. *Optics Letters*, 34:3490–3492, Nov. 2009.

[204] N. Belabas, S. Bouchoule, I. Sagnes, J. A. Levenson, C. Minot, and J. M. Moison. Confining light flow in weakly coupled waveguide arrays by structuring the coupling constant: towards discrete diffractive optics. *Optics Express*, 17(5):3148–3156, Feb. 2009.

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[208] G. Canat, A. Durecu, G. Lesueur, L. Lombard, P. Bourdon, V. Jolivet, and Y. Jaouën. Structure of the Brillouin spectra in Erbium-Ytterbium fiber. *Optics Express*, 16:3212–3222, Feb. 2008.

[209] G. Canat, L. Lombard, A. Dolfi, B. Augere, C. Besson, Y. Jaouën, S. Jetschke, S. Unger, E. Gueorguiev, and C. Vitre. High brightness 1.5µm pulsed fibre laser for lidar: from fibres to systems. *Fibers and Integrated Optics*, 27:422–439, Sept. 2008.

[210] G. de Valicourt, M. A. Violas, D. Wake, F. van Dijk, C. Ware, A. Enard, D. Maké, Z. Liu, M. Lamponi, G. H. Duan, and R. Brenot. Radio over fibre access network architecture based on new optimized RSOA devices with large modulation bandwidth and high linearity. *IEEE Transactions on Microwave Theory and Techniques*, 58(11):3248–3258, Nov. 2010.

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### Invited Papers and Conferences

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[399] F. Grillot. Non-linear dynamics in quantum dot photonic circuits: From optically injected to passively mode locked lasers. In *International Workshop on Nonlinear Dynamics in Semiconductor Lasers*, Berlin, Germany, Apr. 2012. Conférence Invité.

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utilisant un D-EML à 10GB/s. In *Journées nationales d'optique guidée (JNOG)*, Lyon, July 2012.

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O. Vasseur. Combinaison cohérente d'amplificateurs à fibre en régime 100-ns. In *Journées nationales d'optique guidée (JNOG)*, number P182, Marseille, July 2011.

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### 2.5.2 Public Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008 | CMCU - Collaboration avec Sup'com Tunis | Univ. Lyon | P.Gallion | 6 |
| 2008-2010 | BONE European Network of Excellence : Building the future optical network in Europe | Europe | D. Erasme | 15 |
| 2008-2012 | EURO-FOS European Network of Excellence : The Pan-European Photonics Task Force | Europe | D. Erasme | 280 |
| 2009-2012 | TRILOB : Design and fabrication of optical emitters end receivers for very high optical budget 10Gbit/s WDM acces network | FUI | D. Erasme | 152 |
| 2009-2012 | CHRONOS : CHROmatic dispersioN compensatOrS | FUI | R. Gabet | 150 |
| 2009-2012 | MODULE : Integrated optical source with dual modulation for access and metropolitan networks | ANR | D. Erasme (coord.) | 177 |
| 2010-2013 | PERSEE-Plateforme 100G : Optical transmission, coherent reception plateform including electronc signal processing for ultra high rate systems | Région IDF | B. Thedrez (coord.) | 150 |
| 2010-2014 | 100G-Flex : OFDM multi-bands 100G FLEXible transmissions | FUI | Y. Jaouën | 119 |
| 2011-2014 | OCELOT : Development of an all-optical linear sampling scope for constellation assessment | ANR | P. Gallion | 149 |
| 2012-2014 | MPAC Manipulation of the Phase-Amplitude Coupling Factor in Quantum Nanostructure Based Devices for On-Chip Chirp Compensation & Low-Cost Applications | USA-EOA | F. Grillot (coord.) | 44 |
| 2012-2014 | SASER CELTIC+ Project : Safe and Secure European Routing | Europe | Y. Jaouën | 293 |

### 2.5.3 Private Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008 | 3S-Photonics : Développement de composants lasers modulateurs intégrés pour modules TOSA à très faible consommation | OSEO | P. Gallion | 2 |
| 2008-2009 | FTRD-Transmission : Digital signal processing applied to multi level modulations for bit rates of 40 and 100 Gbit/s | FT TR&D | Y. Jaouën | 82 |
| 2009-2012 | CIFRE Karaki : 100 Gbps Coherent MB-OFDM for long-haul WDM optical transmission | FT R&D | Y. Jaouën | 15 |
| 2009-2012 | CIFRE Sikali Mamdem : distributed Brillouin fibre optics sensors : discrimination of the temperature and strain dependency | EDF | Y. Jaouën | 70 |
| 2010 | Etude de photorécepteur optique complément thèse C. Caillaud | 3-5Lab | D. Erasme | 13 |
| 2010-2013 | Thèse Deniel : Very high bit rate optical access evolution | FT R&D | D. Erasme | 43 |
| 2011-2014 | CIFRE Lucas : design and development of pulsed laser sources around 2 microns wavelength | Keopsys | Y. Jaouën | 9 |
| 2011-2014 | CIFRE Henry : Characterization of new optical filtering devices | Yenista Optics | R. Gabet | 39 |
| 2012-2014 | CRE SDFEC : Advanced forward error correction methods (such as SD-FEC), for phase noise and non linear compensation in coherent fiber optics systems | FT R&D | Y. Jaouën | 40 |

### 2.5.4 Patents and software

[440] J. M. Moison and C. Minot. Composant optique à hétérostructure de réseaux de guides d'ondes. (08/05307), Sept. 2008.

[441] G. Moreau, S. Lesoille, F. Taillade, Y. Jaouën, and R. Gabet. Dispositif de mesure de deformations le long d'au moins une fibre optique, utilisation d'une fibre optique pour faire une mesure de deformations et procede de mesure de deformations. (SP 52990 ET), Sept. 2012.

[1125] S. Mumtaz, G. Rekaya-Ben Othman, and Y. Jaouën. Procédé et dispositif de modulation mettant en œuvre une modulation différentielle, procédé et dispositif de démodulation, signal et produits programme d'ordinateur correspondants. (FR 09/52207 et EP 2415193 A0), Apr. 2009.

[1126] S. Mumtaz, G. Rekaya-Ben Othman, Y. Jaouën, and B. Thedrez. Méthode et système de transmission wdm à codage chromato-temporel. (FR 10/58204), Oct. 2010.

[1133] G. Rekaya-Ben Othman, Y. Jaouën, and S. Mumtaz. Méthode et système de transmission sur fibre optique multi-mode et/ou multi-coeur. (FR 11/55537), June 2011.

## 2.6 PhDs (Appendix 7)

### 2.6.1 Defended PhDs

[445] a. Azarian. *Combinaison cohérente de lasers à fibre : étude en régime impulsionnel et mise en phase d'un grand nombre d'émetteurs*. PhD thesis, Télécom ParisTech, Nov. 2012.

[446] J.-C. Antona. *Novel design tools enabling to predict the qulity of transmission and to design optical betworks modulated at 10, 40 and 100 Gb/s*. PhD thesis, Telecom ParisTech, Sept. 2011.

[447] B. Bennai. *Etude mise en phase fibres faiblement multimodes*. PhD thesis, Télécom Paris Tech, Jan. 2010.
[448] B. Bennai. *Mise en phase de lasers à fibre : Etude de l'influence de la turbulence atmosphérique et de l'utilisation de fibres faiblement multimodes*. PhD thesis, Telecom ParisTech, Jan. 2010.
[449] O. Bertran-Pardo. *On coherent detection for optical transmission at 40Gb/s and 100Gb/s*. PhD thesis, Telecom ParisTech, Sept. 2010.
[450] C. Caillaud. *Photorécepteur intégré SOA-PIN pour les applications à 100 Gbit/s*. PhD thesis, Télécom ParisTech, Dec. 2010.
[451] S. Cordette. *Continuum de fréquences optiques pour application OCDMA*. PhD thesis, Télécom ParisTech, July 2010.
[452] G. de Valicourt. *Design and Fabrication of Reflective Semiconductor Optical Amplifier for Access and R-o-F Network*. PhD thesis, Télécom ParisTech, Oct. 2011.
[1140] P. Delesques. *Analyses of transmission and switching capacities in optical networks*. PhD thesis, Telecom ParisTech, Dec. 2012.
[454] D. Fafchamps. *Communications numériques dans les réseaux d'accès optique : Modélisation, codage, performances*. PhD thesis, Thèse de Télécom ParisTech, Nov. 2011.
[455] A. Farhat. *Etudes des performances d'un système CDMA optique*. PhD thesis, Thèse l'Université El Manar, Ecole Nationale d'Ingenieurs de Tunis„ July 2011.
[456] M. Gharei. *Nouveaux concepts pour les réseaux d'accés optiques*. PhD thesis, TELECOM ParisTech, ENST, July 2010.
[457] F. Gómez Agis. *Boucle à verrouillage de la phase opto-électronique*. PhD thesis, Télécom Paris Tech, Oct. 2008.
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[459] E. Gueorguiev. *Conception et réalisation d'amplificateurs de forte puissance à base de fibre dopée Erbium et Erbium-Ytterbium double gaine fonctionnant en régimes continu et impulsionnel*. PhD thesis, Télécom ParisTech, July 2009.
[460] P. Hamel. *Réflectométrie à faible cohérence sensible à la phase : principe et application à l'étude de composants optiques innovants*. PhD thesis, Telecom ParisTech, Mar. 2009.
[461] S. Hocquet. *Optimisation de la modulation de phase utilisée pour les lasers de puissance : minimisation de la conversion FM-AM tout en conservant les fonctionnalités d'élargissement spectral nécessaire à la fusion*. PhD thesis, Telecom ParisTech, Nov. 2009.
[462] S. Jiang. *Contributions à l'étude théorique des bruits quantiques et classiques dans les amplificateurs Raman distribuées*. PhD thesis, ENST, Feb. 2008.
[463] J. Karaki. *100 Gbps Coherent MB-OFDM for long-haul WDM optical transmission*. PhD thesis, Telecom ParisTech, Apr. 2013.
[464] K. Kechaou. *Modélisation et caractérisation de sources optiques pour les réseaux d'accès et métropolitains*. PhD thesis, Telecom ParisTech, Dec. 2012.
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[1150] S. Mumtaz. *Modern coding techniques for optical communications*. PhD thesis, Telecom ParisTech, Jan. 2011.
[467] J.-M. Petit-Ferrufino. *"Dual Electroabsorption odulated Laser" Etude et caractérisation d'une nouvelle source optique laser-modulateur intégrée pour les transmission numériques à haut-débit et les applications radio-sur-fibre*. PhD thesis, Télécom ParisTech, Sept. 2010.
[468] M. Sabban. *Sécurité en cryptographie quantique utilisant la détection homodyne d'états cohérents à faible énergie*. PhD thesis, ENST, Apr. 2009.
[469] F. Saliou. *Etudes des solutions d'accès optique exploitant une extension de portée*. PhD thesis, Télécom ParisTech, June 2010.
[1159] M. Selmi. *Advanced digital signal processing tools for QAM-based optical fiber communications*. PhD thesis, Telecom ParisTech, Oct. 2011.
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[472] S. Tsyier. *Caractérisation des profils d'indice de réseaux de Bragg innovants en module et phase*. PhD thesis, Télécom ParisTech, Apr. 2013.
[473] Q. Xu. *Détection Optique Homodyne : Application à la Cryptographie Quantique*. PhD thesis, Apr. 2009.

[474] J. Zhou. *Mathematical and experimental study on nonlinear optical fiber amplifiers*. PhD thesis, TELECOM ParisTech and Shanghai Jiao Tong University„ Oct. 2008.

### 2.6.2 Ongoing PhDs

- Q. Deniel Liu (10/10–), Evolution de l'accès optique vers le très haut débit.
- E. Lucas (01/11–) Etude et mise en oeuvre de sources laser à fibre impulsionnelles autour de 2 microns.
- E. Awwad (10/11–) Communications optiques à très haut débit utilisant le codage spatio-temporel.
- V. Henry (10/11–) Caractérisation d'une nouvelle génération de composants optiques filtrants.
- M. Chaibi (09/12–) Etude de composants d'émission optique pour les réseaux d'accès de nouvelles générations.
- Xin You (09/12–) Caractérisations vectorielles statistiques des signaux optiques pour les communications à très haut débits et les communications quantiques.
- M. Song(10/12–) Vers une gestion et un contrôle de services dynamiques, adaptatifs et avec une qualité de services dans les réseaux ambiants.
- Ivan Aldaya (visiting 07/12–07/13)
- Cheng Wang (co-supervision, registered at Foton)

# Chapter 3

# Circuits and Communication Systems (C2S)

## 3.1 Executive Summary (Appendix 1)

**Team Leader** Patricia Desgreys (AP) (Patrick Loumeau (FP), –08/13)

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**Initial staff** 1 Full Professor, 4 Associate Professors (2 HDR), 2 Engineers and 6 Phd Students.
**Staff who Left** 13 PhD students (389 months), 5 Engineers (151 months), 2 Post Doct.(61 months) and 13 Internships (45 months)
**Staff who Were Hired** 1 Research Engineer (recruited in June 2008), 3 Engineers, 3 Post Doct. and 16 PhD. Students.

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**Scientific Highlights**

- The period was characterized by a particular emphasis on Cognitive Radio Systems with a focus on Frequency-agile and reconfigurable receiver.
- Non Uniform Sampling receiver for multi-standard signal digitization [476] was demonstrated for the first time in order to avoid the use of automatic gain control and to relax the antialiasing filter.
- Three state-of-the-art reconfigurable ADCs were designed and fabricated during the period. First-in-class figure of merit was achieved: 0.94 pJ per conversion step for GSM/EDGE [511].
- The intrinsic signal shaping achieved in Delta Sigma modulators was exploited for the first time to create a Continuous Time Frequency Band Decomposition parallel digitalization. This work led to a patent “Method for Multiband Multilevel ADC“ [563] and three publications [490][551][550]
- Work on reliability of analog or mixed-signal architectures were initiated in October 2008 and developed after that within the European RELY project.

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**Scientific Production** 18 Journals; 2 Book chapters; 59 Articles in Proceedings; 2 Invited Articles in Proceedings; 6 Patents; 1 Software

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**Major Publications**


- D. Camarero, K. B. Kalaia, J. F. Naviner and P. Loumeau. Mixed-Signal Clock-Skew Calibration Technique for Time-Interleaved ADCs. IEEE Transactions on Circuits and Systems I : Regular Papers, 55(11):3676-3687, Dec 2008
- H. Khushk, P. Loumeau and V. T. Nguyen. A Comparative Study of Loop Filter Alternatives in Second-Order High-Pass $\Sigma\Delta$ Modulators. IEEE Transactions on Circuits and Systems I : Regular Papers, 58(11):2604-2613, Nov 2011
- D.-K G. Pham, P. Desgreys, P. Loumeau and Tim Ridgers. Multi-stage noise band cancellation SD Modulator for digitisation of distorded signal. Electronics Letters, 48(10) May 2012.
- M. Ben Romdhane, C. Rebai, A. Ghazel, P. Desgreys and P. Loumeau. Non-Uniformly Controlled Analog-to-Digital Converter for SDR Multistandard Radio Receiver. IEEE Transactions on Circuits and Systems II, 58(12):862-866, Dec 2011
- Hao Cai, H. Petit and J. F. Naviner. Reliability aware design of low power continuous-time $\Sigma\Delta$ modulator. Microelectronics Reliability Journal 51(9): 1449-1453, Aug 2011


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**Impact and Attractivity**

- One C2S group member (Van-Tam Nguyen) : Rank A guest researcher from NICT (National Institute of Information and Communication Technology - Japan), and visiting Professor at Electrical Engineering & Computer Sciences, UC Berkeley
- Tutorials and Invited Papers at international conferences : IEEE NEWCAS, IEEE FTFC, EuMW, International Conference on Awareness Science and Technology - Plenary talk at International Conference on ”Communication Languages & Signal Processing - with reference to 4G Technologies“
- Guest Editor of a Special Issue in Analog Integrated Circuits and Signal Processing
- Organizers (General Chair and TPC) of IEEE NEWCAS2013 and Technical Program Chair (TPC) of IEEE NEWCAS 2012
- Member of the Steering Committee of CNRS SoC-SiP GDR involving 600 researchers in Circuit Design for SoC-SiP

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**Interaction with Economic and Social Spheres**

- Six European projects (CATRENE APPSGATE - ENIAC ARTEMOS - CATRENE RELY - FP7 SACRA - CATRENE PANAMA - InterCarnot Fraunhofer TEROPP)
- Main leader of the InterCarnot Fraunhofer TEROPP project
- Many CIFRE and bi-lateral collaborations (NXP, RENESAS, STMicroelectronics, THALES)

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**Contributions to Higher Education**

- Creation and coordination of the Master of Sciences ”Digital Radio“
- Coordination of the set of courses (parcours) ”Electronics for Radiocommunication applications“
- Coordination and implementation of five Master modules
- With the help of the TEROPP project partners, creating a training session on the topic of ”Cognitive and Opportunistic Radio Applications“

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## 3.2 People

**Team leader** Patrick Loumeau (FP).

**Faculty**

Patricia Desgreys (AP), Hussein Fakhoury (Eng), Patrick Loumeau (FP), Jean-François Naviner (AP), Van Tam Nguyen (AP), Hervé Petit (AP).

**PhD students**

A. Latiri (07/04–06/08), R. Mina (03/05–12/08), H. Khushk (09/06–11/09), W. Altabban (12/06–12/09), C. Jabbour (10/07–09/10), A. Gruget (10/08–12/11), P. Maris Ferreira (10/08–09/11), S. Kowlgi (05/09–03/13), F. Ghanem (10/09–09/12), A. Maalej (01/09–05/12), D. Pham (01/10–01/13), H. Cai (09/10–), M.T. Nguyen (07/11–), O. Jamin (10/11–03/13).

**Post-docs and engineers**

D. Camarero De La Rosa (07/07-12/08), R. Guelaz (09/07–03/09), H. Khushk (09/06–12/10), A. Beydoun (02/08–08/09), C. Jabbour (10/10–), C. Ouffoue (11/10–10/12), M. Homayouni (11/12–), G. Pham (01/13–).

## 3.3 Overview

The C2S team gathers altogether one professor, four associate professors and one research engineer. Two faculties graduated HDR during the period. The previous AERES review pointed out the rising international recognition of the C2S team in the domain of cognitive radio systems, circuits and communication systems. This trend was pursued during the period: Over 80% of the contractual funding of the C2S team in the last three years was based on international projects. The scientific production includes almost four papers per year, an average of eleven conference papers by year and a patent. The average of PhD defense is 2 per year.

Most of the research funding in the period were based on six major European projects:

- CATRENE APPSGATE European project 2012-2015: Applications Gateway
- ENIAC ARTEMOS European project 2011-2014: Agile RF Transceivers and Front-Ends for Future SmartMulti-Standard COmmunications ApplicationS
- CATRENE RELY European project 2011-2014: Design for RELIABILITY of SoCs for Aeronautics Applications
- FP7 SACRA European project 2010 - 2013: Spectrum and energy efficiency through multiband Cognitive Radio
- CATRENE PANAMA European project 2009 -2012: Power Amplifiers aNd Antennas for Mobile Applications
- InterCarnot Fraunhofer TEROPP project 2008 - 2011: Technologies for terminals in opportunistic radio applications

Besides Europe, we also started specific relations with the Asia area with the STIC ASIE project GREENRAN. As output of GREENRAN, one faculty spent 6 months at NICT (national Institute of Information and Communication Technology) in Japan.

Fuelled by our international networks, we took an active involvement in the IEEE International NEWCAS Conference with a Technical Chairman position in the 2012 edition and the complete organization of the 2013 edition in Paris with the positions of General Chairman and Technical Chairman. 250 papers were submitted from 35 countries.

The group was also active in national networks, with two faculties members of the Steering Committee of the CNRS GDR SOC-SIP which gathers altogether 600 researchers on SOC-SIP Circuit Design. At the regional level, the GIS eSys was created for the Electronics Systems in Ile de France with SUPELEC, ISEP, ESIEE, Paris 6 and Paris 11 Universities. Two team members are in the Steering Committee of the GIS.

The team has also strong interactions with the economical sphere and works with key industrial groups: NXP semiconductors, Renesas, Thales, ST Microelectronics. Two bilateral PhD

contracts were signed with STMicroelectronics, two with NXP Semiconductors, one with RENESAS and one with Thales.

In addition, the group had projects funded by internal calls of Institute Telecom:

- 2013 project REFLEX: algorithm for extracting coefficients of a DPD from a multirate information
- 2012 project SigmaDeltaReceiver: Agile RF Receiver for future Wireless Communication Systems based on RF Sampling and Sigma Delta Modulation
- 2009 project ARMURE: ARchitecture MUltivoie à très large bande pour REcepteur à mobilité généralisée

## 3.4 Research Themes

### 3.4.1 From frequency-agile and reconfigurable transceiver to cognitive radio systems

**Faculty** V.T.Nguyen, P.Loumeau, H. Fakhoury, P.Desgreys, H.Petit, J.F.Naviner

**Highlights: Scientific Production** [489] [482] [486] [478] [490]

**Highlights: Impact**

- V.T. Nguyen, member of C2S group is a Rank A guest researcher from NICT (National Institute of Information and Communication Technology - Japan) and Visiting Professor at Electrical Engineering & Computer Sciences, UC Berkeley
- 1 Tutorial and 1 Invited Paper, 1 invited talk, 1 Plenary talk at international conferences (IEEE NEWCAS 2011, IEEE iCAST 2011, EuMW 2012, ICCLP 2012)
- Technical Program Chair (TPC) of IEEE NEWCAS 2012 and organizers (General Chair and TPC) of IEEE NEWCAS2013
- Member of the Steering Committee of CNRS - Research group on SoC-SiP in charge of animating the community of 600 French researchers on Circuit Design for SoC-SiP
- Projects (5 Europeans): FP7 SACRA, ENIAC ARTEMOS, CATRENE PANAMA, CATRENE APPSGATE, ANR-07-P2IC TEROPP

**Highlights: Interactions with Society**

- Leadership on “multi-standard and multiband transceiver for cellular applications” in one of the largest European ENIAC project (ARTEMOS)
- An actor visible in Catrene and ENIAC European programs with 4 projects
- Industrial contracts : 2 Ph.D Thesis (CIFRE) with NXP, and 1 Ph.D Thesis (CIFRE) with Renesas; 1 Ph.D thesis (CIFRE) with THALES; 2 Ph.D thesis (CIFRE) with ST Microelectronics.
- 6 patents: [558] [559] [560] [561] [562] [563]

**Frequency-agile and reconfigurable receiver** The focus of this research is on frequency agile high dynamic range digital friendly RF architectures suitable for nanoscale CMOS. The work which is in close collaboration with ST-Ericsson is part of the European ENIAC ARTEMOS project where we are the leader of the task on multi-standard and multiband transceiver for cellular applications. The project intends to set new communication standards with advanced research on new reference for RF carrier frequency, channel bandwidth, noise figure, linearity and selectivity characteristics [542].

**High performances, reconfigurable ADCs** One of our main research topics for years has been high performances, reconfigurable ADCs. This is a key building components In any receiver. Our main expertise is on delta sigma modulator architecture in advanced CMOS technology. We have proposed novel architectures for high-pass delta sigma modulator [486] [485], circuit reconfigurability based on high-pass and low-pass [484], unity signal transfer function with global feedback loop [545] and high performance ADC designed in 65nm CMOS technology [511]. Our work on continuous-time modulator led to improve performance in power consumption and to higher bandwidth. A very high performance ADC designed in 65 CMOS technology with 40MHz of bandwidth, 76dB of SNR, 88dB of SFDR and with less than 100 mW of power consumption using an innovative continuous-time modulator was recently sent to foundry. This work is part of FP7 SACRA project and the ENIAC ARTEMOS project. This newly designed ADC will be part of the final SACRA demonstrator on cognitive radio systems.

The layout of the prototype implemented in a 65nm CMOS process is shown in Fig. 3.1 left. The simulated performances of the ADC are compared to the state of the art in Fig. 3.1 right. Regarding the dynamic performances, our design is the first ADC with 74dB of SNDR in 40MHz bandwidth.

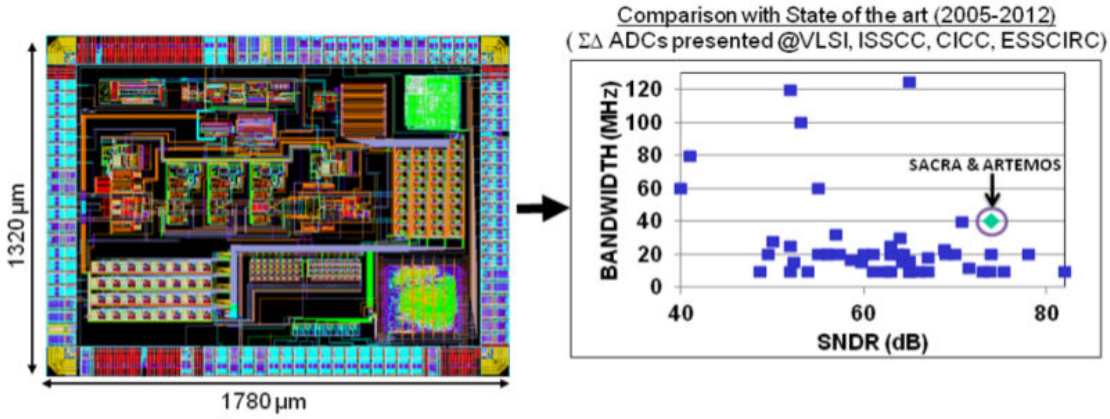


Figure 3.1: Left) Layout of the Delta Sigma ADC designed in the FP7 SACRA project and the ARTEMOS project Righ)t Comparison of our performances (bandwidth & resolution) to prior published works

The development of the software radio is still significantly limited by the available resolution and speed of the ADC stage. Parallel ADCs are a promising way of increasing analog-to-digital conversion rates. After the demonstration of time-interleaved (TI) Sigma Delta ADC with a four channel [504] [478] [477], we are studying TI architecture employing Nyquist pipeline ADCs with the objective of eliminating the frequency response error between the different channels. This work is ongoing in a bilateral project with NXP semiconductors. An alternative solution for parallel architecture is to employ hybrid filter banks. The advantage compared to TI architecture is robustness against channel mismatch at the cost of more complex analog and digital parts. We proposed an innovative solution [562] based on both time multiplexing and frequency multiplexing in order to retain the advantages of both architectures (TI and hybrid filter banks). This work is a part of ANR-07-P2IC TEROPP on opportunistic and cognitive radio, but can be extended to other demanding applications.

**Non-uniform sampling** The issue is inventing new architectures and new sampling schemes to relax the constraints on the analog parts, in particular anti-aliasing filters which are the more costly and the less reconfigurable parts in RF receivers.

To deal with the suppression of RF anti-aliasing filtering, Non Uniform Sampling (NUS) has been studied in a collaborative project with SUP'COM Tunis. We have demonstrated relaxed

constraints on both RF filter and ADC dynamic power consumption, using an appropriate NUS architecture. Our team proposed the first NUS receiver for multi-standard signal digitization [476].

**Digital correction of analog/RF imperfections** To overcome the loss of accuracy of analog/mixed/RF circuits designed in digital technologies, a great challenge is to develop new digital correction techniques, based on pre or post-rectification of distortions. These techniques have begun to show interesting results and will continue to benefit of sub-micron digital technologies with implementation low cost and low power consuming.

One promising solution to increase the bandwidth of ADCs is to operate several channels in a parallel architecture exploiting either the time domain (Time Interleaved TI ADCs) or in frequency domain (Frequency Band Decomposition FBD ADCs). One example of FBD ADC is proposed in the next paragraph.

The main limitation of TI ADC arises from slight variations between the M parallel channels. Solutions already exist to correct offset and gain mismatches, but as the repetition rate increases, timing skew and bandwidth mismatch become critical issues. The challenge in implementing efficient algorithms against frequency mismatch non linearities is to derive blind solution, i.e. without any knowledge on the input signal, for Nyquist converters. Recently, we demonstrated a new background extraction technique for bandwidth mismatch error resulting in an error between two channels down to 0.03% equivalent to 95dB of SFDR [515]. In the framework of the European Catrene project APPSGATE we will extend our results to both the detection and correction of a 64-channel ADC.

**ADC design in the non linearity correction path of base station PA** Driving a power amplifiers (PA) in a low bias regime can drastically reduce its consumption, yet significantly enhances its nonlinearities. Applying digital predistortion (DPD) can provide a very effective compensation for such impairments if the digitization covers all the PA nonlinearities spectrum, including the low power adjacent signal bands resulting from intermodulation. This requires a wide band Analog-to-Digital Converter (ADC) operating on typically 5 times the input signal bandwidth. The design of one single ADC, meeting the requirements of high dynamic range (> 80 dB) and wide bandwidth (>75 MHz),leads however to an oversized power consuming solution. We have demonstrated that one primary A/D converter to convert the high power signal band (15 MHz) and two secondary converters for the adjacent bands (30 MHz each) with lower signal powers significantly reduces the total ADC consumption. To avoid saturation of the secondary converters by the high power signal band without additional analog filtering, we proposed to use the inherent signal shaping achieved in Delta Sigma modulators to perform this attenuation. This innovative solution led to a patent “Method for Multiband Multilevel ADC“ [563] and several publications [490],[551],[550]. This work was part of the European Catrene project PANAMA. We continue on this research theme thanks to a new project named REFLEX, supported by Institut Mines-Telecom in which a specific DPD algorithm, dedicated to our digitalization solution is being developed for low power consumption.

**Cognitive Radio Systems** CRS is a multidisciplinary arena that has attracted a large number of researches. The challenges yet remain numerous, namely intelligence distribution and implementation, security, delay/protocol overhead, cross-layer design, flexible hardware design, etc. Our contribution has been on high-level concept of CRS, RF receivers for spectrum sensing as well as for communication chains and sensing algorithms taking into account implementation constraints. We started recently on cognitive radio resource management and smart spectrum management, taking into account in our circuit designs implementation constraints, computational resources, power dissipation and size. The work on CRS is part of ANR-07-P2IC TEROPP, FP7 SACRA project and ENIAC ARTEMOS project.

### 3.4.2 Nanoelectronics architectures and circuits

**Faculty** P.Desgreys, J.F.Naviner, H.Petit

**Highlights: Scientific Production** [483] [480] [481] [488] [475]

**Highlights: Impact** European projet RELY, "Design for RELIABILITY of SoCs for Applications like Transportation, Medical, and Industrial Automation"

**Highlights: Interactions with Society** – 1 software [564]

**Reliability of mixed-signal architectures and circuits** The works on the reliability of analog or mixed-signal architectures was initiated in Oct. 2008. Considering that many circuits today are Systems-on-Chip (SoC), that they often include various analog or mixed-signal sub-circuits and that the reliability of a SoC results from both the reliability of each sub-parts and the connections/interactions between them, our main objectives are:

- to assess the reliability of basic functions considering the physical causes of failures (ageing effects or other causes)
- to assess the reliability of an architecture working at behavioural level
- to compare basic functions circuitries and architectures on both performance and reliability metrics
- to define methods of architecture/circuit design that includes the reliability criteria

The present work is focusing on the reliability of A/D converters [480]. After studying the causes of degradation and failures in nanoscale integrated circuits with ageing [488], we are working on the early prediction (in the design process) of the circuit lifetime facing process variability and devices aging (European project: RELY).

A reliability-aware methodology has been applied to the hierarchical evaluation of ageing effects and process variations in a 2nd order continuous-time sigma-delta modulator designed in 65 nm CMOS technology, for ultra low power cardiac pacemaker. Appropriate simulation efficiency and accuracy for both ageing effect and process variations have been demonstrated using our approach [481],[507].

# 3.5 Achievements (Appendix 6)

## 3.5.1 Scientific Productions

### Articles in Journals


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Washington DC, USA, Aug. 2010.

**Invited Talks**

[556] P. Desgreys, F. Ghanem, G. Pham, H. Fakhoury, and P. Loumeau. Beyond 3G wideband and high linearity ADCs. In *IEEE Faible Tension Faible Consommation (FTFC)*, pages 59–62, Marrakech, Morocco, May 2011.

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### 3.5.2 Public fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008-2012 | TEROPP - Technologies for terminals in opportunistic radio applications | ANR, InterCarnot Fraunhofer | P. Loumeau | 163 |
| 2009 | ARMURE - ARchitecture MUltivoie à très large bande pour REcepteur à mobilité généralisée | Institut Mines-Télécom | P. Loumeau | 57 |
| 2009-2012 | PANAMA - Power Amplifiers aNd Antennas for Mobile Applications. Funding Europe | CATRENE | P. Loumeau P. Desgreys | 227 |
| 2010-2012 | SACRA - Sensing and access techniques for cognitive radio applications | FP7 | V.T. Nguyen H. Fakhoury | 486 |
| 2011-2014 | ARTEMOS - Agile RF Transceivers and Front-Ends for Future Smart Multi-Standard Communications Applications | ENIAC | V.T. Nguyen | |
| 2011-2013 | GREEN RAN - Green radio network | MAE/AFD | V.T. Nguyen | 506 |
| 2012 | SigmaDeltaReceiver - Agile RF Receiver for future Wireless Communication Systems based on RF Sampling and Sigma Delta Modulation | Institut Mines-Télécom | V.T. Nguyen | 40 |
| 2012-2015 | APPSGATE - Applications Gateway: Open Platform combining set-top box and residential gateway and integrating multiple home applications | CATRENE | V.T. Nguyen P. Desgreys | 426 |
| 2013 | RACOM | DGA | V.T. Nguyen | 27 |
| 2011-2014 | RELY - Design for Reliability of SoCs for Applications like Transportation, Medical, and Industrial Automation | CATRENE | L. Naviner H. Petit | 342 |
| 2013 | REFLEX - algorithm for extracting coefficients of a DPD from a multirate information | Institut Mines-Télécom | P. Desgreys | 36 |

### 3.5.3 Private Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008 | ADPLL | NXP-Semicon. | H. Petit | |
| 2009-2012 | Cifre Ghanem | NXP-Semicon. | P. Loumeau | 34 |
| 2012-2015 | Cifre Kamdem | Renesas | P. Loumeau | |
| 2012-2015 | Cifre Vansebrouck | NXP-Semicon. | P. Desgreys | 81 |
| 2013-2016 | Cifre Meyer | Thales Syst. Aero. | P. Desgreys | 45 |

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[563] D.-K. G. Pham, P. Desgreys, P. Loumeau, and T. Ridgers. Method for multiband multilevel analog-to-digital conversion. (EG/VP-FR 12 53436), Apr. 2012.

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## 3.6 PhDs (Appendix 7)

### 3.6.1 Defended PhDs

[565] W. Altabban. *Conception portable d'une ADPLL pour des applications TV*. PhD thesis, Télécom ParisTech, Dec. 2009.
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[569] C. Jabbour. *Reconfigurable Parallel Delta Sigma Analog to Digital Converters*. PhD thesis, Telecom ParisTech, Sept. 2010.
[570] O. Jamin. *Etude et réalisation d'un récepteur basé sur l'échantillonage durect RF pour des applications TV et internet par câble*. PhD thesis, Télécom Paris Tech, Mar. 2013.
[571] H. Khushk. *Modulateur Delta Sigma passe-haut et application dans la réception RF multistandards*. PhD thesis, Telecom ParisTech, Nov. 2009.
[572] M. A. Latiri. *Architecture et réalisation d'un récepteur cellulaire multi-mode, multi-bande reconfigurable SDR*. PhD thesis, Ecole Nationale Supérieure des Télécommunications, July 2008.
[573] A. Maalej. *Contribution sur Echantillonnage Non Uniforme appliqué à la Numérisation des signaux Radio Multistandard*. PhD thesis, Télécom ParisTech, May 2012.
[574] P. Maris Ferreira. *Méthodologie de conception AMS/RF pour la fiabilité : conception d'un frontal RF fiabilisé*. PhD thesis, Télécom ParisTech, Oct. 2011.

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### 3.6.2 Ongoing PhDs

- R. Vansebrouck (11/12 –) Modélisation et correction numérique à posteriori pour la distorsion harmonique dans les circuits intégrés RF & mixtes
- H. Le Duc (12/12 –) Background calibration of channel mismatch for Time-Interleaved Converter in Cognitive Radio Applications
- A. Meyer (05/13 –) Etude de nouvelles structures d'Echantillonneurs Bloqueurs pour la conversion analogique numérique très large bande en technologie SiGe
- M. T. Nguyen ( 07/11 –), Flexible receiver for LTE-A based on RF sampling and sigma delta modulation
- G. Kamdem de Teyou (09/12 –), Adaptive and Blind Background Calibration of Frequency Response Mismatches in Time-Interleaved ADCs
- H. Cai (09/10 –) Fiabilisation de Convertisseurs Analogique-Numérique à Modulation $\Sigma$-$\Delta$

# Chapter 4

# Complex Digital Electronics Systems (SEN–LabSoC)

## 4.1 Executive Summary (Appendix 1)

**Team Leaders** Jean-Luc Danger - Renaud Pacalet

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**Initial Staff** 3 Full Professors, 7 Associate Professors, 2 Research Scientists, 5 Engineers, and 13 PhD Students.
**Staff who Left** 1 Associate Professor (10 months), 8 Engineers (231 months), 23 PhD Students (707 months), 2 Sabbaticals (10 months) and 30 Internships ( 213 months).
**Staff who Were Hired** 1 Associate Professor, 1 Research Engineer, 2 Adjunct Professors, 9 Engineers, 39 PhD Students.

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**Scientific Highlights**

- Creation of a laboratory dedicated to **hardware security**. The laboratory monitors the behaviour of embedded systems under physical attacks and evaluates their vulerability.
- Creation of a laboratory dedicated to **hardware dependability**. This laboratory allows us to study new metrics of reliability and robust architectures.
- Winner of the **Google award Fellowship** 2013 together with the Digital Communication group.
- Design of an open source **Digital Signal Processor** for the Software Defined Radio
- Release of the UML modeling and verification tool **TTool**.

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**Scientific Production** 38 Journals, 2 Books, 4 Book Chapters, 206 Articles in Proceedings (including two Best Paper Awards), 18 Patents

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**Major Publications**

- [820] D. Teixeira Franco, M. Correia De Vasconcelos, Lirida Alves de Barros Naviner et J. F. Naviner, (2009), SPR Tool: Signal Reliability Analysis of Logic Circuits, "Design, Automation and Test in Europe, DATE", Nice, France.
- [777] Maxime Nassar, Shivam Bhasin, Jean-Luc Danger, Guillaume Duc et Sylvain Guilley, (2010), BCDL: A High Speed Balanced DPL for FPGA with Global Precharge and no Early Evaluation, "DATE", Dresden, Germany, pp. 849-854.
- [595] Sylvain Guilley, Sumanta Chaudhuri, Laurent Sauvage, Philippe Hoogvorst, Renaud Pacalet et Guido Marco Bertoni, (2008), "Security Evaluation of WDDL and SecLib Countermeasures against Power Attacks", IEEE Transactions on Computers, vol. 57, n° 11, pp. 1482-1497.
- [735] D. Knorreck, L. Apvrille, R. Pacalet, "Formal System-level Design Space Exploration", Concurrency and Computation: Practice and Experience, John Wiley & Sons, Ltd, 2012.
- [579] E. Amador, R. Knopp, R. Pacalet, V. Rezard, "Dynamic Power Management for the Iterative Decoding of Turbo Codes", IEEE Transactions on Very Large Scale Integration Systems, vol. 99, pp. 1-5, October 2011

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**Major Documents**

- Creation in August 2008 and organization of four versions of the international *DPA Contest*[1]
- Tape-Out of 3 ASICs : SECMATV3 (STM 130nm), SeFPGA(STM 65nm); PUF (STM 65nm)
- UML modeling and verification tool **TTool**: http://ttool.telecom-paristech.fr/
- Open source DSP for Software Defined Radio **EMBB**: https://embb.telecom-paristech.fr/

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**Impact and Attractivity**

- Creation, co-organisation of 2012 and 2013 PROOFS workshop[2]. Springer JCEN edition.
- Organization of COSADE workshop in 2013[3]. Proceedings in Springer LNCS.
- Best Paper Awards at WISTP 2011 ([746] ) and ICWMC 2010 ([629])
- Creation, organization of annual Sophia-Antipolis Formal Analysis workshop (2008 to 2011)

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**Interaction with Economic and Social Spheres**

- Creation of the spin-off Secure-IC[4] with 3 founders from COMELEC.
- Active partner of the common Research laboratory with MORPHO and the INFRES department : Identity and Security Alliance (ISA)
- 12 CIFRE Phd with industrials: INFINEON, THALES, EdF, STM, Oberthur, BULL, MORPHO, Orange-LAbs, Secure-IC, EADS-Cassidian
- Founding member of the CIM-PACA regional cluster on micro-electronics

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**Contributions to Higher Education**

- Participation in Télécom ParisTech Master degree classes:
  - Parcours "Embedded System Architecture".
  - Parcours "System On a Chip"
  - Parcours "Security of embedded Systems"
- Participation in the UPMC (Paris 6 University) Masters:
  - Mention "Computer Sciences". Classes in Digital Electronics
  - Mention "Engineering sciences". Classes in Embedded Systems
- Lectures given in the EURECOM curriculum, ”Real-time and Embedded Systems” track (engineering, master, master of science and industrials):
  - Operating systems
  - Computer architecture
  - Formal specification and verification of systems
  - UML for embedded systems
  - Electronic design for communications
  - Hardware security

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1. http:///www.dpacontest.org
2. http://www.proofs-workshop.org/
3. http://cosade.org
4. http://www.secure-ic.com

## 4.2 People

**Team Leaders** Jean-Luc Danger(FP), Renaud Pacalet(FP)

**Faculty**

Ludovic Apvrille (AP), Rabea Ameur-Boulifa (AP), Sophie Coudert (AP), Jean-Luc Danger (FP), Guillaume Duc (AP 04/09-), Tarik Graba (AP), Sylvain Guilley (AP –11/08), Philippe Hoogvorst (JRS), Philippe Matherat (JRS), Yves Mathieu (FP), Lirida Alves De Barros Naviner (AP –11/09, FP 12/09–), Renaud Pacalet (FP), Alexis Polti (AP), Laurent Sauvage (Eng 01/11–).

**Adjunct Professors**

Hervé Chabanne ((FP) Chef du pôle Recherche Sécurité et Cryptographie, Sagem Sécurité, 12/08–), Sylvain Guilley ((AP) Corps Interministériel Des Mines, 12/08–)

**PhD students**

L. Sauvage (09/04–09/10), W. Muhammad (10/05–12/08), D. Teixeira Franco (11/05–12/08), S. Mekki (01/06–06/09), S. Chaudhuri (02/06–12/08), L. Su (10/06–03/10), Z. Larabi (10/06–12/09), N. Selmane (11/07–12/10), C. Jaber (11/07–01/11), E. Amador (03/08–12/11), D. Knorreck (07/08–10/11), S. Bhasin (11/08–12/11), Y. Souissi (11/08–12/11), O. Meynard (11/08–01/12), J. Torras Flaquer (01/09–10/11), M. Nassar (01/09–03/12), G. Pedroza (01/09–01/13), P. Bernal (01/09–01/13), G. Gonzalvez D.S. (05/09–09/12), G. Barbu (02/09–09/12), M. Slimani (06/09–04/13), J. Gonzalez Pina (06/09–05/13), S. Thomas (09/09–07/13), T. Ban (05/09–09/12), H. Mokkrani (10/09–07/13), H. Maghrebi (10/09-12/12), T. Chouta (11/10–), Z. Cherif (11/10–), F. Ben Abdallah (11/10–), M. Ben Romdhane (02/11–), N. Debande (01/11–), C. Murdica (02/11–), S. Nascimento (07/11–), T. An (10/11–), A. Ben Dhia (10/11–), J. Brunel (10/11–), K. Liu (10/11–), S. Sarrasin (11/11–), C. Bottoni (01/12–), X. Pons-Masbernat (09/12–), A. Heuser (09/12–), N. Jovanovic (10/12–), P. Rauzy (10/12–), A. Enrici (11/12–), S. Ouaarab (11/12–), P. Belgarric (12/12–), X.T. Ngo (01/13–), N. Bruneau (04/13–).

**Post-docs, engineers**

L. Sauvage (–12/10), V. Vong (–02/08), R. Rasheed (–09/09), D. Comalrena (–12/09), S. Cerdan (–07/13), G. Letourneux (01/08–02/10), F. Flament (06/08–12/10), S. Somsavaddy (06/09–12/11), F. Lozac'h (01/10–), A. Becoulet (05/10–), Y. Souissi (01/12–), S. Bhasin (01/12–), L. Thierry (04/12–09/12), Z. Najm (01/13–).

**Sabbaticals**

N. Homma (Associate Professor, Tohoku University Japan, 06/09–03/10),
S. A. Huss (Darmstadt Technical University, Germany, 11/11).

## 4.3 Overview

The "Complex Digital Electronic System" CDES team performs research on architectures and methodologies for efficient design of digital electronic systems under harsh requirements. The team develops cutting edge techniques to help electronic designers to meet ever growing constraints on complexity management, reliability, power consumption, speed, security and flexibility. This research is characterized by a strong link to industrial requirements.

Hence it studies new concepts for future technologies, but is also involved in providing significant improvements to existing products. This is illustrated by the scientific production, which consists of both academic publications and of patents or releases of free software. Both patents and free software have found applications in industrial environment.

The CDES research correspond to a high demand from both academic and industrial communities.

It focuses on four main themes:

- Design methodologies are coverered by the **Design Space exploration and assisted refinement of integrated systems** theme.
- Architectures with security constraints are dealt within the **Trusted computed hardware** theme.
- Architectures with a high constraint in Dependability are in the theme **Analysis and Design of Reliable Processors Based on Unreliable Technologies**
- Architectures with constraints of complexity and Power Consumption are in the **Optimal architectures for complex algorithms implementations** theme. Architectures for the "Software Defined Radio" (SDR) and multimedia applications stands within this theme.

The team has research collaborations with well known companies such has STMicroelectronics, NXP, EdF, CEA, Orange, Thales, Intel, BMW or Texas Instruments. Among the French academic laboratories the most representative ones are the CNRS laboratories LIP6 (UMR7606), LIRMM (UMR5506), GIPSA-Lab (UMR5216) or TIMA (UMR51599), the ISAE-SUPAERO group, EURECOM and INRIA. The team has also strong relationship with international universities as Tohoku University (Japan), Darmstadt Technical University (Germany), Umass (USA), University of Madrid (Spain), UCL Louvain la Neuve (Belgium),...

The team has been highly involved in the CIM (Centre Intégré de Microélectronique) PACA regional framework, which it co-founded in 2004, and the SAME (Sophia Antipolis MicroElectronics) association, two important academic-industrials French consortia. In order to balance industrials concerns and advanced academic research, we increased during the five recent years our effort on PhD supervision.

Team members, located in the settings of Paris (DES: Digital Electronics Systems) and Sophia-Antipolis (LabSoC: Laboratory on Systems-on-a-Chip), have a strong teaching activity at the undergraduate and master level, both in Telecom ParisTech and in EURECOM. Lectures are in the fields of digital electronic design, embedded systems design, Systems-on-a-Chip (SoC) design and embedded systems security. An important part is given to practical aspects with the supervision of numerous student projects. The latest research results feed our teaching activity, for example, ANR SoCLib project methods are directly used in the "Systems-on-a-Chip Design" track of our master of engineering and our recent advances in hardware security are used in our lab sessions on security. Team members have teaching activities and responsibilities at master level in other institutions such as Paris-6 University (UPMC).

## 4.4 Research Themes

### 4.4.1 Design Space exploration and assisted refinement of integrated systems

**Faculty** L. Apvrille, R. Pacalet, S. Coudert, R. Ameur-Boulifa

**Main events** Release of the free toolkit TTool[5], steering of the SAFA (Sophia-Antipolis Formal Analysis Group) workshop

**Projects** Cifre Ph.D. with Freescale, FP7 european project EVITA, LIP6-Telecom ParisTech project *Robustar*, Institut Telecom Futur/rupture Ph.D. on power-consumption aware design space exploration, Carnot funding on the design of Software Defined Radio applications.

The increasing complexity of Systems-on-Chip and distributed embedded systems - e.g., mobile platforms, automotive systems - requires new design and verification methodologies. Three contributions have been made in that scope: (i) A Design Space Exploration environment for early verifications in the design cycle. (ii) The assisted refinement of complex systems based on a top–down approach. (iii) The definition of Model Driven Engineering techniques. The main common points of these contributions is the definition of models, simulation and formal proofs techniques, and the development of a free software toolkit (TTool). In the scope of these three

5. http://ttool.telecom-paristech.fr/

contributions, the main achievements for the period Jan. 2008– June 2013 are:

**(i) System-level Design Space Exploration (DSE):** Definition of a four-step methodology named DIPLODOCUS, comprising requirement / property capture [699] [599], application modeling, architecture modeling and mapping [599] [853]. Simulation and formal verification are used in the first and second steps [599]. The focus is on the property modeling step [599] and on the modeling of advanced communication schemes and hierarchical scheduling [726] [853], on achieving very fast simulations [854], on performing efficient model-checking at mapping stage [854] [600], and at last taking account security analysis [852].

In particular, in the scope of **Very fast simulation techniques**, a new speculative and transaction-based simulator has been designed [646]. Comparisons have been made with others simulation engines to demonstrate the very efficiency of our simulation approach. Moreover, the simulator offers an intermediate scheme between a on-trace simulation, and an exhaustive computation of all system traces, with the definition of a **coverage-enhanced simulation engine** that can explore a given percentage of a mapping model [854]. To achieve this, definition and implementation of a new model-checker with possible variability in the system coverage have been done. Thus, a formal definition and implementation of the mapping phase has been proposed [735] [600]. The current focus is on adding power consumption estimation during simulation.

We also demonstrated that **security analysis** can benefit from design space exploration, and reciprocally [852].

**(ii) Assisting Abstration-Refinement :** A new methodology for rigorous development of dependable embedded systems intends to allow explicit modelling, analyzing and proof of systems at varying degrees of details. Indeed, design often involves the use of multiple models that represent different views of a system at different levels of granularity. The design process usually proceeds in top-down approach, from the requirements to the implementation, and/or in bottom-up approach, by integrating library components, by iterating model construction, model analysis, and model transformation. Some transformations between models can be automated, and should guide the model construction. Efforts have been made to identify a set of guidelines and reusable patterns [766, 762, 605] for the development of dependable embedded systems.

**(iii) Model-Driven Engineering techniques:** Contributions have been made with academic partners (e.g., ISAE, INRIA) in the scope of system dimensioning, requirements elicitation, system analysis, system design, and system prototyping. An important contribution is also to offer formal proofs at the push of a button from UML models. Also, these methodological features have been defined inside of the same environment (AVATAR) and implemented in TTool.

Efforts have been made so as to efficiently adapt UML/SysML to embedded systems, in particular, the definition of temporal operators for efficiently capturing and proving temporal requirements [699], and the definition security extensions in SysML [786]. The complexity of graphical modeling environments also lead us to define methodological assistant in the form of modeling patterns [582]. **System dimensioning** has been tackled with the definition of models formally defined with Network calculus techniques [584]. We also integrated, in the same modeling environment, the ability to perform both **safety and security proof** at the push of a button [851].

**Component-based design.** Whereas refinement approaches decompose complexity of systems "vertically", by splitting the design into multiple design levels, component-based approaches reduce complexity "horizontally" whereby designs are obtained by assembling existing components. The global correctness of a design is based on the correctness of components and their assembly. Using that approach, we have defined a semantic model for the analysis and verification of safety properties of component-based applications [587, 631, 632].

**The TTool toolkit:** design and open–source release of a toolkit. This toolkit shares several features with related works of the team (e.g., DIPLODOCUS, AVATAR). TTool has been supported by Texas Instruments and Freescale. The whole framework has been used in the context of the European project EVITA for security modelling and analysis on automotive security [786] and in the context of the European SACRA project [701]. It is also used by academic partners, for

example in the scope of fault tolerance in embedded systems (projet Robustar) and by ISAE - Institut Supérieur de l'aéronautique et de l'Espace [642]. TTool is now used by several academic institutions for master-level courses and industrial trainings.

**Examples of Embedded systems** that have been modeled and verified with our techniques are automotive systems [785], avionics systems [584], base–stations systems [726], Software Defined Radio applications [701].

### 4.4.2 Trusted Computing Hardware

**Faculty** J-L Danger, G. Duc, T. Graba, S. Guilley, P. Hoogvorst, Y. Mathieu, R. Pacalet, L. Apvrille, S. Coudert

**Main events** International DPA Contest V2 & V3, creation of the spin-off "Secure-IC", winner of the CNCE'2010 contest, in "création-développement" section, organization of CryptArchi'2010, chair of IEEE FDTC'2011, sabbaticals of Prof. Naofumi Homma (Tohoku U., Japan) and Prof. Sorin A. Huss (Darmstadt U., Germany), creation and co-organisation of PROOFS'2012, organisation of COSADE'2013.

**Projects** ANR SeFPGA, ANR SECRESOC, System@tic Pôle "Secure Algorithm", DGA RAPID "BCDL", ANR-JST "SPACES", ENIAC "TOISE", PhD CIFRE BULL, PhD CIFRE OBERTHUR, PhD CIFRE Secure-IC, PhD CIFRE STMicroelectronics, STMicroelectronics contracts "PACA-Lab", ANR CALISSON, FP7 TRESCCA [6].

Embedded systems can be the threatened by physical attacks which take advantage of the physical characteristics of electronic devices under execution (data-dependent computation time, power consumption or electro-magnetic emanations, sensitivity to operating conditions, faults, probing, etc.) The attack goals can be almost anything from recovering confidential information, like the secret keys of cryptographic algorithms or confidential contents, to taking the full control of the target under attack and force it to behave differently from what was intended. The physical attacks can be either passive or active. Passive attacks also called "Side Channel Attacks" are based on the non-disturbing observation of the activity of the target. The observation can for instance be carried out on the power lines, the electromagnetic radiations, the computing time, the data carried by communication channels like primary inputs and outputs or even internal buses. Active attacks mainly consist in injecting faults or modifying the target's structure in order to alter the target's behaviour.

The Trusted Computing Activity of the "Complex Digital Electronic Systems" research group aims at understanding the attacks mechanisms and at providing efficient, cost effective and provable countermeasures. The attacks and their countermeasures are studied at the integrated circuit level or at the electronic board level. Circuit level attacks can target any integrated circuit from smartcards to much larger devices like SoCs or high end multi-core microprocessors.
Board-level attacks frequently target the metal tracks of communication buses, like memory buses, or discrete components like dynamic memories or non-volatile memories.

**CIRCUIT LEVEL:**

The main objectives are to provide a better attack understanding and consequently robust architectures to thwart novel threats. The security is evaluated on real devices and take advantage of fours evaluation platforms specifically designed for this purpose. Three ASICs in 65nm and 130 nm technologies have been designed during this period. Commercial FPGAs have been intensively used to validate new countermeasure concepts. Here are the main lines of the progress during the 2008-2013 period:

**Electromagnetic Analysis**: It has been shown that the attack can be enhanced by using pre-characterized models [757] or by performing a pre-stage of cartography which allows to locate accurately the spatial position of interests for the analysis [794, 863, 793, 795]. The observation

6. http://www.trescca.eu/

traces represented in the frequency domain have also been studied and can greatly enhance the attack [758, 759, 760, 604, 858].

**Template Attack**: This attack does not need any details about the implementation, but a profiling stage. It has been shown that it is possible to improve this attack by reducing the noise and by using appropriate models [585]. Also the technique of Principal Component Analysis has been studied to find and combine the best points of interest [809]. It has also been shown that the combination of different attack parameters, like the model and the points of interest, provides a great enhancement of the attack success [712, 813].

**Fault attacks**: have been studied when applied globally to the device by under-powering the power supply [801, 619]. Also faults have been injected at relatively far distance on the power line by coupling EM interferences to the line [610, 796]. New specific fault attacks and their associated countermeasures on asymmetric crypto-processor have been devised [767, 691].

**Digital signal processing for security analysis**: Techniques like the Kalman filtering, allowed to reduce the noise of the acquired traces and thus the efficiency of the attack [866, 807, 808]. The DSP techniques can also be used to analysed protected implementation where a jitter has been added on traces to avoid a synchronization operation [716]. Also the Wavelets representation can enhance the analysis efficiency in some cases [694].

**Theoretical security evaluation** Evaluations are often performed experimentally as no sound theory on attack estimation is yet available. We started to tackle this issue by developping a theory of security metrics and particularly on distinguishers using information theory tools [1012].

**Reverse engineering**: Studies to reverse by using either the side-channels [715] or fault injection techniques [789] have been carries out. Efficient protections have been proposed [668].

**Countermeasures with Dual rail with Pre-charge Logic (DPL)** : It has been shown that the DPL logic which is a good protection against Side-Channel Attack has also good properties against fault attack [802, 660, 864]. Moreover techniques to show the impact and enhance the place and route stages of DPL implementations have been carried out [596, 792, 608]. A powerful DPL logic called “BCDL” (Balanced Cell Differential Logic), has been devised to avoid the flaws of the traditional WDDL logic [849, 708, 705, 690, 777, 662]. However special care has to be taken to implement a crypto-processor in BCDL , as explained in [705, 664, 597].

**Countermeasures by masking**: They have been analysed and formalized by using second order attacks [743, 744, 745]. Therefore powerful countermeasures have been devised in order to thwart high-order attacks. Their goal is to squeeze the leakage by encoding the data to be masked and the mask itself [746, 778, 615, 748, 749, 747, 670]. A very low-cost countermeasure based on masked tables has been proposed [861, 780]

**Protections at protocol level**; They have been studied by using resilience properties [718]. They greatly reduce the needs to protect the implementations at physical level.

**Protections by shielding** The circuit can be protected by a shield to avoid any probing or fault injection. Studes about active shielding have shown promising results [681, 667].

**Randomness generation**: This is a sensitive operator for cryptographic systems. A True Random Number Generator (TRNG) has been studied to provide both speed and high level of robustness [593]. It has been validated in silicon [656], but also by a stochastic model [657]. The circuit can generate its own signature, also called Physically Unclonable Function (PUF), by taking advantage of randomness during the manufacturing process. A study of Physically Unclonable Function (PUF) led to a novel PUF characterization at design stage [677]. A novel PUF structure, the Loop-PUF, with low complexity and high reliability, has been devised [678].

**Security for Biometrics** An architecture of a Match-On-Card function, which is to verify fingerprints on a smartcard,has been designed and analyzed against physical attacks [680].

**Proven security** This research work consisted first of formalizing the BCDL countermeasure [800, 588] by using a theorem prover.

**BOARD LEVEL:**

**Information leaks across hardware components**: A framework dedicated to data dependency analysis across hardware components has been designed and developed. It has been

formally proven as sound and has been experimented on classical hardware peripherals like UARTs or arithmetic units. It allows the detection of undesirable information leaks through the hardware and is complementary to the more classical software analysis techniques.

**The SecBus project**: In order to protect the confidentiality and the integrity of embedded systems against board-level attacks and DMA-based injections, a complete architecture, called SecBus[867], has been proposed. It is based on classical, software-implemented, cryptography for most of the communications and storage facilities but the dynamic external memories. The latter are protected thanks to a sophisticated mixture of hardware and software components. This architecture has been combined with an internal protection mechanism to build a completely secure MPSoC [685]. It is at the heart of the TRESCCA[7] FP7 European project which aims at designing a computing platform that would remain trustworthy even in the hands of attackers and administrated by non-trusted administrators. This technology is an enabling one for the true trusted cloud *computing* which is unachievable with the currently available security technologies.

**Fault attacks against JavaCard**: The impact of fault injection attacks on smartcards that implement the JavaCard standard has been studied. New combined hardware/software attacks and new attack paths that highlight flaws in the JavaCard standard and on some implementations, have been discovered and some counter-measures have been proposed [702, 703, 704, 848].

**The EVITA hardware security module:** In the scope of the European project EVITA for security modelling and analysis on automotive security, we have participated to the definition and implementation of a secure architecture for automotive embedded system. A new global methodology has been settled, from requirements and attack tree captures [852], to the definition of the architecture [722] [799] - including a hardware security module, and cryptographic protocols relying on this hardware security module - and the formal verification of this architecture [786] [785], altogether with its implementation and tests [851].

### 4.4.3 Analysis and Design of Reliable Processors Based on Unreliable Technologies

**Faculty** L. Alves de Barros Naviner, P. Matherat, A. Polti , J-L Danger, G. Duc

**Main events** Invited seminar on DSM Reliability Issues at Universidade Federal do Ceara (Fortaleza, Brazil/August 2011). Organization of STIC-AmSud workshop on Design for reliability and portability of RF Interfaces based on Nanoscale CMOS technology (Paris, France/May 2010). Invited conference at the Schloss Dagstuhl for Informatik GmbH (Dahstuhl, Germany/September 2008).

**Projects** STIC-AmSud NanoRadio, CATRENE Rely, ANR RobustFPGA, CIFRE STMicroeletronics, CIFRE EDF, CIFRE THALES.

Fault-tolerant architectures have been historically targeted to Mission-Critical applications, but the current research shows that with the expected reduction in the reliability of nanoscale CMOS, even ordinary circuits will need fault protection. In this latter case, the associated overheads must be minimized to guarantee some gain in the scaling process. Indeed, deep submicron technologies (DSM) process is reaching some important limits that reflect negatively in the reliability of the integrated circuits. Some of these are manufacturing imprecision, increased susceptibility to environmental factors and physical parameters variability. This results in accelerated aging of components and increased number of faults in the system. Our work deals with the challenges related to reliability analysis and reliability improvement of digital circuits. The objective is to propose efficient methods and tools for, on the one hand, accurate reliability analysis and, on the other hand, design of economically viable and reliable complex processors. Initial results have led to the establishment of cooperation with renowned academic laboratories (Delft University, IMEC, Fraunhofer Institutes, CEA, LIP6, TIMA, UDR, UFRJ, UFRGS...) and with suppliers/end-users industrials (ATMEL, EADS, NXP, ARM, THALES, STMicroelectronics, ...) in the context of cooperative or billateral contracts.

7. http://www.trescca.eu/

**Reliability Assessment:** Our initial studies focused on estimating the reliability of logic circuits and we proposed two new approaches (Probabilistic Binomial Reliability-PBR [683] and Signal Probability Reliability- SPR [591]) as mentioned in previous reports. Both proposed approaches deal with different fault models and allow several trade-offs between accuracy and computation complexity for reliability assessment that outperform state of the art solutions. During the period concerned by this report, we have explored new approaches to the analysis of reliability, such as the use of Petri nets [741] and progressive analysis [696]. Our search for even more effective approaches lead to two new methods (CPA and H-CPA) [844, 614, 826] based on SPR. These solutions use conditional probabilities and clustering approach to produce accurate estimation with linear complexity. We also proposed a smart IP for generating fault vectors[689]. This IP has been embedded in a FPGA based solution to accelerate reliability analysis of digital circuits. This fully parameterizable platform, named FIFA and based on PBR model, deals with several fault models and supports multiple faults [577]. Furthermore, we studied the problem of defining appropriate metrics for reliability assessment taking into account the processor target application [688] in order to compare some fault tolerance approaches [821]. Work in progress include reliability analysis of SRAM based FPGA [652, 655] and arithmetic processors [633].A study to anticipate the failure inside a circuit has been carried out with the cooperation of Thales avionics. The principle is to use a non intrusive technique in order to obtain a signature of every signal. Then a comparison between this reference signature is done to prevent the failure which can occur with aging effects [822].

**Reliability Improvement:** Studies on improving the reliability voluntarily began after those on the analysis of reliability. This is because the development of efficient algorithms and tools for reliability assessment is crucial to establish effective cost-quality trade-offs related to different reliability improvement schemes. Among the produced results, we can mention a simple fault-tolerant voter for TMR schemes [647], a tool for automatic reliability improvement based on TMR [592], a progressive module redundancy approach [586]. We have defined the concept of significance as an indicator of the relative importance of a sub-system with respect to reliability properties of the system which it is part of [624]. This powerful approach allows to guide efficient redundancy insertion and constitute the basis of our actual work on selective hardening [770, 606]. Work in progress include fault tolerance in FPGA. We proposed hardening approaches [836] and a new CLB architecture [651], as well as design of cost-effective noise-tolerant digital operators [840] and hardening/test of embedded processors [790].

### 4.4.4 Optimal architectures for complex algorithms implementations

**Faculty** P. Matherat, Y. Mathieu, L. Naviner, R. Pacalet, A. Polti

**Main events**

**Projects** Telma(ANR) Calder(ANR), IDROMel (ANR), PFMM (French cluster SCS, DGE), SYMPA (French cluster SCS, DGCIS), SACRA (FP7 European project), SPECTRA (CELTIC European project, DGCIS)

**Architectures for image and multimedia processing:** Studies on n-dimensional generic cache architectures for FPGA-based image processing systems gave promising results. We have demonstrated the efficiency of a low-cost cache solution exploiting spatial and temporal locality in a smarter manner than classical associative caches [739, 740, 601, 751, 855]. This work was carried out in collaboration with the Gipsa-Lab laboratory with the support of the ANR project TELMA. Recent advances on high resolution LCD displays lead to emerging applications with 3D lenticular screens. In close partnership with ST-Ericsson and the MultiMedia team (granted through ANR project Calder) we developed new architectures for real time hardware renderering on mobile 3D LCD screens [841, 827, 3370].

**Energy consumption of digital circuits and clockless systems:**

We continue the study on the fundamental minimum digital circuits dissipation, by focusing on the logical rather than the technological origins of this dissipation. The thesis carried out by Mariem Slimani is an overview of these issues, and tries to understand how aspects that appear

to be technological are in fact related to architectural issues. In particular, the leakage currents of modern technologies have to be balanced with the switching energy, and this balance is clearly related to the choice of architecture implementations [805, 804]. In addition, we continue the study of more fundamental sources of dissipation related to synchronization issues, and this leads us to explore the logical foundations of clockless circuits [602]. Regarding education, we published a book on the history of microelectronics [616].

**Flexible architecture for the Software Defined Radio (SDR)**

Nowadays mobile communication systems operate in different radio spectrum, radio access technologies, and protocol stacks depending on the network being utilized. Moreover, new services and applications, like Cognitive Radio (CR) or digital correction of RF impairments (dirty RF), require new digital signal processing capabilities (sensing, digital pre-distortion, reduction of peak-to-average power ratio, etc.) This gives rise to the need of a flexible hardware platform that would be capable of supporting the baseband digital processing for all the different standards in the entire wireless communication frequency range. This platform shall of course be extremely power efficient.

In a large multi-projects context we propose EMBB [8] a generic baseband prototype architecture for SDR applications[730, 781]. This architecture embeds a general purpose micro-controller and a collection of specialized Digital Signal Processors (DSP), each dedicated to a class of algorithms like, for instance, interleaving - de-interleaving of sequences of data samples[783], vector processing, sample rate conversion[598, 797] or channel decoding[846, 579, 578]. Most existing works in the field are based on specialized micro-processors (vector processors, VLIW, ASIP, etc.) and on advanced interconnects (Networks on Chip). Unfortunately these solutions are still usually above the maximum power budget for such applications. Our approach mainly consists in identifying a small set of very complex hard-wired processing blocks that will take in charge 90 to 95% of the total baseband processing power in a very power-efficient way. Each block is highly parametrizable and is assisted by a minimal micro-controller allowing it to run sequences of operations (e.g. channel estimation) from basic commands (Fourier transforms, component-wise products, etc.) The platform is open and the whole project will be distributed under the French equivalent of the GPL-LGPL free software licenses, both for hardware models and embedded software.

The baseband processor is complemented by a free software development kit comprising a high level Application Programming Interface (API), an embedded Operating System (OS), cross-compilers, linkers, debuggers and several simulation environments. It is currently used in several national and European projects (SYMPA, SACRA, SPECTRA); depending on the projects' specificities, several target technologies are considered, from high end, FPGA-based, prototyping boards to System-on-Chip integrated circuits.

8. https://embb.telecom-paristech.fr/

# 4.5 Achievements (Appendix 6)

## 4.5.1 Scientific Productions

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### 4.5.2 Public Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008-2009 | STM PACA 6 - Secured circuit architectures | C.R. PACA | R. Pacalet | |
| 2008-2009 | EPOMI - Security and trust for mobiles and NFC applications | DGE | S. Guilley | |
| 2008-2010 | SeFPGA - Secure-FPGA based on a tree topology | ANR | J.L. Danger | |
| 2008-2010 | SECURE ALGO - Cryptographic algorithm robust to side-channel attacks | DGE | S. Guilley | |
| 2008-2011 | EVITA - E-safety vehicle intrusion protected applications | Europe | R. Pacalet | 1165 |
| 2009-2011 | EM analysis - far distance EM analysis | DGA | J.L. Danger | |
| 2009-2012 | CALDER - 3D screen on a mobile | ANR | Y. Mathieu | |
| 2009-2012 | SYMPA - System on chip for software radio. | DGCIS | R. Pacalet | |
| 2009-2013 | SecreSoC - secure architectures of MPSOC | ANR | J.L. Danger | 561 |
| 2010-2011 | NanoRadio - Increase the dependability of radio interfaces | MAEE | L. Naviner (coord.) | |
| 2010-2012 | BCDL - BCDL countermeasure in FPGA | DGA | J.L. Danger | |
| 2010-2012 | SACRA - Cognitive radio | Europe | R. Pacalet | |
| 2010-2013 | BMOS - Architecture and security of a "Match On Card" | ANR | J.L. Danger | |
| 2010-2014 | SPACES - Security assesment at design stage | ANR-JST | J.L. Danger | 631 |
| 2011-2014 | SPECTRA - Cognitive radio | DGCIS | R. Pacalet | |
| 2011-2014 | TOISE - Security of smartgrids, trust anchors | Europe | J.L. Danger | |
| 2011-2014 | digital circuits dependability tests | CEA | L. Naviner | |
| 2011-2014 | RELY - Bottom-Up approach for dependability assesment | Europe | L. Naviner | |
| 2011-2014 | MASHAL+ Protection against algorithm reverse engineering | OSEO | J.L. Danger | |
| 2011-2014 | Robust FPGA - FPGA architecture robust to failures | ANR | L. Naviner (coord.) | 1124 |
| 2012-2015 | TRESCCA - Trusted embedded systems for cloud computing | Europe | G. Duc | |
| 2012-2015 | NVRAM design and characterization of NVRAMs | CEA | L. Naviner | |
| 2012-2015 | Theoretical study to formalize the distinguishers analysis | IMT | J. L. Danger | |
| 2012-2016 | HOMERE+ - How to detect and prevent Hardware Trojans in IC ? | OSEO | J.L. Danger | 706 |
| 2013-2015 | PISCO - Provide secure HSM | OSEO | J.L. Danger | 195 |

### 4.5.3 Private Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008 | Casa 5 - Multimedia applications modelling | Texas Instruments | R. Pacalet | |
| 2008 | Expertise for patent infringement | Cab. Beau De Lomenie | A. Polti | |
| 2008-2011 | Cifre Amador - Reconfigurable architectures for wireless communications | INFINEON | R. Pacalet | |
| 2008-2011 | Cifre Torras - Probabilist method for robustness assesment | STM | L. Naviner | 102 |
| 2009 | BOBYCK - Mise au point d'un profil UML temps-réel | Docea Power | L. Apvrille | |
| 2009-2012 | Cifre Barbu - Robustnes of Javacard against fault attacks | Oberthur | P. Hoogvorst | |
| 2009-2012 | Cifre Thomas - Failure prediction by non intrusive tests | Thales Avionics | J.L. Danger | |
| 2009-2012 | Cifre Nassar - Protections in FPGAs against side-channel attacks | Bull P&S | J.L. Danger | |
| 2009-2012 | Cifre Goncalves - Robust architecture in FPGA | EDF | L. Naviner | 149 |
| 2010 | Expertise for patent infringement | Cab. Beau De Lomenie | A. Polti | |
| 2010-2013 | Cifre Debande - Methods to analyze and protect smartcards against physical attacks | MORPHO | J.L. Danger | 58 |
| 2011-2012 | YOPLAIT - Outil d'analyse side-channel | SEITEL | J.L. Danger | |
| 2011-2014 | Cifre Ben Romdhane - Design of a fast and robust TRNG | Secure-IC | J.L. Danger | |
| 2011-2014 | Cifre Murdica - Design of robust ECC cryptoprocessor | Secure-IC | J.L. Danger | 198 |
| 2012-2013 | YOPLAIT 2 - Outil d'analyse side-channel | SEITEL | J.L. Danger | |
| 2012-2015 | Cifre Bottoni - Design flow to enhance robustness of ICs in critical environment | STM | L. Naviner | |
| 2012-2015 | Cifre Belgarric - Attacks and protections of smartphones against physical attacks | Orange Labs | J. L. Danger | |
| 2012-2015 | Cifre Pons Masbernat - concept "Green" appliqué aux réseaux radiomobiles PMR | Cassidian | L. Naviner | 238 |

### 4.5.4 Patents and software

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## 4.6 PhDs (Appendix 7)

### 4.6.1 Defended PhDs

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[846] E. Amador. *Aspects of energy efficient LDPC decoders*. PhD thesis, Eurecom, Télécom ParisTech, Dec. 2011.
[847] T. Ban. *Méthodes et Architectures Basées sur la Redondance Modulaire pour Circuits Combinatoires Tolérants aux Fautes*. PhD thesis, Télécom ParisTech, Sept. 2012.
[848] G. Barbu. *De la sécurité des plateformes JavaCard face aux attaques matérielles*. PhD thesis, Télécom ParisTech, Sept. 2012.
[849] S. Bhasin. *Logic-Level Counetermeasures to Secure FPGA based designs*. PhD thesis, Télécom ParisTech, Dec. 2011.
[850] S. Chaudhuri. *Asynchronous FPGA Architectures for Cryptographic Applications*. PhD thesis, Télécom ParisTech, May 2009.
[851] G. Gonçalves dos Santos Jr. *Conception de Circuits Numériques Robustes en Technologie Nanométrique*. PhD thesis, Télécom ParisTech, Sept. 2012.
[852] M. Idrees. *A Requirements Engineering Driven Approach to Security Architecture Design for Distributed Embedded Systems*. PhD thesis, Telecom ParisTech, EDITE, Sept. 2012.
[853] C. Jaber. *High-Level SOC Modeling and performance estimation applied to a muti-core implementation of LTE Enode B physical layer*. PhD thesis, Telecom ParisTech, EDITE, Sept. 2011.

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[855] Z. Larabi. *Architecture et stratégies de caches pour les circuits de traitement d'images*. PhD thesis, Telecom-Paristech, Dec. 2010.
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[858] O. Meynard. *Caractérisation et utilisation du rayonnement électromagnétique pour l'attaque de composants cryptographiques*. PhD thesis, Télécom ParisTech, Jan. 2012.
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[860] W. Muhammad. *Assistance à l'Abstraction de Composants Virtuels pour la Vérification Rapide de Systèmes Numériques*. PhD thesis, Université de Nice Sophia-Antipolis, Jan. 2009.
[861] M. Nassar. *Low-cost Countermeasures against Physical Attacks on Cryptographic Algorithms Implemented on Altera FPGAs.* PhD thesis, Télécom ParisTech, Mar. 2012.
[862] G. Pedroza. *Assistance à la conception d'applications sécurisées pour les véhicules mobiles*. PhD thesis, Télécom Paris Tech, Jan. 2013.
[863] L. Sauvage. *Cartographie Électromagnétique pour la Cryptanalyse Physique*. PhD thesis, Télécom ParisTech, Sept. 2010.
[864] N. Selmane. *Global and local Fault attacks on AES cryptoprocessor: Implementation and Countermeasures*. PhD thesis, Télécom ParisTech, Dec. 2010.
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[866] Y. Souissi. *Méthodes optimisant l'analyse de cryptoprocesseurs sur les canaux cachés*. PhD thesis, Télécom ParisTech, Dec. 2011.
[867] L. Su. *Confidentialité et Intégrité du Bus Mémoire*. PhD thesis, Télécom ParisTech, Mar. 2010.
[868] D. Teixeira Franco. *Fiabilité du Signal des Circuits Combinatoires sous Fautes Simultanées Multiples*. PhD thesis, Télécom ParisTech, Nov. 2008.
[869] J. Torras Flaquer. *Méthodes Probabilistes pour l'Estimation de la Fiabilité dans la Logique Combinatoire: Application aux durcissement sélectif et l'analyse FMDEA*. PhD thesis, Télécom ParisTech, Oct. 2011.

### 4.6.2 Ongoing PhDs

- H. Mokrani (10/09–), Formal relationships between abstract and concrete hardware architectures, formal refinement, formal properties preservation.
- T. Chouta (11/10–), Biometric Match On SmartCard.
- Z. Cherif (11/10–), Sources d'aléa et d'authentification pour la cryptographie.
- F. Ben Abdallah (11/10–), Modeling and Formal Verification of Power Management for the Design of Systems-on-Chip.
- M. Ben Romdhane (02/11–), Caractérisation et modélisation de générateurs d'aléas basés sur la métastabilité.
- N. Debande (01/11–), Advanced techniques for Side Channel Analysis.
- C. Murdica (02/11–), Architectures sécurisées et optimisées en vitesse et en complexité pour la cryptographie à base de courbes elliptiques.
- S. Nascimento (07/11–), Bottom-up Realibility Prediction of Digital Circuits.
- T. An (10/11–), Architectures d"opérateurs numériques auto-contrôlables.
- A. Ben Dhia (10/11–), Tolérance aux défauts dans les FPGA.
- J. Brunel (10/11–), Protection des bus et des mémoires dans les systèmes embarqués - Aspects logiciels.
- K. Liu (10/11–), Reliability of Probabilistic Circuits.
- S. Sarrasin (11/11–), Hardening and Test of Embedded Processors.

- C. Bottoni (01/12–), Méthodes de Conception de Circuits Numériques Robustes aux Erreurs de Type Collage ou Inversion de Bit.
- X. Pons-Masbernat (09/12–), Green Concept Appliqué aux Réseaux Radiomobiles 4G de Type PMR.
- A. Heuser (09/12–), Distinguishing Distinguishers: A Theoretical Approach to Side-Channel Analysis.
- N. Jovanovic (10/12–), Conception et caractérisation de mémoires à accès aléatoire non volatiles.
- P. Rauzy (10/12–), Techniques logicielles de modélisation et programmation pour la sécurité des systèmes embarqués.
- A. Enrici (11/12–), Memory and Real-Time Scheduling Analysis of EMBB Platforms Performed from High-Level Models.
- S. Ouaarab (11/12–), Protection des bus et des mémoires dans les systèmes embarqués - Aspects matériels.
- P. Belgarric (12/12–), Etude des fuites d'nformation des smartphones/NFC par analyse électromagnétique.
- X.T. Ngo (01/13–), Detection and Prevention of Hardware Trojans in Integrated Circuits.
- N. Bruneau (04/13–), Amélioration des distingueurs par apprentissage.

# Chapter 5

# Digital Communications (ComNum)

## 5.1 Executive Summary (Appendix 1)

**Team Leader** Philippe Ciblat

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**Initial Staff** 5 Professors ; 1 Research Scientist ; 2 Postdocs ; 18 PhD Students.

**Staff who Left** 28 PhD Students (801 months) ; 4 Postdocs (70 months).

**Staff Who Were Hired** 2 Professors (Postdoc at MIT recruited in Oct. 2008; Postdoc at UC-SanDiego recruited in Dec. 2009) ; 1 Research Scientist (previously at UNSA recruited in Oct. 2009) ; 6 Postdocs ; 22 PhD Students.

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**Scientific Highlights**

- We exhibited low complexity lattice-based code constructions and associated decoding schemes for physical layer network coding and security which are optimal under natural performance criteria
- We proposed a class of powerful estimation algorithms, based on random matrix theory, which applies in a number of settings including electromagnetic spectrum sensing and MIMO channels.
- We investigated a variety of distributed network information processing problems, including consensus type problems, function computation problems, and information retrieval for distributed storage, and provided corresponding efficient algorithms.
- We proposed and tested efficient polar-time schemes, based on the Silver and the Golden codes, to combat the so-called Polarization-Dependent-Loss (PDL) in coherent optical communications.
- We investigated the benefits of feedback and the impact of asynchronism over communication networks in terms of Shannon capacity.

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**Scientific Production** 72 Journals; 1 Book; 2 Book chapters; 144 Articles in Proceedings (including 2 Best Paper Award and 1 Best Poster Award) ; 23 Invited Articles in Proceedings, 36 Invited talks without proceedings, 4 Articles in french-speaking conferences, 18 Patents

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**Major Publications**


- M. Pischella, and J.-C. Belfiore, "Power Control in Distributed Cooperative OFDMA Cellular Networks," IEEE Trans. on Wireless Communications, vol. 7, no. 5, pp. 1900-1906, May 2008. [922]
- W. Hachem, O. Khorunzhiy, Ph. Loubaton, J. Najim, and L. Pastur, "A New Approach for Capacity Analysis of Large Dimensional Multi-Antenna Channels," IEEE Trans. on Information Theory, vol. 54, no. 9, pp. 3987-4004, Sep. 2008. [888]
- A. Tchamkerten, V. Chandar and G. Wornell, “Communication under Strong Asynchronism,” IEEE Trans. on Information Theory, vol. 55, no. 10, pp. 4508-4528, April 2009. [938]

- L. Luzzi, G. Rekaya, and J.-C. Belfiore, "Augmented Lattice Reduction for MIMO decoding," IEEE Trans. on Wireless Communications, vol. 9, no. 9, pp. 2853 - 2859, Sep. 2010. [910]
- O. Rioul, "Information Theoretic Proofs of Entropy Power Inequalities," IEEE Trans. on Information Theory, vol. 57, no. 1, pp. 33-55, Jan. 2011. [927]

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**Impact and Attractivity**

- 4 Associate Editors at IEEE Trans. on Information Theory, IEEE Trans. on Signal Processing, IEEE Communications Letters. 1 Senior Area Editor at IEEE Trans. on Signal Processing. Track Chairs in PIMRC'2008 and EUSIPCO'2011. TPC members for the flagship conferences (ICASSP, ICC, GLOBECOM, ISIT, ...)
- 1 deputy director of GDR ISIS, 1 GRETSI Board of Directors, 1 TPC member of GRETSI conference
- Organization of the International Conference SETA 2010
- 6 sabbatical stays (India, Israel, Morocco, Saudi Arabia, Singapore, Spain)
- Tutorials at EUSIPCO'2011 and IHP. Plenary Talks at ISWCS'2012. 3 lectures in spring schools (GTEM'2009, EPIT'2013, RFTE'2013). General chair for summer school Peyresq in 2013.

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**Interaction with Economic and Social Spheres**

- 5 European projects (NEWCOM++, PHYLAWS, SMARTEN, LEXNET, SIEGFRIED)
- 1 ANR "Chair of Excellence", 1 Emergence program of City of Paris
- 5 CIFRE PhD fellowships, 1 Google Award PhD fellowship
- 18 Patents (especially, [1124, 1122, 1133, 1129, 1123, 1116])
- Organization of LIESSE schools for professors of the so-called Classes Préparatoires

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**Contributions to Higher Education**

- Organization of the whole education track on digital communications at Telecom ParisTech (180h)
- Main contributor (180h) to the joint Research Master M2 STN with UPMC
- Master of Science in Digital Communications
- Lectures at Ecole Polytechnique, ENSTA, Université Paris-Sud (M2 SAR)
- Continuing Education courses (6 short programs)

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## 5.2 People

**Team leader** Philippe Ciblat (AP, –11/10; FP, 12/10–).

**Faculty** Jean-Claude Belfiore (FP), Philippe Ciblat (AP, –11/10; FP, 12/10–), Walid Hachem (SRS), Ghaya Rekaya-Ben Othman (AP, –11/12; FP, 12/12–), Olivier Rioul (AP), Georges Rodriguez (AP), Patrick Solé (SRS, 09/08–), Aslan Tchamkerten (AP, 09/08–), Michele Wigger (AP, 12/09–).

**PhD students** A. Le Poupon (09/02–09/09), S. Dubouloz (10/03–06/08), A. Alloum (12/03–09/08), M. Sarkiss (12/04–02/09), A. Mahmood (01/05–07/08), A. Zhao (10/05–09/10), C. Hucher (01/06–07/09), R. Ouertani (01/06–11/09), M. Pischella (03/06–03/09), Y. Liu (09/06–11/09), M. Badr (09/06–03/10), E. Bouton (09/06–02/10), L. Mroueh (10/06–01/10), A. Salah (10/06–07/10), A. Bouzegzi (11/06–10/09), A. Le Duc (01/07–03/10), M. Nahas (09/07–12/10), S. Mumtaz (09/07–01/11), C. Abgrall (02/08–10/10), M. Selmi (09/08–09/11), A. Osmane (10/08–12/11), A. Charaf (11/08–04/12), M. Plainchault (11/08–05/12), M. Sefidgaran (10/09–04/13), C. Mihoubi (11/09–12/12), D. Serrano-Velarde (11/09–12/12), P. Delesques (12/09–12/12), S. Marcille (01/10–02/13), S. Mirghasemi (03/10–), F. Iutzeler (10/10–), A. Mejri (10/10–), L. Sok (01/11–), J. Vinogradova (09/11–), S. Belhadjamor (10/11–), Y. Wu (10/11–), E. Ebrahemi Khaleghi (10/11–), R. Massin (01/12–), A. Heuser (09/12–), F. Jardel (09/12–), A. Amari (04/13–).

**Post-docs, engineers and sabbaticals** F. Kharrat (09/07–10/08), L. Luzzi (10/07–05/10), M. Sarkiss (02/09–08/10), F. Chapon (11/10–10/11), N. Ksairi (02/13–), D. Conti (03/13–), T. Courtat (04/13–), M. Sefidgaran (04/13–).

## 5.3 Overview

Communication networks involve a variety of communication media (*e.g.*, wireless, wired, optical) for information transmission, information retrieval, and information processing. These tasks must typically be performed under constraints which take into consideration an array of performance metrics including complexity, reliability, latency, and secrecy. Moreover, depending on the nature of the network, these constraints should be met in a centralized or decentralized way.

The main thrust of the Digital Communication group's research effort has been on providing a better understanding of the fundamental limitations of communication networks and on providing means to achieve these limits. Accordingly, our contributions span the areas of information theory, coding, and signal processing.

Main results were obtained in the context of single-user MIMO communication, cooperative communications (*i.e.*, when a source and a destination are helped by additional nodes called relays), multi-user cellular networks (one-to-many or many-to-one communication), and ad hoc networks (many-to-many communication). For these settings, the team has developed

- fundamental limits and related coding techniques for information transmission over wireless, wired, and optical channels;
- resource allocation techniques for wireless networks ;
- fundamental limits and related estimation techniques for centralized or distributed contexts.

Over 2009-2013, the group had a high publication rate in leading journals and conferences—about $2$ journals/year/member and $4.5$ conferences/year/member—and obtained two Best Paper Awards. All our research activities are supported by national, European, or industrial funding.

In addition to its research activities, the team is on the editorial board of the IEEE Transactions on Information Theory, the IEEE Transactions on Signal Processing, and the IEEE Communications Letters and is part of technical committees of flagship conferences in communications (*e.g.*, ISIT, ITW, GLOBECOM, ICC, ICASSP, ....)

In addition, the group organizes seminars with external visitors (around $10$ seminars per year), and his members are often invited to external seminars in France and abroad (around $7$ seminars per year).

Our group is also very active in teaching for the Engineering school as well as for various Masters programs. In particular, we organize and teach in a Master program ("Master Recherche" ST/SDI/SYSCO/STN) jointly delivered by the Université Pierre et Marie Curie.

## 5.4 Research Themes

### 5.4.1 Point-to-Point Communications

**Faculty** J.-C. Belfiore, P. Ciblat, W. Hachem, G. Rekaya-Ben Othmann, O. Rioul, P. Solé, A. Tchamkerten, M. Wigger

**Highlights: Scientific Production** [940], [931], [926], [920], [943]

**Highlights: Impact** European funding (NoE NEWCOM++, CELTIC/SASER), ANR (ORIANA, RISC, TCHATER), FUI (100GFLEX), a few Telecom foundation PhD fellowships. P. Ciblat has served as Associate Editor (resp. Area Editor) for IEEE Trans. on Signal Processing from 2008 (resp. 2010) to 2012. He has been Track Chair for EUSIPCO'2011. P. Ciblat, G. Rekaya-Ben Othman have been invited professor at International University of Rabat (Morocco) and Indian Institute of Technology (Bangalore), respectively. P. Solé is the recipient of the Best Poster Award in *IEEE Information Theory Workshop* (ITW) in 2009.

**Highlights: Interactions with Society** CIFRE conventions (MITSUBISHI, Orange Labs, Eutelsat). G. Rekaya-Ben Othman contributed to the event "1000 chercheurs parlent d'avenir".

**Asynchronism mitigation** Synchronization is an important component of any communication system and one of the main thrust of our research effort. To understand the importance of synchronization, it is helpful to consider two opposite types of applications. In the first type, transmission of data happens on a continuous basis. Examples include voice and video. The cost of initially acquiring synchronization, say by sending a pilot sequence, is small since it is amortized over the many symbols transmitted. In the second type, transmissions are very bursty, with amounts of data transmitted once in a long while. Examples include sensor networks with sensor nodes transmitting measured data once in a while. Here the cost of acquiring synchronization is more significant because the number of information bits transmitted per burst is small. What are the fundamental limitations due to a lack of a priori synchrony between the transmitter and the receiver in bursty communication? This question has been investigated for point-to-point communication in [880, 938, 940, 939, 1103] by considering an extension of Shannon's classical communication model. In these works fundamental trade-offs between communication rate, asynchronism level, delay, error probability, and output sampling rate have been derived and corresponding optimal communication strategies have been investigated. One of the many surprising conclusions is that training based schemes where synchronization and information transmission are carried using separate degrees of freedom can be very suboptimal. In these cases, efficient codes integrate error correction and detection properties which prompted the investigation of bounded weight or spherical codes [2236, 1080].

We also investigated the impact of asynchronism for multiuser communication, specifically for relay networks without a direct line of sight between the source and the destination, we constructed delay-tolerant codes based on cross product of cyclic division algebras and analyzed the performance of such schemes in terms of outage probability [916]. These codes have the compelling properties of achieving full rate, full diversity, and a non-vanishing determinant similarly to perfect codes in the synchronous case.

**Fading mitigation** A popular way to cope with fading is to introduce space diversity (through so-called MIMO techniques). To achieve this we focused on space-time code design and introduced

for the first time codes over rings with non Hamming metrics which are then used to construct space-time codes by a concatenation process similar to the so-called Construction A of lattices [920].

The implementation of space-time codes requires low complexity decoding algorithms, in particular in the context of MIMO channels where the optimal decoding rule has a complexity that grows exponentially with the number of antennas. In this context, we proposed three very efficient algorithms: the SB-Stack, the Algebraic reduction and the augmented LLL reduction. For example, the SB-Stack is a sequential decoder which combines the tree search strategy of the original stack decoder with the search region of the sphere decoder.

Finally, we investigated space diversity through relaying schemes. In this framework, we proposed a new protocol, called the DoQF, which combines a decoding step with a quantified step. We proved that the performance of this protocol is very close to the so-called Diversity-Multiplexing gains Trade-off (DMT), and hence outperforms the existing ones [3918].

The best known protocol for cooperative communication is the Dynamic Decode and Forward (DDF) protocol according to the DMT. We were interested in the practical implementation of this protocol when the source does not know whether a relay is present. We defined a new metric called Macro diversity (coming from long term SNRs) which represents the number of links necessary to achieve some QoS when all other links experience very low SNRs. We proposed so-called patching techniques in order to maximize the micro and macro diversity which resulted in very efficient schemes: patched Monostream, Patched Alamouti, Patched Golden Code, and Patched Silver Code.

**Optical fiber based communications** Due to emergence of new applications (*e.g.*, video streaming, cloud computing), the amount of data in the optical core networks have strongly increased. To handle the saturation of the core network, advanced digital communication tools have to be applied to the optical communications field. Indeed, due to recent technological progress, the information (passing through the optical fiber) can now rely on both the intensity and the phase. Therefore standard wireless digital communications can now be advocated for optical communications. In this new paradigm, we have focused on various facets.

Phase estimation represents an key issue in optical communication. We studied low complexity phase estimators for phase uncertain channels under BPSK and QAM modulation, and proved their asymptotic optimality—via a conditional gradient descent algorithm. Interestingly, these estimators can have very simple expressions depending on the modulation.

Inter-symbol interference—generated by the dispersion of the fiber or by the polarization mixing—and the carrier frequency offset represent other major issues often mitigated through sample by sample estimation techniques. We proposed an alternative method which uses the property that the channel often varies slowly over time and hence allows the use of estimation methods which operate over blocks of samples. This alternative enables to drastically reduce the estimation error for a given number of samples [932].

It is well known that polarization multiplexed optical systems can be seen as MIMO systems thereby allowing the use of space-time coding techniques for which the team has a renowned expertise. We exhibited space-time codes that efficiently mitigate polarization dependent loss (PDL) impairments, and characterized their performance in terms of error and outage probability [979].

Ultimately, the limits to optical communication are obtained through information theoretic arguments. In this context we derived channel capacities when nonlinear impairments occur and also when only intensity based detector is carried out [943].

### 5.4.2 Network Optimization

**Faculty** J.-C. Belfiore, P. Ciblat, W. Hachem, G. Rekaya-Ben Othmann, A. Tchamkerten, M. Wigger

**Highlights: Scientific Production** [4025], [933], [913], [1024] (Best Paper Award), [899]

**Highlights: Impact** European fundings (FP7/SMARTEN, FP7/LEXNET), DGA PhD fellowship, Emergence Grant from the City of Paris (PINS). J.-C. Belfiore has served as Associate Editor for IEEE Trans. on Information Theory since 2010. M. Wigger has served as Associate Editor at IEEE Communication Letters since 2012. J.-C. Belfiore has been Track Chair for PIMRC'2008. D. Tuninetti (University of Illinois, Chicago) spent one year (2011) in sabbatical stay. M. Wigger has been visiting professor at Technion (Summer 2011). Collaborations with EPF Lausanne, ETH Zürich, UC San Diego, KTH Stockholm, NTU, University of Southern Australia, Notre Dame University. J.-C. Belfiore has given several talks, especially in Ecole Polytechnique, Univ. of Campinas (Brazil), NTU (Singapore), Imperial College (UK).

**Highlights: Interactions with Society** CIFRE conventions (THALES)

**Interference management** A major impairment in modern networks (cellular or ad hoc ones) is user interference (rather than the noise). Different ways exist to handle it. The first one is through Physical Layer Network Coding (PLNC). We considered cooperative systems with several pairs of source/destination communicating at the same time using the same physical resources. In that case, we are facing interference problems which degraded drastically the system performance. The PLNC aims to optimize the throughputs and to enhance system performance. The protocol Compute and Forward has been recently proposed for PLNC. We have study the optimization and implementation of this protocol using algebraic tools and lattice theory. We have also proposed optimal and sub-optimal decoding methods at the relay side [1024].

Another way to handle interference is through power and bandwidth allocation. Assuming a fast fading channel model with or without decision feedback, we designed new algorithms for mitigating the multi-cell interference and computed the best frequency reuse factor. We showed that a proper use of feedback can significantly reduce the throughput per unit energy [913].

When the network is centralized (typically the mobile cellular systems), feedback signals can be sent to the transmitters in order to help interference management. We studied the benefits of such feedback signals on the largest data rates (called capacity) that can be achieved over broadcast channels (BC) and over multi-access channels (MAC). We proved that any arbitrary small (but nonzero) number of feedback bits strictly increases the capacity of *strictly less-noisy* BCs. We further showed that for some Gaussian BCs the gain in capacity can even be unbounded when the feedback is perfect, and for others it allows to achieve the same rates as if the two receivers could cooperate in their decoding. To prove these results we proposed new coding schemes. For some memoryless BCs our new schemes are optimal and achieve the capacity with feedback [933]. We further showed that an estimation-based coding scheme is optimal among a wide class of linear-feedbacks scheme [872].

**Distributed Information Processing** This topic, at the edge between signal processing, coding, and information theory, has seen tremendous research activities recently. It encompasses many different subfields including consensus reaching, distributed computation, distributed estimation/detection, and distributed optimization. For each of these we provided interesting contributions.

For consensus reaching, we proposed new distributed algorithms for maximum and average functions computation that are well suited for wireless communications [898, 899].

For distributed computation, we characterized upper and lower bounds on the minimum amount of information that needs to flow across certain types of networks so that a receiver can reliably compute a given function of sources of information [1069].

For distributed estimation we investigated two settings. In the first setting, all the nodes in a network want to estimate a certain parameter related to its observations. In the second setting there is only one node (the fusion center) who wants to estimate the parameter. For the first case, we developed new algorithms based on so-called stochastic approximation. In particular, the asymptotic performance of these algorithms have been obtained [4025]. For the second case, we investigated the performance of the optimal Neyman-Pearson detector at the fusion center [891].

For distributed storage, we investigated a setting where receivers—who wish to retrieve the stored or compressed data—have some a priori side-information about this data (this information can be obtained by measuring correlated data for instance). For a class of single-encoder two-decoder systems (the Kaspi/Heegard-Berger setup) we derived the maximum possible compression ratio that still allows the decoders to reconstruct their intended data with the desired precision [1087]. We also demonstrated that when the two decoders need to reconstruct their intended data perfectly, then knowledge of the side-information at the encoder strictly improves the maximum compression ratio.

### 5.4.3 Security: Communications and Devices

**Faculty** J.-C. Belfiore, O. Rioul, P. Solé, A. Tchamkerten

**Highlights: Scientific Production** [937], [1082], [879], [1012], [874]

**Highlights: Impact** European fundings (FP7/PHYLAWS, ENIAC), Google Award PhD fellowship, Telecom Foundation PhD fellowship. J.C. Belfiore was invited professor at NTU (Singapore) in 2011. Sabbatical Stay of P. Solé at University of Jeddah (Saudi Arabia) in 2012. Collaborations with Université Paris 8, Electronic team of Telecom ParisTech. P. Solé and J.C. Belfiore organized the International Conference SETA 2010.

Secure communication has been investigated at the physical and at the application layers. Security at the physical layer has been recently proposed as a means to enhance or complement security at the application layer (cryptography). A classical model is the so-called (Gaussian) wiretap channel where a passive eavesdropper tries to decode a message sent to a legitimate receiver. For this channel we proposed code constructions based on nested lattice codes which also operate under a MIMO setting. The code performance are related to the theta series of the lattice in the single antenna case and to some zeta function, Epstein or Solomon, in the MIMO case. These results gave a design criterion for lattice codes.

The same model but in a multi-user setting has been investigated and corresponding fundamental rate-equivocation trade-offs have been derived derived [937].

At the application layer, we proposed an authentication protocol for RFID applications. This is one of the most efficient and lightweight protocols currently available which thwarts many active attacks, including the Mafia fraud [1082].

Finally, we investigated so-called side attacks in which information is gained from the physical implementation of a cryptosystem. We developed a hypothesis test framework which applies in the situation where the side attack aims at extracting cryptographic keys from a device by analyzing its leakage knowing its input or output. The correct key is distinguished from the bad key by selecting the key that maximizes some distinguisher such as DPA, CPA or MIA. In this work, we analyze the distinguishers' efficiency for certain types of leakage (especially in the presence of countermeasures like masking) which are independent of the device.

### 5.4.4 Cross-disciplinary Information Theory and Statistics Tools

**Faculty** W. Hachem, O. Rioul, A. Tchamkerten

**Highlights: Scientific Production** [936], [927], [893], [883], [1857] (Best full paper award).

**Highlights: Impact** ANR chair of excellence (ACE), ANR (DIONISOS), Digiteo grant (DESIR). W. Hachem served as Associate Editor for IEEE Trans. on Signal Processing from 2007 to 2010. Sabbatical Stay of W. Hachem at Centre Tecnologic de Telecomunicacions de Catalunya during Summer 2010. Collaborations with University of North-Carolina, Russian Academy of Sciences, ENSTA, LSS, UPE-MLV, SUPELEC. Tutorial on "Large Random Matrix" at EUSIPCO'2011 and at Institut Henri Poincaré. W. Hachem is Deputy Director of GDR-ISIS and is Scientific Director of Summer School at Peyresq in 2013. O. Rioul is Adjunct Professor at Ecole Polytechnique.

**Highlights: Interactions with Society** O. Rioul organized LIESSE schools for teachers of the so-called Classes Préparatoires.

The investigation of communication networks also represents an opportunity to develop analytic tools which can then be applied in other contexts, thereby spurring interdisciplinary research.

An important effort has been devoted to the theory of large random matrices. Random matrices appear in a wide range of applications, ranging from MIMO systems in communications to portfolio optimization in finance. Besides theoretical results related to the behavior of the eigenvalues and eigenspaces of certain classes of such matrices [895, 3906], new algorithms have been designed for estimating the angles of arrivals and source powers in the context of array processing [893, 894, 930] or for detecting failure in large sensor networks [883].

Motivated by feedback communication, we proposed a natural generalization of the classical Bayesian change-point detection setup by letting the change-point be a stopping time with respect to an unobserved process. This new statistical inference framework is relevant in a number of areas including forecasting, communication, and monitoring. We investigated optimal detection policies for different stopping times and different classes of observation processes [918, 936, 877, 878].

While most useful information theoretic inequalities can be deduced from the basic properties of entropy or mutual information, Shannon's entropy power inequality (EPI) was an exception. We derived a unified view of the existing proofs by showing that they share two essential ingredients: a data processing argument and an integration over a path of a continuous Gaussian perturbation. Using these, we developed a new and brief proof of the EPI through a mutual information inequality.

Fitts' law is a well-known model of human pointing movement in experimental psychology. We reviewed the celebrated stochastic optimized-submovement theory proposed by Meyer *et al.* to show that it implies a quasi-logarithmic (Shannon-like) model, rather than a quasi-power model. Also, by testing the prediction that throughput is conserved across variations of speed/accuracy, we found it to be affected by the strategy. This pleads against a currently popular definition of throughput.

# 5.5 Achievements (Appendix 6)

## 5.5.1 Scientific productions

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[1115] Y. Wu, P. Minero, and M. Wigger. Reliability of the gaussian broadcast channel with common message and feedback (invited). In *International Workshop on Signal Processing Advances in Wireless Communications*, Damstadt, June 2013.

### 5.5.2 Public Fundings

| Period | Project details | Funding | Principal investigator | Amount (k€) |
|---|---|---|---|---|
| 2008-2011 | NEWCOM++: Network of Excellence in Wireless Communications | Europe | P. Ciblat | 15 |
| 2009 | DACOMS: Distributed Asynchronous COdes for wireless Mesh networks of Smart devices | Futur& Ruptures | J.-C. Belfiore, G. Rekaya | 40 |
| 2009-2010 | RA-MIMO: Algrebraic Reduction for MIMO systems | Carnot Valo | J.-C. Belfiore, G. Rekaya | 61 |
| 2009-2011 | Distributed function computation | Futur& Ruptures | A. Tchamkerten | 111 |
| 2009-2013 | SMARTEN: Smart Management for Sustainable Human Environment | Europe | G. Rekaya | 260 |
| 2009-2013 | ACE: information theoretic and statistical approaches to Asynchronous Communication and Engineering applications | ANR Chair of Excellence | A. Tchamkerten | 220 |
| 2010-2013 | Design and analysis of distributed estimation algorithms | DGA PhD scholarship | P. Ciblat | 110 |
| 2011-2012 | Structured codes for ad-hoc networks with cooperating users | Sabbatical stay scholarship | M. Wigger | 29 |
| 2011-2013 | DESIR: Design of efficient statistical estimators for radio applications | Digiteo fellowship | W. Hachem | 153 |
| 2011-2014 | PINS: Pushing the performance limits of wireless Networks by exploiting Side-channels | Emergence program (City of Paris) | M. Wigger | 195 |
| 2012-2014 | Distinguishing Distinguishers: A Theoretical Approach to Side-Channel Analysis | Futur& Ruptures | O. Rioul | 111 |
| 2012-2015 | LEXNET: Low EMF Exposure Networks | Europe | P. Ciblat | 85 |
| 2012-2015 | PHYLAWS: Physical Layer Security | Europe | J.-C. Belfiore | 152 |
| 2012-2015 | SASER-SIEGFRIED: Safe and Secure European Routing - Security In EnerGy-efficient Flexible and ResilIEnt Data networks | Europe | P. Ciblat | 248 |
| 2012-2016 | DIONISOS: High dimensional statistical signal processing | ANR | W. Hachem | 81 |

### 5.5.3 Private Fundings

| Period | Project details | Funding | Principal investigator | Amount (k€) |
|---|---|---|---|---|
| 2008 | LDPC | Orange Labs | G. Rodriguez | 12.5 |
| 2008-2010 | Asynchronous cooperative networks | CIFRE - Orange Labs | G. Rekaya | 30 |
| 2009-2011 | Design and Optimization of relaying schemes for wireless communications | CIFRE - Mitsubishi | G. Rekaya | 45 |
| 2009-2011 | Analysis of iterative MIMO-LDPC receivers | CIFRE - Eutelsat | G. Rodriguez | 24 |
| 2010-2012 | Analyses of transmission and switching capacities in optical networks | CIFRE - Mitsubishi | P. Ciblat | 45 |
| 2010-2012 | Resource allocation for HARQ-based MANET | CIFRE - Thales | P. Ciblat | 45 |
| 2013 | Algorithmic study of positions and angles navigation system of an handheld digital image printer | Sanmina-SCI | O. Rioul | 15 |
| 2013-2014 | Spectrum sensing for double-talk satellite networks | BULL | P. Ciblat | 25 |
| 2013-2015 | Distinguishing Distinguishers: A Theoretical Approach to Side-Channel Analysis | Google Award PhD fellowship | O. Rioul | 195 |

### 5.5.4 Patents

[1116] A. Bouzegzi, P. Jallon, and P. Ciblat. Méthode d'estimation aveugle de paramètres de modulation OFDM. (WO/2010/1249896), Apr. 2008.

[1117] A. Bouzegzi, P. Jallon, and P. Ciblat. Méthode d'estimation aveugle de paramètres de modulation OFDM selon un critère de maximum de vraisemblance. (WO/2010/029172), Apr. 2008.

[1118] A. Bouzegzi, P. Jallon, and P. Ciblat. Méthode d'estimation aveugle de paramètres de signal OFDM par filtrage adapté. (WO/2010/029173), Apr. 2008.

[1119] N. Gresset, M. Plainchault, and G. Rekaya-Ben Othman. Method and a device for relaying symbols transferred by a source to a destination in radio cellular communication netwok, and method and device for decoding symbol received by destination in radio cellular communication network. (EP 2293467 A1 et US 2011/0051704 A1), Sept. 2009.

[1120] N. Gresset, M. Plainchault, and G. Rekaya-Ben Othman. Method and a device for relaying symbol transferred by transmission source to destination in radio cellular communication netwok. (EP 2293466 A1 et US 2011/0051821 A1.), Sept. 2009.

[1121] N. Gresset, M. Plainchault, and G. Rekaya-Ben Othman. Method and device for relaying symbols transferred by a source to a destination. (JP 2011/09667 et EP 2326031 A1), Nov. 2009.

[1122] C. Hucher, G. Rekaya-Ben Othman, and A. Saadani. Codage spatio-temporel pour système coopératif. (EP 2191583 B1 (délivré)), June 2011.

[1123] L. Luzzi, G. Rekaya-Ben Othman, and J.-C. Belfiore. Méthode de décodage par réseau de points augmenté pour système multi-source. (FR 09/59680), Dec. 2009.

[1124] S. Marcille, P. Ciblat, and C. Le Martret. Procédé de retransmission à protection inégale adaptée aux paquets réseau fragmentés. (2012-), July 2012.

[1125] S. Mumtaz, G. Rekaya-Ben Othman, and Y. Jaouën. Procédé et dispositif de modulation mettant en œuvre une modulation différentielle, procédé et dispositif de démodulation, signal et produits programme d'ordinateur correspondants. (FR 09/52207 et EP 2415193 A0), Apr. 2009.

[1126] S. Mumtaz, G. Rekaya-Ben Othman, Y. Jaouën, and B. Thedrez. Méthode et système de transmission wdm à codage chromato-temporel. (FR 10/58204), Oct. 2010.

[1127] M. Nahas, A. Saadani, and G. Rekaya-Ben Othman. Méthodologie de construction de codes spatio-temporels pour des réseaux de communications distribués asynchrones. (FR 10/52426 et PCT 2011/050727), Mar. 2010.
[1128] M. Nahas, A. Saadani, and G. Rekaya-Ben Othman. Procédé de transmission d'un signal numérique pour un système distribué, produit programme et dispositif relais correspondants. (FR10/50200), Jan. 2010.
[1129] M. Plainchault, N. Gresset, and G. Rekaya-Ben Othman. Method and a device for determining if an information word transferred by at least a source has to be relayed. (EP 2369760 et US 2011/235754A1 et JP 2011223560), Mar. 2010.
[1130] G. Rekaya-Ben Othman, L. Luzzi, and J.-C. Belfiore. Procédé de décodage dun signal ayant subi un codage espace/temps avant émission, dans un système multi-antennaires, produit programme dordinateur et dispositif de décodage correspondant. (FR 08/55882), Sept. 2008.
[1131] G. Rekaya-Ben Othman, R. Ouertani, and J.-C. Belfiore. Procédé de décodage d'un signal transmis dans un système multi-antennes, produit programme d'ordinateur et dispositif de décodage correspondants. (FR 08/50690 et PCT 2009/098178 et US 2011/058617 A1), Feb. 2008.
[1132] G. Rekaya-Ben Othman, A. Salah, and S. Guillouard. Procédé de décodage d'un signal mettant en oeuvre une construction progressive d'un arbre de décodage, produit programme d'ordinateur et signal correspondants. (FR 08/5298 et PCT 2009/135850 et US 2011/0122004 A15), May 2008.
[1133] G. Rekaya-Ben Othman, Y. Jaouën, and S. Mumtaz. Méthode et système de transmission sur fibre optique multi-mode et/ou multi-coeur. (FR 11/55537), June 2011.

## 5.6 PhDs (Appendix 7)

### 5.6.1 Defended PhDs

[1134] C. Abgrall. *Allocation de ressources dans les réseaux sans fil denses*. PhD thesis, Telecom ParisTech, Oct. 2010.
[1135] A. Alloum. *Construction et analyse de codes en graphes non systématiques adaptés aux services non uniformes*. PhD thesis, Telecom ParisTech, Sept. 2008.
[1136] M. Badr. *Codage Espace Temps pour les canaux MIMO à accès multiple*. PhD thesis, Telecom ParisTech, Feb. 2010.
[1137] E. Bouton. *Algorithmes d'allocation de ressouces pour des systèmes à interférence*. PhD thesis, Telecom ParisTech, Jan. 2010.
[1138] A. Bouzegzi. *Algorithmes de discrimination des signaux pour la radio cognitive*. PhD thesis, Telecom ParisTech, Sept. 2009.
[1139] A. Charaf. *Etude de récepteurs MIMO-LDPC itératifs*. PhD thesis, Telecom ParisTech, Apr. 2012.
[1140] P. Delesques. *Analyses of transmission and switching capacities in optical networks*. PhD thesis, Telecom ParisTech, Dec. 2012.
[1141] S. Dubouloz. *Développement d'architectures avancées pour communications ultra large bande (UWB) dans les applications bas débit.* PhD thesis, Telecom ParisTech, June 2008.
[1142] C. Hucher. *Definition and performance analysis of new cooperative protocols*. PhD thesis, Telecom ParisTech, July 2009.
[1143] A. Le Duc. *Performance closed-form derivations and analysis of Hybrid ARQ retransmission schemes in a cross-layer context*. PhD thesis, Telecom ParisTech, Feb. 2010.
[1144] A. Le Poupon. *Méthodes optimales et sous-optimales d'allocation de ressources efficace en codage numérique*. PhD thesis, Telecom ParisTech, Mar. 2010.
[1145] Y. Liu. *Sychronisation estimation de canal et décodage conjoints*. PhD thesis, Telecom ParisTech, Nov. 2009.
[1146] A. Mahmood. *Computationnaly efficient adaptive algorithms for multicarrier physical layer*. PhD thesis, Telecom ParisTech, June 2008.
[1147] S. Marcille. *Resource allocation for HARQ based mobile ad hoc network*. PhD thesis, Telecom ParisTech, Feb. 2013.
[1148] C. Mihoubi. *Codes cycliques de rendement 1/2*. PhD thesis, Telecom ParisTech, Dec. 2012.
[1149] L. Mroueh. *On Space Time Coding Design and Multiuser Multiplexing Gain over Selective Channels*. PhD thesis, Telecom ParisTech, Jan. 2010.
[1150] S. Mumtaz. *Modern coding techniques for optical communications*. PhD thesis, Telecom ParisTech, Jan. 2011.

[1151] M. Nahas. *Réseaux coopératifs asynchrones : étude de performance et construction de code*. PhD thesis, Telecom ParisTech, Dec. 2010.
[1152] A. Osmane. *Réseaux spontanés et auto-organisants : du codage spatio-temporel au codage de réseaux*. PhD thesis, Telecom ParisTech, Dec. 2011.
[1153] R. Ouertani. *Algorithmes de décodage pour les systèmes multi-antennaires à complexité réduite*. PhD thesis, Telecom ParisTech, Nov. 2009.
[1154] M. Pischella. *Distributed resource allocation in OFDMA multi-cell networks*. PhD thesis, Telecom ParisTech, 2009.
[1155] M. Plainchault. *Conception et Optimisation de techniques d'auto-organisation pour les systèmes de communication radio-mobiles femto-cellulaires*. PhD thesis, Telecom ParisTech, May 2012.
[1156] A. Salah. *Schéma de décodage à faible complexité pour système MIMO*. PhD thesis, Telecom ParisTech, July 2010.
[1157] M. Sarkiss. *Codes espace-temps : nouvelles constructions, décodage et applications.* PhD thesis, Telecom ParisTech, Feb. 2009.
[1158] M. Sefidgaran. *Distributed function computation*. PhD thesis, Telecom ParisTech, Apr. 2013.
[1159] M. Selmi. *Advanced digital signal processing tools for QAM-based optical fiber communications*. PhD thesis, Telecom ParisTech, Oct. 2011.
[1160] D. Serrano-Velarde. *Systèmes de Communications Interactifs par Satellite de deuxième Génération*. PhD thesis, Telecom ParisTech, Dec. 2012.
[1161] A. Zhao. *Contributions à l'implémentation du MIMO pour le Wifi*. PhD thesis, Telecom ParisTech, Oct. 2010.

### 5.6.2 Ongoing PhDs

- A. Amari (05/13–), Non-linear signal processing for ultra high data rate optical communications
- S. Belhadjamor(10/11–), Capacity-Gains with Feedback for Multi-Access and Broadcast Channels
- E. Ebrahemi Khaleghi (10/11–), Advanced techniques of Interference Alignment: Application to Wireless Networks
- A. Heuser (09/12–), Distinguishing Distinguishers: A Theoretical Approach to Side-Channel Analysis
- F. lutzeler (10/10–), Design and analysis of distributed estimation algorithms
- F. Jardel (09/12–), Distributed storage and computation for the networks
- R. Massin (01/12–), Resource allocation and scheduling for ad hoc wireless network
- A. Mejri (10/10–), Coding for Wireless Sensor Network
- S. Mirghasemi (03/10–), Capacity analysis of deletion channel: application to asynchronism
- L. Sok (01/11–), Orthogonal group, Boolean functions and self-dual codes
- J. Vinogradova (09/11–), Large random matrices, statistical inference for next-generation network
- Y. Wu (10/11–), Robustness analysis of capacity for wireless network with side information

# Part III

# Detailed activities: Networks and Computer Science

# Chapter 6

# Network, Mobility and Services (RMS)

## 6.1 Executive Summary (Appendix 1)

**Team Leader** Daniel Kofman (-, April 2010), Maurice Gagnaire (April 2010, July 2012), Jean-Louis Rougier (July 2012, -)

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**Initial Staff** 10 Professors; 4 Research Scientists; 0 Postdocs; 33 PhD Students.

**Staff who Left** 1 Permanent Staff; 29 research scientists; 50 PhD Students ;13 Postdocs.

**Staff who Were Hired** Thomas Bonald (Orange Labs) on Nov 1st, 2009. Luigi Iannone (TU-Berlin/Deutsche Telekom AG Labs) on May 1st 2012.

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**Scientific Highlights** Our group seeks to find a good balance between theoretical and practical approaches, as we believe they are complementary and interlinked means required to assess networking architecture and protocols.

- We have expertise in analytical approaches for performance evaluation and network dimensioning, e.g. on queuing theory [1179] [1324](best paper award), algebraic topology [2368], game theory [1284, 1458, 1312] [1444] (best paper award), statistics [1189] and combinatorial optimization [1337, 1193].
- We have also a strong expertise on architecture and protocol, for instance as expertise contractor for Alcatel Lucent, ARCEP, ETSI, Orange, SFR. We have also contributed to the IETF [1477],[1481]-[1487].
- Our results are validated extensively in realistic environments by means of simulation and even on experimental testbeds, e.g. on generic IP signaling [1298], LISP [1222], LEDBAT [1430]. We are also building a sensor network testbed within the Equipex FIT project.

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**Scientific Production** 75 Journals; 3 Books; 13 Book chapters; 223 Articles in Proceedings; 4 patents; 9 contributions to IETF.

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**Major Publications**


- L.Chen, S. Iellamo, M. Coupechoux and P. Godlewski , "An Auction Framework for Spectrum Allocation with Interference Constraint in Cognitive Radio Networks," INFOCOM, 2010 Proceedings of IEEE Infocom 2010, March 2010.
- A. Finamore, M. Mellia, M. Meo and D. Rossi, "KISS: Stochastic Packet Inspection Classifier for UDP Traffic". IEEE Transactions on Networking, 18(5):1505 - 1515, October 2010.
- S. Secci, J.-L. Rougier, A.Pattavina, F.Patrone and G.Maier. "Peering Equilibrium Multipath routing: a game theory framework for Internet peering settlements", IEEE/ACM Transactions on Networking, vol.19, n.2, 2011.
- T. Bonald and J. Roberts, "Internet and the Erlang formula", ACM Computer Communication Review, vol.42, ns.1, January 2012.
- A. Haddad and M. Gagnaire. "Differentiated Radio-over-Fiber-based Backhauling for Dynamic LTE Capacity Provisioning". IEEE/ACM Transactions on Networking, April 2013.


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**Major Documents**

– Reference Software Implementation (Open Source): OpenLisp (www.openlisp.org).

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**Impact and Attractivity**

– Our team collaborates with a large number of labs worldwide (sabbatical, double Ph.D. programs, etc.): Université Catholique de Louvain and University of Ghent (Belgium), Politechnico of Turino and Politechnico of Milano (Italy), UPC (Barcelona, Spain), Technion (Israel), Novosibirsk State Univeristy (Russia), UCLA (USA), University of Waterloo (Canada), Indian Institute of Science (India), NCRL (National Mobile Communications Research Laboratory, Nanjing , China), NTU (Singapore).
– Lead of the EuroNF Network of Excellence (36 partners from 17 countries, `www.euronf.org`). Technical experts and chairman of the expert committee of ANR VERSO program.
– The team is co-founder of the LINCS laboratory (Laboratory of Information, Network and Communication Sciences), a common lab with ALBLF (Alcatel-Lucent Bell Labs France), INRIA and UPMC (LIP6). `www.lincs.fr`.

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**Interaction with Economic and Social Spheres**

– The team has led the creation of the Network Architecture project within IRT SystemX (`www.irt-systemx.fr`) where Alcatel Lucent Bell Labs, Orange and INRIA are involved.
– The team is co-founder of the SEIDO Lab, a common lab with EDF on Internet of Things and Cyber Security in the context of Electricity grids.
– The team has a close relationship with the major industrial partners, with several grants from Alcatel Lucent, ATOS, Cisco, Orange, SFR, Thales, ...

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**Contributions to Higher Education**

– A new master program "Advanced Communication Networks" has been elaborated in collaboration with Ecole Polytechnique (accreditation on-going, expected to start in Sep 2013).
– Contribution to the definition and the creation of the Villebon-George Charpak Institute (`www.villebon-charpak.fr/`).
– 3 books have been written: [1237, 1238, 1239].
– Creation of educational tools for the analysis of cellular network radio parameters: Vigie (in collaboration with Telecom Bretagne) and Metradip (with funding from SFR).

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## 6.2 People

**Team leader** Jean-Louis Rougier (July 2012, –).

**Faculty** Thomas Bonald (P), Nadia Boukhatem (P), Claude Chaudet (AP), Marceau Coupechoux (AP), Maurice Gagnaire (P), Philippe Godlewski (P), Luigi Iannone (AP), Daniel Kofman (P), Philippe Martins (P), Jean-Louis Rougier (AP), Dario Rossi (P), Noémie Simoni (P).

**PhD students** Paul-Louis Ageneau (02/13–), Houda Alaoui Soulimani (03/09-06/12), Mario Alberto Alvarado Ruiz (01/11–), Rosy Aoun (–11/10), Azin Arya (04/08-10/11), Jordan Auge (–09/08), Ines Ayadi (01/11–), Dorra Ben Cheikh Battik (01/09-05/12), Sameh Ben Fredj (04/11–), Nihel Djoher Benzaoui (06/12–), Paola Bermolen (–03/10), Aruna Bianzino (03/09-05/12), César Cardenas Perez (–09/09), Jing Chi (–11/08), Alpha Amadou Diallo (–09/09), Angel Felipe Diaz Sanchez (01/11–), N'deye Amy Dieng (09/09–), Matthieu Durut (03/09-05/12), Bassem El Zant (10/12–), Marguerite Faycal (–05/10), Sébastien Faye (10/11–), Antoine Fressancourt (02/13–), Massimo Gallo (12/09–11/12), Yixi Gong (10/12–), Romain Guigou-Res (11/10, 09/11), Yoram Haddad (10/05-09/08), Ahmed Haddad (09/09-04/13), Ali Hammami (03/10), Bing Han (04/06-09/09), Sana Horrich (10/04-02/08), Ghida Ibrahim (05/11–), Stefano Iellamo (10/11–), Claudio Imbrenda (11/12–), Raluca-Maria Indre (12/09-11/12), Rim Kaddah (09/12–), Fatima Kaddour (01/11–), Hany Kamal Mahmoud (11/07-11/10), Jean-Marc Kelif (–02/08), Sharique Ali Khan (11/11-10/12), Ahlem Khlass (02/12–), Salma Ktari Ezzahdi (–12/09), Fédérico Larroca (–03/10), Ngoc Khuyen Le (11/12–), Carle Tricana Lengoumbi Makogha (–03/08), Rémy Leone (01/13–), Chuan Li (01/07-02/08), Bin Liu (04/06-04/09), Masood Maqbool (11/06-11/09), Mattia Minelli (08/10–), Farhan Hyder Mirani (11/08-01/12), Xavier Misseri (09/10–), Rachad Nassar (02/10-06/12), Huu Quynh Nguyen (–03/08), Mathis Obadia (05/13–), Netzahualcoyotl Ornelas (03/08-09/11), Soumia Oua-Nouche Kessal (04/08-09/11), Kalpeshkumar Patel (–06/08), Antoine Pichot (–04/08), Ludovic Pietre-Cambacedes (09/07-11/10), Giuseppe Rossini (10/10-09/13), Erwing Ricardo Sanchez San-chez (04/08-03/09), Stefano Secci (–12/09), Qing Shen (01/11–), Meng Song (–10/08), Rodrigo Soule De Castro (02/08-06/11), Claudio Testa (11/09-10/12), Phuoc Nguyen Tran (–09/10), Silvio Valenti (08/08-09/11), Jean-Philippe Vasseur (03/12-01/13), Paolo Veglia (08/08-09/11), Thuong Van Vu (01/13–), Lu Sheng Wang (–09/09), Yijun Wu (–06/10), Feng Yan (11/09-04/13), Chun Yang Yin (–02/09), Mayssa Youssef (10/08-04/12), Xiaoxing Yu (06/11–).

**Post-docs, engineers and sabbaticals** Nedal Ababneh (03/10-06/11), Sawsan Al Zahr (01/08–), Lin Chen (01/09-09/09), Davide Cuda (03/12-10/12), Ahmed Haddad (04/13–), Konstantinos Katsaros (02/12-02/13), Sukru Kuran (05/13–), Bin Liu (05/09-05/11), Muriel Mabiala Moundele (01/08-05/08), Masood Maqbool (12/09, 01/10), Meng Song (03/09, 01/10), Claudio Testa (11/12, 04/13), Minh Anh Tran (01/09, 09/09), Yijun Wu (07/10-10/10).

**External Collaborators** Jesus Alcober (03/08-02/09), Tatiana Aubonnet (09/12-02/13), Alexandre Brandwajn (01/11-03/11), Haim Dayan (04/10-10/10), Gladys Diaz (09/12-02/13), Yoram Haddad (07/12-08/12), Matthieu Jonckeere (01/12-02/12), Sukru Kuran (02/13-03/13), Catherine Rosenberg (05/12-12/12), Izhak Rubin (04/13-05/13) Wojciech Szpankowski (08/12-09/12), Sami Tabbane (08/09-09/09), Jean-Philippe Vasseur (2012–)

## 6.3 Overview

Our team focuses on network architecture and protocols with a relative comprehensive approach: from access (sensor networks, Internet of things, wireless mesh and cellular networks) to core networks (Future Internet, optical networks, cloud) and from service provisioning and applications to random access and dynamic spectrum management. During the last five years, our research activities have been concentrated on four main themes presented below : "Wireless networks and mobility", "Future Internet and Internet of Things", "Optical Networks", "Cloud and Service Architectures, Applications Services".

Our research encompasses performance evaluation and network dimensioning (using queuing, stochastic process theory and game theory for example), architecture and protocol design (including normalization activities), simulations and experimental validation on national and international testbeds. Our expertise in these complementary and fundamental aspects appears essential to us in order to assess the networking domain.

Our team is greatly involved in national and european collaborative research projects founded by the FP7, the ANR and national competitiveness clusters.The members of our group are deeply involved in the ANR's VERSO program, as technical experts or chairman of the expert committee. Moreover, the team regularly responds to requests for expertise from various French and European institutions. Our group was the initiator of the PF7's European Network of Excellence Euro-NF and has chaired this NoE's Steering Committee since it was created. We are also working closely with key industrial partners in this area with bilateral contracts with Alcatel-Lucent, Cisco, Orange, SFR, and Thales for instance.

The RMS group also maintains close links (joint works, double Ph.D. program, co-advisorship, sabbaticals and visits) with various international laboratories, including Université Catholique de Louvain and University of Ghent (Belgium), Politecunico di Torino and Politecnico di Milano (Italy), UPC (Barcelona, Spain), NCRL (National Mobile Communications Research Laboratory, Nanjing, China), NTU (Singapore), UCLA (USA), University of Waterloo (Canada). The team is also co-founder of the LINCS laboratory (Laboratory of Information, Network and Communication Sciences), a common lab with ALBLF (Alcatel-Lucent Bell Labs France), INRIA and UPMC (LIP6).

## 6.4 Research Themes

### 6.4.1 Wireless Networks and Mobility

**Faculty** Thomas Bonald, Nadia Boukhatem, Marceau Coupechoux, Philippe Godlewski, Philippe Martins.

**Highlights: Scientific Production** [1312] [1232] [2661][1179][2368]

**Highlights: Impact** Public grants: Carnot, Futur and Rupture (IMT), DGA, Labex Digicosme, EDITE (doctoral school), SINGA (NTU, Singapore), KIC ICT, ANR (TEROPP, Trafic, 3MING), FUI Systematic (NimbleNet, URC). Sabbatical Sojourns: NCRL, Nanjing, China (2008,2009, July-August 2010, July-August 2011), IISc, Bangalore, India (2011-2012), UCLA, USA (2012).

**Highlights: Interactions with Society** External research contracts with Orange Labs, SFR and Cassidian.

**Cellular network performance and algorithms.** We are working with Orange Labs with the aim of deriving easy-to-use outage probability formulas in cellular networks. These formulas are taking into account path-loss [1199], shadowing [1391, 1211] and fast fading [1166], assume MIMO [1272, 1271, 1167], MU-MIMO [1273], and CoMP transmissions [1168], and relays [1392] (in collaboration with NTU,Singapore, and Marc Sigelle from the TSI Dpt.). We have studied the effect of transmit power reduction in green cellular networks in [1372], proposed dimensioning rules for OFDMA networks in [1187, 1209, 1250, 1319]. Optimal policies based on Markov Decision Processes have been derived for admission control in HetNets in [1323] and for antenna selection in [1452] (in collaboration with IISc Bangalore). We proposed (in collaboration with SFR) a clustering technique to compress the radio database in the context of cellular fingerprinting systems [2661]. We also analyzed (in collaboration with Orange Labs) the radio capacity improvement provided by the dual-cell feature of R7 [1290] and by the multiple transmission point feature of R11 [1294], using traffic models derived from queueing theory.

**Geometry of cellular networks: spatial models for wireless networks.** Algebraic topology is a branch of topology that tries to classify topological spaces according to the number and to

the features of their areas of discontinuity. These methods have recently arise significant interest in the community of wireless and mobile communications. Our contributions (joint work with MIC2 team) lay in the performance evaluation and design of decentralized algorithms that do not require location information on sensor nodes [2370, 1185, 2371]. Most recently energy saving algorithms have been proposed based on a reduction algorithm for simplicial complex [2368]. New dimensioning methods based on stochastic geometry have been proposed for OFDMA networks. Concentration inequalities have been applied to obtain an analytical upper bound of the loss probability in terms of sub-channels [2351]. Finally new closed forms for handover outage probability have been proposed in [2369].

**Dynamic Spectrum Management and Cognitive Radio.** We have studied and proposed inter-operator spectrum sharing schemes within the URC project [1324, 1198, 1368, 1369, 1370, 1367, 1197]. In the ANR project TEROPP, we have studied distributed radio resource allocation schemes for cognitive radio networks (with LRI) [1311]. These schemes are based on an auction mechanism [1312, 1183], on the Multi-Armed Bandit problem [1313] and on imitation strategies [1365, 1366]. We have proposed in [1450] the utilization of GSM logical channels and UMTS signaling of the Broadcast Channel to transmit a Cognitive Beacon Channel. We have proposed (with the National Mobile Communications Research Laboratory, Nanjing, China) average transmission capacity and upper bound transmission capacity expressions, for cognitive radio systems in a primary/secondary network scenario [1165, 1269].

**Random access schemes.** We have analyzed the performance of CSMA in multi-channel wireless networks, accounting for the random nature of traffic [1178, 1179]. We assessed the ability of CSMA to fully utilize the radio resources and to stabilize the network in a dynamic setting with flow arrivals and departures. We proved that CSMA is optimal in ad-hoc mode but not in infrastructure mode. We proposed a slight modification of CSMA, that we refer to as flow-aware CSMA, which corrects the bias of CSMA against downlink traffic and makes the algorithm optimal in all cases. We also worked on wireless mesh networks (with LIP6), for which we designed OFDMA based MAC protocols [1314].

**Handover management in heterogeneous and simultaneous access.** We have developed expertise in the field of mobility and handover management in heterogeneous and simultaneous mobile access. Studies on dynamic interface selection were carried out in [1463]. A prototype (a Linux based WiFi/3G mobile terminal IEEE 802.21 support) has been developed with Bell Labs France for performance evaluation and validation. Layer-2 handover solutions that take advantage of multi-homing have been developed to enable soft handover and make-before-break handover in the integrated and tight coupling architectures of WiMAX and 3G [1208, 1207, 1385]. Stochastic heuristic optimization methods are studied [1396] and flow/interface association strategies using evolutionary game theory are investigated in [1458].

**Network coding for wireless networks.** We are conducting research studies on network coding applied to wireless networks. Adaptive mechanisms for network coding redundancy are investigated. We proposed (with LIP6) an adaptive redundancy control to mitigate losses based on link quality [1467, 1466]. We are studying (with UCLA) deployment issues of network coding and its interaction with TCP [1477]. Besides, we focus on the cost of coding in terms of energy consumption. The aim of this work (funded by DGA and IDEX Digicosme) is to build cooperative organizations of network coding capable nodes and to distribute the coding operations over a set of nodes, while optimizing the throughput and considering the energy consumption constraints.

### 6.4.2 Future Internet and Internet of Things

**Faculty** Thomas Bonald, Nadia Boukhatem, Marceau Coupechoux, Claude Chaudet, Luigi Iannone, Jean-Louis Rougier, Dario Rossi.

**Highlights: Scientific Production** [1255][1189][1226][1588][1180] [1222]

**Highlights: Impact** Public projects: CELTIC (TRANS, TIGER2), FP7 (EuroNF, ETICS, mPlane); ANR (DIAFORUS, CONNECT, SUN, 3MING), Futures et Ruptures (iGate). Sabbatical Sojourn: UCLA, USA (2012).

**Highlights: Interactions with Society** Co-lead of IRT SystemX Network Architecture Project (with Alcatel Lucent Bell Labs France, Orange and Thales). Creation of the SIEDO Lab (common lab with EDF) on Internet of things for Smart grid. Two grants from Cisco in 2012/2013. External research contract with Orange Labs. 2 Contributions to IETF [1477], [1481, 1487]. 2 Patents submitted.

**Wireless Sensor Networks** / **Internet of Things.** Even if sensors networks are getting more and more mature, duty cycling, medium access control and cross-layer optimization remain active areas of research [1435]. We also believe that asynchronous communications are well adapted to the sensors context and we have thus modeled the distribution of relay nodes in a publish/subscribe architecture [1588]. Finally, we have also contributed to adapt sensor network protocols, architectures and mechanisms to fit specific applicative scenarios. In the transportation domain, for example, we have proposed a distributed algorithm that uses a sensor network to control green lights to resolve congestion [1604, 1590]. We've also investigated routing solutions for vehicular networks taking advantage of the sensors deployed along the road infrastructure [2022, 2010]. For emergency networks, we have studied (in collaboration with the Indian Institute of Science, Bangalore, India) the optimal deployment of relays in a sensor network [1304, 1303]. We've finally participated to the development of location management systems for an Internet of Things environment [1252, 1232].

**Future Internet Architectures.** The continuous growth of the Internet, and in particular (i) the inter-domain routing tables and (ii) the diffusion of popular content, raise concerns on the scalability of today's Internet architecture. As for (i) Re-Architecturing the Internet is no easy task, but the locators/identifier separation paradigm looks as a promising solution, with a strong interest from the industry. In such context we have evaluated the scalability improvements that such a paradigm brings [1201, 1222], the way it can be incrementally deployed [1221], its security level [1251] and its resiliency [1484], as well as proposing new mechanisms in order to provide new useful features [1434]. The activity includes a strong effort and contribution in the Internet Engineering Task Force (IETF) standardization body [1481, 1487] as well as open source software development (www.openlisp.org). As for (ii), after Over the Top (OTT) diffusion technologies, such as peer-to-peer (P2P) and Content Distribution Networks (CDN), one possibility for the Future Internet is to embed caching functions deep in the network core, as proposed by the paradigmatic shift toward an Information Centric Network (ICN). Our research in ICN dwelves the caching, forwarding and strategy layers aspects[1418, 1432, 1317] and has also released an open source simulator (`http://www.enst.fr/~drossi/ccnSim`) with contributions in IETF ICNRG [1417].

**Towards a Multi-Path Internet.** Our work concentrates on adding multi-path routing capabilities to the Internet for robustness and traffic engineering purposes. We first concentrated on peering links between two adjacent providers and proposed a new scheme which leads to reduced congestion and improved route stability [1444, 1225, 1443, 1226, 1445, 1224]. We also considered collaborations between carriers within an alliance of carriers [1438, 1437, 1439, 1440, 1223, 1405]. For the global Internet, we have proposed an architecture based on the LISP architecture to by-pass current BGP limitations in order to use (almost) arbitrary paths [1398, 1400, 1399]. We have also shown how the standard route export policies (so called "Gao-Rexford" rules) can be relaxed in our framework [1401].

**Exploiting path diversity.** Once multipath capabilities are available, exploiting this diversity requires specific load-balancing and multipath transport protocols. In the context of dynamic load balancing, we have proposed a novel scheme which makes no assumption on the network characteristics, thanks to the use of modern regression and learning heuristics [1377, 1433, 1203]. It was also shown to be very robust w.r.t. abrupt traffic variations [1378, 1379, 1182]. We also obtained approximations for various performance measures under an insensitive sharing mechanism called balanced fairness, which can be viewed as the large system limit of proportional fairness [1291]. In the context of the transport layer, we have developed a scheduling mechanism which alleviates the out-of-order data reception problem for both SCTP and mTCP (multipath TCP), thereby avoiding re-orderings at the receiver entity [1395, 1394, 1397]. A prototype was developed with the collaboration of BearsTech Enterprise [1393].

**Minimum Energy Routing in IP Networks.** We have studied "green networking" technologies in fixed networks [1174]. We pointed out the incongruence of several results published and made several proposals [1283, 1173, 1172]. We first concentrated on centralized 'resource consolidation' approaches [1281, 1282]. We have also proposed an original method based on collaborative game theory (Shapley) for computing the importance of nodes/links in a network. This ranking is used to decide which nodes/links should be switched off [1284, 1286, 1176]. We have also investigated distributed green routing mechanisms ('à la' OSPF) [1285, 1175].

**Classification of Internet Traffic.** There is a growing need in IP networks for 'on the fly' flow identification in order to dynamically allocate resources in the network. Our contributions relies on similarities with verbal communications, with a new class of methods called Stochastic Packet Inspection (SPI)[1189, 1343] on the one hand, and with behavioral classification [1170, 1420] on the other hand, possibly above 10Gbps[1436]. A software implementing both technics has been provided to the scientific community [1344], that allowed to compare both methods [1345], which are now used for the observation and classification of network traffic in several european Internet Service Providers (ISP) [1403, 1190]. With the constant increase of traffic volumes, ISPs are required to use sampling for monitoring traffic: we have thus studied the impact of sampling on the monitoring of different variables [1412] and on performances of traffic classification [1422, 1421] under sampling.

### 6.4.3 Optical Networks

**Faculty** Thomas Bonald, Maurice Gagnaire.

**Highlights: Scientific Production** [1202] [1181] [1193]

**Highlights: Impact** Co-chair in 2012 of the first IEEE Workshop on Hybrid Optical Wireless Access Networks. Public projects: FP7 (DICONET, BONES), ANR (ECOFRAME), Futur et Ruptures (FIMOBA).

**Highlights: Interactions with Society** 4 Patents [1475, 1476, 1478, 1479]. Several grants from Orange Labs.

**Design of transparent WDM networks.** We have considered the problem of optimally locate electrical regenerators under quality of transmission constraints. We have first proposed an original heuristic called COR2P (Cross Optimization for RWA and Regenerator Placement) [1472], [1474], [1236], [1473]. We have then investigated the tradeoff between network costs and flexibility against traffic uncertainty [1338], [1259], [1348]. In collaboration with the Univ. of Barcelona (UPC), we have contributed to the hardware implementation of the COR2P control plane in FPGA [1411], [1164]. We have also proposed innovative rerouting strategies [1202].

**Fault management in transparent WDM networks.** Two techniques have been recently proposed for single failure detection in transparent WDM networks: monitoring cycles (m-cycles) and monitoring trails (m-trails). We have proposed an original heuristic to determine the number of m-trails and their routes on mesh infrastructure. The algorithm deals with very large networks and dense traffic matrices [1355, 1195]. The main drawback of the m-trail approach is its inherent cost in the number of required out-of-band optical channels. We have developed the concept of "monitoring-tree" (m-tree) that considerably increases network capacity while enabling a non-ambiguous single failure localization [1337]. Two patents have been filled on that topic [1478], [1479].

**Power aware routing in WDM networks.** In current WDM networks, transceivers are powered-on permanently, whatever the activity of the data sources at the electrical layer. In order to minimize network's power consumption, we have proposed an optimal mapping of a set of scheduled traffic demands onto an optical mesh infrastructure [1474].

**Subwavelength switching techniques in transparent WDM networks.** We have proposed and analysed various subwavelength switching techniques to build all-optical packet-based WDM networks. These include MAC protocols for time-slotted WDM rings [1289, 1288], adaptive optical burst switching [1292], multipoint-to-multipoint lightpaths for core networks [1184], hybrid opto-electronic switches [1330] and dynamic optical combiners for access networks [1181]. The latter has been patented [1475, 1476]. Various metro network architectures have also been compared in terms of cost, power consumption and performance [1171]. The work has been done in collaboration with Orange, Alcatel-Lucent and Politecnico di Torino.

**Radio over Fiber for mobile backhauling.** We have focused on the impact of the densification of cellular networks on the cost of the mobile backhaul infrastructure. We have proposed an innovative network architecture based on existing WDM Passive Optical Networks. We have developed an original Control Plane (CP) that maps radio frequencies with optical carriers by means of Sub-Carrier Multiplexing (SCM) taking into account various physical layer impairments [1356, 1357, 1354]. A genetic algorithm called PaGeO has been proposed to investigate the Pareto front to deal with static traffic periods [1353, 1347]. From the PaGeO tool, we have developed a meta heuristic called DBS (Differentiated Backhaul Service) to deal with medium traffic fluctuations. The performance of these algorithms has been evaluated analytically [1193, 1194].

### 6.4.4 Cloud and Services Architecture, Applications Services

**Faculty** Maurice Gagnaire, Dario Rossi, Noémie Simoni.

**Highlights: Scientific Production** [1428] [1231] [1265]

**Highlights: Impact** Open source software on LEDBAT `http://www.enst.fr/~drossi/ledbat`. Public Projects: FP7 (NAPAWINE), ANR (AVIPS, UBIS); Systematic (CompatibleOne, CARIOCAS, TIOSAFE), CapDigital (Sebastian 2). FNS (OpenCloudWare).

**Highlights: Interactions with Society** Bilateral projects with Orange Labs, SFR and ETSI.

**Service architecture.** The integration of new usages in the NGN / NGS context [1204], requires to address differently content delivery. Our work focuses on the design and engineering of service-oriented architecture allowing continuity seamless [1375, 1406]. The main result is a model of "autonomic Service" [1268], providing a "user-centric" [1451, 1454, 1352] approach and answering to "Cloud" objectives, [1266, 1409]. So, the whole system is designed on "service" composition (application services, networks, and equipments) [1261], self-manageable [1228, 1410], using the loosely coupled interconnection to meet the needs of users operating in a completely mobile environment (mobility users, devices, networks and services), [1261, 1376].

This approach is also based on a QoS model [1407], for E2E behavior [1373, 1374], ensuring continuity of service with maximum transparency [1260, 1227], guaranteeing full integration [1449]. The customization of the workflow of the user requires the convergence of services and induces a secure [1362, 1361, 1359, 2015, 1358], mobile session [1448], based on sharing and ubiquity [1408] of service components. For the protocol aspect, SIP+ is proposed [1360], in order to integrate the application service level.

**Cloud Computing.** Our activities have been mainly focused on dynamic resource allocation [1332]. We have proposed pricing strategies taking into account the real time CPU usage fluctuations [1453]. We have also investigated how computing resources dedicated to image processing could be shared efficiently between distant industrial partners [1265]. More recently, we have focused our studies on pricing, in the context of Cloud brokering [1334, 1333, 1331] or of Cloud Federation.

**Peer-to-peer (P2P) Applications.** Recently, BitTorrent has changed its file transfer algorithm, such that most of BitTorrent traffic is now transported by LEDBAT (on top of UDP) and no longer TCP. Our recent work on LEDBAT has focused on identifying and solving problems in the protocol [1429, 1302] (with impact on the homonym IETF WG) and assessing its impact at flow [1301, 1430] and swarm [1455, 1456] levels. Open source software is available at `http://www.enst.fr/~drossi/ledbat`. With the increase of P2P traffic in the 2000s, it has become very important to better understand the nature of P2P traffic and its impact on networks. We have contributed to this issue with the design and development of the Sherlock software [1419, 1217]. The recent explosion of video traffic has led us to particularly focus on P2P-TV applications. We have studied the topological awareness of the most widely used P2P-TV applications [1213] and their impact on ISPs[1233, 1218] and the Internet [1231].

# 6.5 Achievements (Appendix 6)

## 6.5.1 Scientific Productions

### Articles in Journals


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### 6.5.2 Public Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008-2010 | BONE | FP7 | M.Gagnaire | 74 |
| 2008-2010 | DICONET | FP7 | M Gagnaire | 292 |
| 2008-2012 | EuroNF | FP7/NoE | D.Kofman | 164 |
| 2008-2010 | EIFFEL | FP7 | D.Kofman | 94 |
| 2008-2011 | NapaWine | FP7 | D.Rossi | 331 |
| 2008-2011 | TRANS | Celtic | D.Kofman | 251 |
| 2008-2010 | TIGER 2 | Celtic | D.Kofman | 183 |
| 2010-2013 | ETICS | FP7 | J.L.Rougier | 325 |
| 2011-2014 | EASI CLOUDS | ITEA | M.Gagnaire | 588 |
| 2011-2012 | FITTING | ICT Labs | C.Chaudet | 24 |
| 2012-2015 | mPlane | FP7 | D.Rossi | 516 |
| 2008-2011 | UBIS | ANR/Verso | N.Simoni | 336 |
| 2009-2013 | SINARI | ANR/CSOSG | C.Chaudet | 191 |
| 2010-2012 | CONNECT | ANR/INFRA | D.Rossi | 180 |
| 2012-2015 | CORMORAN | ANR/INFRA | C.Chaudet | 173 |
| 2012-2014 | HABITELE | ANR/INFRA | C.Chaudet | 115 |
| 2009-2013 | VELCRI | ADEME | ??? | 91 |
| 2011-2012 | TELEWATT | ADEME | M.Gagnaire | 498 |
| 2011-2013 | FIT | Equipex | C.Chaudet | 333 |
| 2012-2015 | OPENCLOUDWARE | FSN | N.Simoni | 199 |
| 2008-2010 | SEBASTIAN 2 | FUI | M.Gagnaire | 117 |
| 2009-2011 | TIOSAFE | FUI | M.Gagnaire | 65 |
| 2009-2012 | NimbleNet | FUI | J.L.Rougier | 135 |
| 2010-2012 | COMPATIBLE ONE | FUI | M.Gagnaire | 133 |
| 2011-2014 | RESILIENCE | FUI | M.Gagnaire | 150 |
| 2009-2010 | Expertise | ETSI | N.Simoni | 43 |
| 2012-2015 | Fiabilité et performance du codage réseau dans les réseaux sans-fils | DGA+IDEX | N.Boukhatem | 110 |

### 6.5.3 Private fundings.

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008 -2011 | Cifre A. Arya | SFR | P.Godlewski | 46 |
| 2008 -2010 | CRE Gestion dynamique de services | SFR | N.Simoni | 149 |
| 2009 -2012 | Cifre R. Indre | Orange | T.Bonald | 24 |
| 2009 -2012 | Cifre D. Ben Cheick | Orange | M.Coupechoux | 30 |
| 2009 -2012 | Cifre M. Gallo | Orange | D.Rossi | 24 |
| 2009 -2012 | Cifre H. Alaoui Soulimani | SFR | N.Simoni | 60 |
| 2010 -2011 | Internet des objets | ALU | D.Kofman | 27 |
| 2010 -2011 | CRE Coordination multi-points LTE | Orange | T.Bonald | 60 |
| 2011 -2014 | Cifre S. Ben Fredj | ALU | D.Kofman | 30 |
| 2011 -2014 | Cifre Q.S. Yu | Orange | N.Simoni | 30 |
| 2011 -2014 | Cifre G. Ibrahim | Orange | D.Kofman | 30 |
| 2011 -2012 | CRE LOCARN ++ | Orange | D.Rossi | 53 |
| 2011 -2014 | Cifre S. Khan | Orange | T.Bonald | 9 |
| 2011 -2014 | Cifre A. Khlass | Orange | T.Bonald | 30 |
| 2011 -2012 | TELEWATT 1 | Citelium | M.Gagnaire | 498 |
| 2012 -2015 | Cifre N. Benzaoui | ALU | T.Bonald | 30 |
| 2012 -2013 | Futur de l'Internet | CAS | D.Kofman | 8 |
| 2012 -2013 | Smart Grid | Cisco | D.Kofman | 165 |
| 2012 -2016 | Seido Lab | EDF | D.Kofman | 63 |
| 2012 -2013 | LTE Security | SFR | P.Martins | 30 |
| 2013 -2016 | Cifre R. Leone | Thales | C.Chaudet | 45 |
| 2013 -2016 | Cifre A. Fressancourt | ATOS | M.Gagnaire | 45 |

### 6.5.4 Patents and software

#### Patents and contributions to normalization

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[1477] C. C. Chen, M. Gerla, M. Sanaddidi, and N. Boukhatem. Tcp over network coding. Technical report, Paris, Mar. 2013.

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[1483] L. Iannone, D. Saucez, and O. Bonaventure. Locator/id separation protocol (lisp) map-versioning. Technical Report RFC 6834, Jan. 2013.

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## 6.6 PhDs (Appendix 7)

### 6.6.1 Defended PhDs

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[1490] R. Aoun. *Resource virtualization for Grid services over WDM optical networks*. PhD thesis, Telecom ParisTech, Nov. 2010.
[1491] A. Arya. *Localisation à base d'empreintes radio (fingerprinting) : méthodes robustes de positionnement pour les terminaux cellulaires*. PhD thesis, Telecom ParisTech, Sept. 2011.
[1492] J. Augé. *Evaluation by emulation, simulation and analytic modelisation of a flow-level traffic engineering proposal*. PhD thesis, Telecom ParisTech, Sept. 2008.
[1493] D. Ben Cheikh. *Modélisation analytique des systèmes MIMOs dans un contexte multi-utilisateurs multi-cellulaires.* PhD thesis, Telecom ParisTech, July 2012.
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[1496] C. Cardenas. *Potentialité des architectures orientées flots pour la gestion du trafic grille dans les réseau IP*. PhD thesis, Telecom ParisTech, Oct. 2010.
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[1500] Y. Haddad. *Evaluation de performances des réseaux locaux sans fils : modélisation stochastique du mécanisme d'accès avec QoS, et double réutilisation de fréquences pour les femtocells dans les réseaux de types OFDMA*. PhD thesis, Telecom ParisTech, Sept. 2008.
[1501] A. Hammami. *La sécurité des futures architectures convergentes pour des services personnalisés: Aspect architectural et fonctionnel*. PhD thesis, Telecom ParisTech, July 2013.
[1502] B. Han. *Allocation distribuée des requêtes dans le réseau de capteurs sans-fil.* PhD thesis, Telecom ParisTech, Sept. 2009.
[1503] S. Horrich. *Gestion des ressources radio dans un contexte de réseaux hétérogènes*. PhD thesis, Telecom ParisTech, Feb. 2008.
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[1510] P.-C. Ludovic. *Des relations entre sûreté et sécurité*. PhD thesis, Telecom ParisTech, Nov. 2010.
[1511] H. K. Mahmoud. *Allocation dynamique du spectre pour réseaux d'accès cellulaires*. PhD thesis, Telecom ParisTech, Dec. 2010.

[1512] M. Maqbool. *Ingénierie radio des réseaux d'accès OFDMA*. PhD thesis, Télécom ParisTech, Mar. 2010.
[1513] F. H. Mirani. *Load-sharing and data scheduling in multi-homed mobile terminals*. PhD thesis, Telecom ParisTech, Jan. 2012.
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[1520] M. Song. *Vers une gestion et un controle de services dynamiques, adaptatifs et avec une qualité de services dans les réseaux ambiants*. PhD thesis, Telecom ParisTech, Oct. 2008.
[1521] R. Soule de Castro. *Amélioration des performances det la capacité dans les systèmes d'accès dynamique au spectre*. PhD thesis, Telecom ParisTech, June 2011.
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[1526] P. Veglia. *Applications TV pair-à-pair conscientes du réseau*. PhD thesis, Telecom ParisTech, Sept. 2011.
[1527] L. S. Wang. *Sélection de réseau dans les réseau sans fil hétérogènes*. PhD thesis, Telecom ParisTech, Jan. 2010.
[1528] Y. Wu. *"User-Centricc session" et "QoS dynamique" pour une approche intégrée du NGN*. PhD thesis, Telecom ParisTech, June 2010.
[1529] C. Y. Yin. *Vers l'autogestion pour une continuité de service intégrée et"sans couture"*. PhD thesis, Telecom ParisTech, Nov. 2008.
[1530] M. Youssef. *WDM optical networks: regenerator placement and green networking*. PhD thesis, Telecom ParisTech, Dec. 2011.

### 6.6.2 Ongoing PhDs

- Paul-Louis Ageneau (02/13–), *Le codage réseau dans les réseaux sans fil : Efficacité et déploiement*.
- Mario Alberto Alvarado Ruiz (01/11–), *Conception, dimensionnement et évaluation de performance d'un réseau innovant pour la recharge des véhicules électriques en zone urbaine*.
- Ines Ayadi (01/11–), *La virtualisation de bout en bout pour la gestion du Cloud sous contraintes de QoS*.
- Sameh Ben Fredj (04/11–), *Architecture de services auto-organisés liés à des espaces intelligents*.
- Nihel Djoher Benzaoui (06/12–), *Mécanismes multicouches pour les réseaux de paquets optiques*.
- Angel Felipe Diaz Sanchez (01/11–), *Allocation dynamique de ressources en environnement Cloud: profil d'usage, aspects énergétiques et inter-domaine*.
- N'deye Amy Dieng (09/09–), *Indoor Localization in Wireless Networks*.
- Bassem El Zant (10/12–), *Accounting, Pricing and Billing in inter-Cloud environment*.
- Sébastien Faye (10/11–), *Modèles et algorithmes pour le contrôle du trafic routier urbain par un réseau de capteurs*.

- Antoine Fressancourt (02/13–), *Conception et mise en oeuvre d'overlays réseau dynamiques pour la résilience du Cloud Vers une flexibilité et une résilience accrue du Cloud computing*.
- Yixi Gong (10/12–), *Foundations of an Internet measurement science*.
- Ghida Ibrahim (05/11–), *Evolution du plan de commande pour les futurs services de distribution de contenu*.
- Stefano Iellamo (10/11–), *Schémas d'allocation de ressources distribués pour réseaux cognitifs*.
- Claudio Imbrenda (11/12–), *A network traffic measurement infrastucture for the characterization of Internet Multimedia Content*..
- Rim Kaddah (09/12–), *Optimizing electricity distribution during crisis time periods in a smart grid environment*.
- Fatima Kaddour (01/11–), *Optimisation de l'allocation de ressources et d'ordonnancement dans un réseau OFDMA*.
- Ahlem Khlass (02/12-) *Évaluation des schémas de coordination multipoint dans les réseaux LTE-Advanced hétérogènes*.
- Ngoc Khuyen Le (11/12–), *Politiques d'ordonnancement et d'allocation de ressources dans un réseau d'antennes multiples distribué multi utilisateurs basés sur des indicateurs de qualité de service orienté utilisateur.*.
- Rémy Leone (01/13–), *Networks Flexible and Energy Efficient Wireless Sensor for Critical Infrastructures Surveillance*.
- Mattia Minelli (08/10–), *Evaluation des Performances des Reseaux Cellulaires avec Relais*.
- Xavier Misseri (09/10–), *Routage et ingénierie de trafic pour l'Internet du futur*.
- Qing Shen (01/11–), *Vers un Contrôle Programmable pour le Futur Internet et le Cloud Computing*.
- Thuong Van Vu (01/13–), *Application du codage de réseau à la transmission de données multi-chemin*.
- Feng Yan (11/09–), *Algorithmes distribués pour la détermination de la couverture: application aux réseaux mobiles et aux réseaux de capteurs*.
- Xiaoxing Yu (06/11-). *Propagation modeling of mobile access networks based on methods of stochastic geometry and spatial statistics*.

# Chapter 7

# Software, Systems and Services (S3)

## 7.1 Executive Summary (Appendix 1)

**Team leader** Isabelle Demeure (-, January 2010), Elie Najm (January 2010, -)

**Initial staff** 8 Professors ; 13 PhD Students.

**Staff who left** 1.6 Permanent Staff (149 months) ; 19 PhD Students (725 months) ;

**Staff who were hired:** A. Diaconescu (10/09, Post-Doc LIG Lab UJF), T. Robert (09/09, PhD LAAS), E. Borde (12/10, Post-Doc Univ. Mälardalens), R. Sharrock (09/12, AP Mines Nantes and INRIA), P. Kuznetsov (02/13, Senior Researcher TUB Berlin/Deutsch Telecom Lab).

**Scientific Highlights**

- Michael Lafaye and Laurent Pautet received the Best Research Paper Award to the IEEE Digital Avionics Systems Conference 2011, in Seattle, USA (a major conference in avionic systems domain) for their paper [1631]: *Model Driven Early Exploration of IMA Execution Platform*.
- Patent number 11 01017 entitled “Procédé de modélisation, simulation et évaluation en avance de phase d’une plate-forme de calcul” registered on 04/05/2011 by Laurent Pautet from Télécom ParisTech and Marc Gatti, Michael Lafaye and David Faura from Thales.
- RAMSES (Refinement of AADL models for Synthesis of Embedded Systems) is a model driven architecture framework dedicated to integrate design patterns as a set of AADL-to-AADL model transformation. It has been officially released as an open-source contribution, and is now running on CMU/SEI servers. RAMSES is based on OSATE (Open-Source AADL Tool-Suite Environement), developed by the CMU/SEI who now uses RAMSES to automate non-regression testing of OSATE.
- [1543] A. R. Khakpour and I. Demeure, (2010), "Chapar: A Persistent Overlay Event System for MANET", Mobile Networks and Applications, vol. 15, n° 6, pp. 866 875. An early version of this paper obtained the best paper award and best presentation award at Mobilware 2009, Berlin, Germany, Avril 2009.
- [1536] J. Bourcier, A. Diaconescu, P. Lalanda and J. A. McCann, ”AutoHome: an Autonomic Management Framework for Pervasive Home Applications”, ACM Transactions on Autonomous and Adaptive Systems (TAAS), Volume 6, Issue 1, February 2011, pp 8:1-8:10. (10 pages).

**Scientific Production** 21 Journals; 4 Books; 5 Book chapters; 114 Articles in Proceedings; 5 Invited talks; 5 Talks

**Major Publications**

- [1555] The first practical guide to autonomic computing for advanced students and researchers - Philippe Lalanda, Julie A. McCann and Ada Diaconescu, ”Autonomic Computing - Principles, Design and Implementation”, Undergraduate Topics in Computer Science Series, Springer, due: May 31 2013, 298 pages, ISBN 978-1-4471-5006-0, web: http://www.springer.com/computer/swe/book/978-1-4471-5006-0
- [1547] J. Michaux, E. Najm and A. Fantechi, "Session types for safe Web service orchestration", Journal of Logic and Algebraic Programming. June 2013.
- [1534] E. Borde, P. H. Feiler, G. Haïk and L. Pautet, "Model driven code generation for critical and adaptive embedded systems", ACM SIGBED Review, vol. 6, n° 3, pp. 10:1 10:5.

- [1633], M. Lafaye, L. Pautet, E. Borde, M. Gatti, and D. Faura. Model driven resource usage simulation for critical embedded systems. In IEEE/ACM Design, Automation, and Test in Europe, Dresde, March 2012.
- [1575] Patrick Bellot and Loic Baud, Efficient Caching for Java Autonomous Web Application (Best Research Paper Award), in Proceedings of the 2nd Annual International Conference on Web Technologies & Internet Applications (WebTech 2012), Bali (Indonesia), April 2012.

**Impact and Attractiveness**

The group has a strong involvement in conference organisation. As initiators and organizers, P. Bellot (IEEE RIVF 2002 to 2010) and A. Diaconsecu (MAASC 2011, demo session SASO 2013); as PC chairs, I. Demeure and T. Robert (NOTERE 2011) and S. Vignes (NGMAST 2012); as hosts and organisers, E. Borde and E. Najm (Neptune 2010 to 2013), R. Sharrock and S. Tardieu (MobiCASE 2013); and as hosts and general chairs, E. Najm and T. Robert (ICSSEA 2008 to 2013); and as members of numerous program committees.

E. Najm was elected Chair of IFIP WG6.1 - Working Group 6.1 on Architectures and Protocols for Networked and Distributed Systems (2005 to 2011). He chaired the steering committees of FORTE and DAIS conferences during that period. He received the IFIP Silver Core Medal (September 2010). He is currently the chair of the steering committee of the DisCoTec cluster of conferences (regrouping Coordination, FORTE and DAIS and several satellite workshops).

E. Najm was invited for lectures and talks on the topic of Service Orchestration: WWV'11 (7th International Workshop on Automated Specification and Verification of Web Systems, Reykjavik), Seminar at KAIST (Dec 2011), Distinguished Lecture at Postech (Dec 2011), Seminar of INRIA Rennes (March 2010), seminar of MeFoSyLoma (April 2009).

**Interaction with Economic and Social Spheres**

The *Chaire*, ISIC, i.e., a joint lab relative to Complex Systems, was signed on November 7, 2011 for a duration of 3 years. It was first initiated and then held at Telecom ParisTech by Isabelle Demeure. Laurent Pautet is in charge since December 2012. The *Chaire* involves 4 industrial partners : Thales, Dassault Aviation, DGA (Direction Générale de l'Armement), DCNS and 3 ParisTech schools : Ecole Polytechnique, ENSTA ParisTech and Télécom ParisTech. The goal of this *Chaire* is to create a reference master program (Comasic) and a reference research in France regarding complex system architecture and engineering.

The projet *Investissement d'avenir* Cluster CONNEXION, http://www.cluster-connexion.fr, is a BGLE project (*Brique Générique du Logiciel Embarqué*) handled by EDF and joining a lot of industrial and academic partners. This program, with a duration of 4 years and a funding of 38 M€, has the aim of defining and validating an innovating architecture for the control command of nuclear power plant. Among the research works in which Telecom Paris is involved, we can cite the verification and validation of numerical systems, the intelligent display of numerical information and the resilient middleware for transporting the sensors and actuators components and for accessing Web services. The Cluster CONNEXION will be materialized by an experimentation laboratory on the EDF site in Chatou.

**Contributions to Higher Educations**

- Isabelle Demeure acted as "dean of education" of the Computer Science and Networks Department from 2009 to 2011.
- Isabelle Demeure was in charge at Telecom ParisTech of the COMASIC (Conception et Management des Systèmes Informatiques Complexes) master co-habilitated with Ecole

Polytechnique, Ecole Centrale, Supélec, INSTN and University Paris-Sud, from 2008 to 2012. Sylvie Vignes took over the responsibility in December 2012.

– Isabelle Demeure coordinated the conception of the ACN (Architecture of Complex Networks) master program with a team of Ecole Polytechnique and Telecom ParisTech until the proposal was submitted and accepted.
– Isabelle Demeure was awarded the title of “Chevalier” and Laurent Pautet and Sylvie Vignes the title of “Officier” in the “ordre des palmes académiques” (decoration for services to education), respectively in 2009, 2011 and 2013.

## 7.2 People

**Team leader** Isabelle Demeure (– January 2010), Elie Najm (January 2010 –).

**Faculty**

P. Bellot (FP), E. Borde (AP, 12/10–), I. Demeure (FP, 40% since 01/13), A. Diaconescu (AP, 10/09–), J. Hugues (AP, –09/09), P. Kuznetsov (FP, 02/13–), E. Najm (FP), L. Pautet (FP), T. Robert (AP, 09/09–), R. Sharrock (AP, 09/12–), S. Tardieu (AP, 80% since 02/13), S. Vignes (AP).

**PhD students**

Kh. Barbaria (10/04– 09/08), E. Borde (01/07–01/10), F. Cadoret (11/09–10/13), C. Castellanos (10/10–09/13), B. Debbabi (01/09–12/13), J. Delange (10/07–07/10), M. Franecki (01/10–07/11), S. Frey (10/10–09/13), O. Gilles (03/07–03/10), X. Grehant (11/06–03/10), H. Ha Duong (10/06–10/10), I. Hamid (02/05–05/08), X. Jean (05/11–04/14), Z. Kazi Aoul (01/10/03–18/01/08), M. Lafaye (09/09–11/12), G. Lasnier (09/08–09/12), V. Legout (03/11–02/14), L. Martin (04/05–05/08), Y. Maurel (01/08–12/10), J. Michaux (10/10–10/13), G. Nicolas (02/10–01/13), C. Ngo, (05/12–05/15), Gu. Paroux (10/04–09/09), I. Perseil (09/05–09/09), X. Renault (03/08–10/09), E. Richa (05/12–05/15), Y. Sun (01/13–12/15), K. De Vogeleer (02/12–02/15), B. Wang (10/10–05/12), B. Zalila (10/05–09/08), N. Zhao (03/12–03/15).

**Post-docs, engineers and sabbaticals**

Dragutin Brezak (Ing. Recherche, 03/13–03/16), Sébastien Gardoll (Ing. CNRS), Hoa HA DUONG (Post-doc, 03/12 –), Thomas MEGEL (Post-doc, 04/12 – 0413), Peter Feiler (sabbatical, 03/08 – 06/08). Nicola Costagliola (Ing. 11/10-06/12, jointly with RMS team), Salma Ktari (Post-Doc 08/11-12, jointly with RMS team). J.Hernando-Ureta (Ing.12/06-02/08 ).

## 7.3 Overview

It is an inescapable fact that we entered an era where the vast majority of current and future systems, designed and constructed to support human activities, applications and services, are in their various and versatile forms, predominantly characterized by being either distributed or embedded or jointly distributed and embedded. Avionics, Automotive, and the diverse real time systems, on one end; Smart Grids, Clouds, Mobile, Pervasive, Ad hoc or Sensor based, and the various open or large scale systems on the other end; all share at least one of these characteristics. Hence the major role played by Middleware which is a central and essential constituent in providing the functions required by these systems. Middleware is the middle software layer which lies between the hardware resources and the applications and which is responsible for providing proven and working solutions to the increasingly complex problems that are brought by the continuously evolving modern applications. Just to name a few, Middleware is responsible for bringing solutions for the management, distribution, communication, mobility, schedulability, power management and dependability of these systems. More importantly, Middleware is responsible for offering solutions that should operate jointly and in a well coordinated fashion (e.g., communication in the context of mobility, etc.). Hence this incurs an increased complexity in designing and engineering it.

Thus, the research conducted by the S3 group addresses the main challenges faced in designing and building the right middleware functions for the targeted application domains. The variety of the studied systems motivates a variety in the needed functions and in the associated engineering methods. The place of the middleware itself within these systems is dependent on the system categories and on the supported applications. In embedded systems, it is closer to the hardware and processing resources as higher control on these resources is needed to guarantee the real time and dependability constraints. In open or large scale systems, it is more loosely

coupled with hardware resources and more turned towards applications and services. But, nevertheless, in all system categories, rigorous model based approaches are sought in designing and developing middleware solutions in order to reduce development costs while improving quality and correctness.

Hence, the main challenges addressed by the S3 team tackle jointly the two dimensions: (i) Designing the right Middleware, i.e., Finding and developing the needed middleware functions and solutions; and (ii) Designing the Middleware right, i.e., Crafting rigorous methods to design and engineer these functions and solutions. Hereafter we describe these two dimensions in more detail, and in the next section, we present a selection of the findings of the group showing in each how these two dimensions were addressed.

## Designing the right Middleware

In many cases, when building applications for complex systems, the taken approach is to rely on middleware that are slightly modified versions of existing general purpose middleware for communications or scheduling... This approach is not satisfactory, and reaches its limitation especially in large scale, dynamic or highly constrained systems.

For instance, existing middleware technologies for Distributed Real time Embedded Systems (DRE) provide general purpose execution platforms targeting a large spectrum of application domains. Their complex design patterns induce large memory footprints and execution overheads but also produce systems that are difficult to analyze and verify. Also, the constraints and performance of the real system resources, in terms of processing power, are not suitably captured for the analysis in the design stages. This problem is aggravated with the introduction of multi-core processors, for which existing resource management and scheduling solutions are no more valid. Especially that these new types of resources need to be considered in the context of green computing and energy consumption constraints.

A first track in our research is precisely aimed at addressing these pitfalls. Our general goal is to produce highly configurable middleware factory correct by construction (i.e. with verifiable strong semantics). The factory has to rely on a flexible, modular and versatile architecture that allows for clear definition of its interfaces and internal structure to allow early decision making with respect to how specific application requirements will be matched. Such a capability would also help in building provably correct code generation processes. The factory should allow for the verification of its individual components as well as their sound integration in the delivered middleware.

Conversely, a number of situations require dynamically adaptable solutions. For example, in ad-hoc networks, nodes may dynamically enter and leave the network, hence the system must dynamically reconfigure itself; if the nodes are mobile, it should dynamically adapt to the evolving topology. Similarly, the number of devices involved in a pervasive system is a priori unknown and will change over time. Hence the system must dynamically adapt to the evolving configuration. We are therefore designing middleware that takes the dynamic nature of the target systems, as well as their specific capacity and mobility constraints into account. These are the goals pursued in designing middleware for MANets (Mobile Ad-hoc Networks) and in particular for sensor networks.

Going further, autonomic Computing refers to the self-managing (self-configuration, self-healing, self-optimization, self-protection) characteristics of (distributed) computing resources, adapting to runtime changes and hiding intrinsic complexity to operators and users. Hence the team works at developing software architectures and frameworks for facilitating the creation and maintenance of autonomic software systems. We mainly target large-scale, distributed and highly-dynamic systems, such as smartgrids, pervasive or enterprise applications.

## Designing the Middleware right

In order to support our activity in designing next generation middleware, new engineering methodologies have to be defined and experimented. We mainly focused on Model Driven Approaches to support this track of investigation on the engineering process itself. Our main endeavor is to define and build development processes, mainly relying on dedicated transformational tool chain, enabling the design, verification and production tasks to ensure application specific high-level requirements. Model Driven Engineering (MDE) is a key enabling technology: models are versatile as they can describe various software and system engineering artifacts: from requirements down to resources, platforms, application components, infrastructure components, etc.

For instance, the applicability of MDE to Distributed Real time Embedded sytems(DREs) remains one of the sharp edges to be addressed by the research community. One important issue that is still lacking is how to consider the behavior and properties of the resources of the target infrastructure in the early design and verification phases. Our aim is precisely to bring the potential benefits of MDE to reality. Thus, the sought and delivered tool chain has distinctive features that are hard to obtain in DREs. Cost reduction and higher quality are to be achieved by extending the automatic code generation capabilities to distributed code and to the automatic deployment of the system. System quality and correctness is to be enhanced by the use of formal verification of both the functional (deadlock/starvation non-appearance) and non-functional (schedulability, response time) properties of systems. The delivered process should address and integrate the different domains of expertise that are involved in building complex space and avionics systems, from requirements capture, through formal modeling and property assessment, down to to the final implementations.

Furthermore, we apply the model driven approach to the realm of web services. The problems to be solved are those of making autonomously defined and developed services interact safely. Another problem is how to compose and orchestrate services belonging to the Web and Telco domains. Addressing these issues will foster the development of the eco-system of open services.

## 7.4 Research Themes

### 7.4.1 Real Time and Embedded Systems

**Faculty** E. Borde, J. Hugues (–09/09), E. Najm (20%), L. Pautet, T. Robert.

**Highlights: Scientific Production** [1534], [1633], [1595], [1577], Several Chapters in SEE books on Embedded System modeling and verification, [1560, 1556, 1559]

**Highlights: Impact**

- Collaboration with SEI developing software engineering methods and tools in relation with AADL. (3 visits to SEI, 2 students and one assistant professor). In complement to this action, we develop plugins for code generation (RAMSES) and language annex support to enhance SEI toolkit (OSATE), and a support for AADL behavioral annex with another plugin.
- Contributor to the SEIDO Lab on Cyber-security and Dependability with EDF R&D.
- Organization of standardization meetings related to avionics (AADL, DO-178C). Major contributor in AADL standardization process (first author of ARINC 653 AADL annex)
- Production of several teaching text-book [1552, 1553]
- Organization of several conferences and congresses: NEPTUNE'2013, ETR'2009,
- Member of the scolarly society Mefosyloma

**Highlights: Interactions with Society**

- The RAMSES toolkit has been officially released as an open-source contribution (with release of sources at the APP - Agence de Protection des Programmes -
  Ref: IDDN.FR.001.160014.000.S.P.2012.000.20000) and it is now evaluated for a technology transfer with the company Ellidiss. Collaboration with ELLIDISS is now engaged on maturing and industrialisation of the RAMSES toolkit.

  RAMSES is based on OSATE (Open-Source AADL Tool-Suite Environement), developed by the CMU/SEI (Carnegie Mellon University/Software Engineering Institute), who uses RAMSES now to automate non-regression testing of OSATE.
- One of the major academic contributors to IRT SystemX in projects on embedded system for automotive (ELA)and railway systems (FSF).

**Software engineering for high-integrity embedded software systems** benefited for years from advances in both execution platforms design (including middleware technologies or operating systems) and in model driven engineering (including modeling approaches and formal analysis). We developed our research in both fields in order to ease system design [1534], development [1542] and validation [1595]. In the last two years, we focused on approaches which strongly couple execution platform configuration with model driven engineering techniques in order to address difficult issues raised by different domain specific applications (avionic, railways, automotive) [1687].

We applied our approaches to design a highly configurable execution platform POK ([1557, 1689], `http://pok.safety-critical.net/`). We designed this operating system to enforce both safety ([1595]) and security [1597] properties in partitioned systems such as required in ARINC 653 and MILS standards. Our purpose was to provide platforms and tools to largely automate the usually complex process of adapting or configuring the middleware layer to the system requirements. To demonstrate the reliability of this design, the COUVERTURE project tested POK to ensure MC/DC code coverage properties such as required in DO-178C [1548]. We recently continued this work modeling the internal architecture of commodity multicore processors to guide the design of virtual machines with real-time scheduling capabilities [1603]. Such virtual machine manager aims at providing a deterministic implementation of an ARINC 653 kernel on top of a multi-core processor which interconnection introduces non-determinism due to spacial and temporal resources conflicts. Beside these activities on operating system design, we also investigate

a communication and execution model called “periodic delayed communication” to design middleware layers that lower the complexity of schedulability analysis [1583]. This promising approach is currently experimented on different execution platforms such as POK.

We historically contributed for years to the state-of-the-art in the Model Driven Engineering for embedded and safety critical systems [1542]. Several methods and tools were proposed to leverage issues related to the complexity of integrating software on embedded execution, especially in the avionics domain, [1595, 1593, 1537]. Our core idea was to adapt and configure the code generation strategies according to the specific software and hardware deployment requirements (processors, memory, kernel, variables, function...) in order to optimize the wrappers in terms of execution time or memory footprint. This approach has been successfully applied to design and deploy embedded systems with reliable and timely adaptive behavior [1534, 1580]. We developed these ideas contributing to the standardization of an architectural description language dedicated to design and model embedded systems, AADL. A major annex to the Architectural and Analysis Description Language was proposed and accepted, namely the ARINC653 annex `http://standards.sae.org/as5506/2/`. This annex has been reused and adapted for MARTE, the UML profile. Several contributions concerning behavioral models were proposed [1636, 1635, 1638] to illustrate how it can improve system deployment and validation tasks. This point has been investigated further in considering optimizing software architectures [1624] with to respect system schedulability. It leads to consider optimization methods, namely linear programming, to select task set schedule optimizing time spent in context switches or power consumption [1659]. This work is part of actions carried out in the Chaire of Complex Systems.

**Model Driven Engineering Process Design** The integration of the different contributions presented in the previous paragraph have to be considered in parallel to design processes. Indeed, one of the complexity of designing safety critical embedded systems lies in (i) the heterogeneity of requirements, and (ii) the difficulty to assess precisely the validity of these requirements.

The heterogeneity of requirements leads to several challenges we have highlighted in [1642].In particular, the necessity to trace design decisions and their impact on non-functional requirements is an important challenge in model driven engineering. A practical answer to such a problem is to automate the selection and composition of design patterns: well known solutions to classical design problems. In the scope of model driven engineering, we have shown how to implement design patterns for safety and security as model transformations [1584]. We also explained in [1582] how to implement design patterns to improve the precision of model based schedulability analysis.

In order to motivate design decisions, analysis results have to formally assess the compliance of a design with respect to requirements. An interesting paradox here is that: the more detailed the design is, the more precise is the analysis result. But the more difficult is the analysis.

We have proposed a pragmatic solution to this problem when it comes to evaluating execution time of software application: in [1633] and [1695], we use simulation techniques (using SystemC) to evaluate the timing properties of a software application.

Another solution we proposed is to implement embedded systems design as a workflow of endogenous model transformations, i.e. AADL to AADL model transformations (the work was initiated and conducted in several PhD thesis : [1693, 1701, 1700, 1696]. Thus, analysis that could be executed on the input model can also be executed on the output model (typically providing a greater level of details). An AADL to AADL model transformation framework has thus been prototyped in a tool chain called RAMSES (Refinement of AADL models for Synthesis of Embedded Systems). This tool chain has been used for the integration of schedulability, safety and security design patterns [1583, 1582, 1584] and is now experimented for automating the selection and composition of design patterns [1642]. RAMSES has been officially released as an open-source contribution (with release of sources at the APP - Agence de Protection des Programmes -) and it is now evaluated for a technology transfer. This work will be continued in the scope of the IRT-SystemX, applying our techniques to a new application domain: trains design.

### 7.4.2 Distributed Systems and Services

**Faculty**

P. Bellot, I. Demeure (60%), A. Diaconescu, E. Najm (80%), R. Sharrock, S. Tardieu (80%), S. Vignes.

**Highlights: Scientific Production** [1543], [1536], [1575], [1555], [1547].

**Highlights: Impact**

- Public research funding: MEDICAL Project (FUI 10) - *Middleware Embarqué D'Intégration de Capteurs et d'Applications pour les services et L'habitat*; Pôle de compétitivité MINALOGIC; 3 years (03/01/2011 - 31/12/2013); Financed by the Conseil Général de l'Isère and by the OSEO; Overall project financing: 1.854.000 Euro; Partners : Orange R&D, ScalAgent, LIG / Universitï¿½ de Grenoble and Télécom ParisTech. ANR-VERSO DIAFORUS (Middleware for sensor networks), 2009-2012. STREP IST-POPEYE (Middleware for MANets), 2006-2008. ANR-RNRT Transhumance (Middleware for P2P services over MANets, 2006-2008. MOTELI is a Cap Digital project dedicated to the development of an open source orchestration engine for Telecommunication Services, 2009-2013. Public research funding: Digital Society Institute Project (2013-2016 and 2016-2019), 1,75 million euros financed by the IDEX Paris-Saclay, S3 is involved in the INTERCO-QUALIA Subproject (Quality of eLife (QeL) : autonomic management of resources across a neighborhood of smart houses.
- A. Diaconescu is Editorial board member of the Technology and Computer Sciences Journal (TSI - "Technique et Science Informatiques"), 2013-2016, (http://tsi.revuesonline.com)
- Isabelle Demeure acted as an expert for Agence Nationale de la Recherche (ANR) Télécommunication program (VERSO) 2008, Software program (ARPEGE) 2008 and 2009. and also as expert for DGRI/MEI international programs (2008-2012). Elie Najm acted as an Expert for Agence Nationale de la Recherche (ANR) ASTRID 2012 programme and also as expert for the Comité Consultatif Régional de la Recherche et du Développement Technologique d'Aquitaine (CCRRDT) for the year 2011.
- E. Najm was elected and acted as Chair of IFIP WG6.1 - Working Group 6.1 on Architectures and Protocols for Networked and Distributed Systems, from 2005 to 2011. He chaired the steering committees of FORTE and DAIS conferences during that period. He received the IFIP Silver Core Medal (September 2010). He is currently the chair of the steering committee of the DisCoTec cluster of conferences (regrouping Coordination, FORTE and DAIS and several satellite workshops).

**Highlights: Interactions with Society** *Chaire* Complex Systems (initiated and held by Isabelle Demeure. In charge since December 2012 : Laurent Pautet). A Chaire (joint lab) relative to complex systems was signed on November 7, 2011 (duration 3 years). It involves 4 industrial partners : Thales, Dassault Aviation, DGA (Direction Générale de l'Armement), DCNS and 3 ParisTech schools : Ecole Polytechnique, ENSTA ParisTech et Télécom ParisTech. The goal of this *Chaire* is to create a reference master program and a reference research in France regarding complex system architecture and engineering.

The projet *Investissement d'avenir* Cluster CONNEXION, http://www.cluster-connexion.fr, is a BGLE project (*Brique Générique du Logiciel Embarqué*) handled by EDF and joining a lot of industrial and academic partners. This program, with a duration of 4 years and a funding of 38 M€, has the aim of defining and validating an innovating architecture for the control command of nuclear power plant. Among the research works in which Telecom Paris is involved, we can cite the verification and validation of numerical systems, the intelligent display of numerical information and the resilient middleware for transporting the sensors and actuators components and for accessing Web services. The Cluster CONNEXION will be materializd by an experimentation laboratory on the EDF site in Chatou.

**Main results**. We have explored various aspects of distributed systems and services. These can be organized in four contributions: (1) Decentralised architectures and frameworks for autonomic distributed systems ; (2) Designing the right middleware and algorithms for ad-hoc networks ; (3) Designing verifiable service orchestrations ; and (4) middleware for the control command, monitoring & technical supervision of power plants.

**Decentralised architectures and frameworks for autonomic distributed systems.** For this expertise, we identify and document concepts and software artifacts that are reusable (architectures, models, languages, middleware, frameworks, patterns, algorithms or protocols) for the design of autonomic systems. Those systems need to meet functional constraints brought by applicative domains (energy consumption reduction, guaranteeing comfort zones) and non functional constraints (scalability, robustness, quality of service, quality of experience, adaptability, heterogeneity, safety). A new research field being explored starting in 2013 is the final usage of these autonomic systems in terms of human needs or acceptability.

Self-management capabilities are anyway essential to the success of complex computing systems [1555]. Yet, developing and maintaining such capabilities raises significant scientific and technological challenges [1611], [1608], [1563], [1536], [1647] and [1645]. We have concentrated so far on two main sub-projects to tackle these challenges. The first one studies solutions based on the static and dynamic integration of self-management functions, or services, such as monitoring, analysis, planning, execution, entire feedback loops and various combinations of the above [1611], [1608], [1536], [1647], [1646] and [1645, 1698]. They include both hierarchical and completely decentralised architectures. Targeted applications include smart homes and micro smart-grids [1610], [1606]. A simulation platform and smart-home model have been developed in the team for testing and evaluation purposes. The second subproject proposes a decentralised solution for self-managing the lifecycle of large-scale distributed applications, running in dynamic and heterogeneous environments (Cube project). It adopts a multi-agent approach to self-grow, self-adapt and self-repair applications that must meet constraints predefined via an architectural model [1563], [1681], [1600]. More recently, we have started to investigate alternative approaches that rely on rules and evolution-oriented learning processes rather than on predefined architectures [1672].

**Progress in new technologies such as ad-hoc networks and sensors development** bring new challenges in the field of middleware and distributed algorithms. For example, distributed systems built on top of ad-hoc networks, must adapt to the evolving topology of such networks. They must also address variable connectivity of such networks. When the network involves limited capabilities (including battery power) such as sensors and smartphones, they must also take these capabilities into account. Over the past 5 years we have developed middleware solutions and distributed algorithms addressing these constraints. Several results have been obtained. We designed and developed an energy-aware publish/subscribe middleware robust to the frequent disconnections that occur in mobile ad-hoc networks when participants are moving. At the time when this research was conducted, we could not find an equivalent solution. Another contribution was the design of original distributed algorithms for data sharing in stable neighborhoods in such networks, using semantic information to do statistical replication of data over the participant devices ([1543, 1620, 1618, 1619, 1627, 1538, 1613, 1644] ). We pursued with the design of a publish/subscribe based middleware for a wireless sensor network taking into consideration the limited capabilities of the network nodes as well as the limited energy (the sensors are battery operated). We designed solutions enabling the choice of the proper number of publish/subscribe brokers as well as their placement ([1585, 1591, 1587, 1588]).

With the Internet of Things movement, sensors will spread out in a variety of application fields. we proposed a new distributed adaptive traffic lights control algorithm for multiple intersections based on the use of a wireless sensor network. We showed that this algorithm is more efficient in terms of waiting time than a predetermined solution, but also than adaptive solutions. We also showed that the vehicle throughput and the queues size generated by our solution are better than in traditional methods [1590, 1589, 1604]. Finally, with members of the regal team at UPMC we

investigated algorithmic solutions for information dissemination in large-scale ad-hoc networks and proposed a new criterion named "effectual fanout" for the comparative study of epidemic algorithms over a variety of random topologies [1623, 1622].

**Verifiable Service Orchestration.** We considered the issue of safe interaction of orchestrated loosely coupled web services. Such services may interact in an inappropriate and incompatible manner resulting in run-time errors. Interaction errors manifest themselves when unexpected messages or when messages containing values with unexpected types are received. One approach to solve this issue is based on defensive programming and involving complex exception handling mechanisms. We investigated other means to mitigate this problem using a typing approach whereby services that are checked to be well typed at compile time are guaranteed to be interaction safe at run-time. We first elaborated the theoretical basis of our typing approach on an a small language [1602] defined as a case study. Then we revisited two well known orchestration languages in different contexts. *First*, we considered the industry standard WS-BPEL in view of its usage as a web service orchestrator. We enhanced WS-BPEL with the session paradigm by making sessions become first class citizens [1649, 1547]. During a session, a client and a service can engage in a complex series of interactions. We introduced session types in order to prescribe the correct orderings of these interactions. Service providers must declare their provided and required session types. We defined also a typing algorithm that checks if an orchestrated service behaves according to its declared provided and required types. Using behavioral subtyping as a compatibility relation defined on session types, we show that any collection of well typed service partners with compatible session types are interaction safe, i.e., no message comes unexpected to any of the involved partners. Our results were also extended to the case of services communicating over unreliable channels [1652]. *Second*, we considered the Orc process algebra in view of its usage as a service orchestration language in a converged Web and Telecom context [1653, 1654]. We tackled the issue of safe orchestration by defining OrcT, a type enhanced extension of the language based on session types which uses the ReceiveSend subset of WSCL. We formalize the notion of ideally typed execution environment, i.e., an environment populated with well typed entities, i.e., sites, session-stateful objects and data-stateless objects. We defined a decidable type system and made a major step towards proving that all well typed OrcT programs exhibit no runtime errors when run in well typed execution environments [1699]. Furthermore, with our partners of the Moteli project, we conceived and developed an open orchestration platform for converged services based on the formally defined orchestration language Echarts (ATT) [1651].

**Middleware for the control command, monitoring & technical supervision, of power plants.** In this axis, after achieving a comprehensive state of the art, we conducted evaluations on: CORBA (Common Object Request Broker Architecture), OMG DDS (Data Distribution Service), NGSON (Next Generation Service Overlay Network), GSN (Global Sensor Network), SOCAM (Service-Oriented Context-Awareness Middleware), OPC UA (OLE for Process Control Unified Architecture) and a few others. A list of requirements for the sought middleware has then been proposed. Some of the most important requirements for the power plants include: real-time support, context management, distributed architecture and fault-tolerance. To address those issues a generic model for the middleware has been made and the choice has been made to base the middleware on OPC UA, a well-defined standard in industrial control environment. OPC UA has the advantages of supporting real-time monitoring, a detailed working framework and excellent interoperability due to the use of services. However a lot more directions of research are being conducted to overcome the drawbacks of OPC-UA including: distributed architecture to reduce network load, context management in order to quickly adapt to the situation and a fault-tolerance design to increase stability. The research currently focuses on the design of a distributed architecture with its issue on service discovering using semantic description. The semantic searching mechanism will be based on the resilient DHT of ROSA, a distributed overlay network with self-management and self-healing capabilities created at Telecom Paristech.

# 7.5 Achievements (Appendix 6)

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[1666] X. Renault, J. Hugues, and F. Kordon. Formal Modeling of a Generic Middleware to Ensure Invariant Properties. In *10th Formal Methods for Open Object-based Distributed Systems (FMOODS'08)*,, volume LNCS, pages 185–200, Oslo, Norvège, June 2008.
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### Invited Talks

[1675] E. Najm. Service orchestration with orcharts and typecharts. In *MeFoSyLoMa*, Paris, Apr. 2009.
[1676] E. Najm. Service orchestration with orcharts and typecharts. In *Seminaire INRIA*, Rennes, France, Mar. 2010.
[1677] E. Najm. Enforcing compatibility between web services. In *Invited Seminar at KAIST*, Daejeon, South Korea, Dec. 2011.
[1678] E. Najm. Why don't our services get along? In *Distinguished Lectures Series - Postech*, Pohang, South Korea, Dec. 2011.
[1679] E. Najm. Controllability of orchestrated sessions. In *Invited Talk - WWV'11, 7th Int'l Workshop on Automated Specification and Verification of Web Systems*, Reykjavik, Iceland, June 2011.

### Talks in Conferences Without Proceedings

[1680] P. Bellot, M. Hu, F. Vormer, V. DUONG, and Y. Wang. Spatial, temporal, and grouping behaviors in controller communication activities. In *Ninth USA/Europe ATM R&D Seminar*, page 10, Berlin, Germany, June 2011.
[1681] A. Diaconescu, D. Bassem, and P. Lalanda. Self-growing software from architectural blueprints.

In *Morphogenetic Engineering Workshop (MEW), European Conference on Artificial Life (ECAL)*, Paris, France, Aug. 2011.

[1682] J. Moreira, C. Ribeiro, J.-M. Saglio, and M. Scholl. A model of approximations for representing time-varying multidimensional data. In *Data Engineering Workshop, 2008. ICDEW 2008. IEEE 24th International Conference on*, pages 113–120, Cancun, Apr. 2008. ISBN 978-1-4244-2161-9.

[1683] E. Najm and K. Sbata. Une plateforme pour une orchestration sûre de services convergents. In *Interopérabilité des plate-formes mobiles ; intergiciels mobiles*, Paris, Apr. 2013.

[1684] V. Oria, T. T. Pham Quang, and J.-M. Saglio. Webograph: A selective publication model for bloggers. In *IADIS Web Based Communities 2008 (WBC 2008) Conference*, Amsterdam, Nederland, July 2008.

### 7.5.2 Public fundings

| Period | Project details | Funding | Principal investigator | Amount (k€) |
|---|---|---|---|---|
| 2008-2009 | ESA-ESTEC-ASSERT - LAB Activities - Improvement and Documentation of the Assert Virtual Machine | Bilatéral public - Organisme public/Etudes et recherches | J. Hugues | 29 |
| 2008-2010 | COUVERTURE - COUVERTURE NON INTRUSIVE D'APPLICATIFS CRITIQUES | Subventionné National - Autre ministère/Etudes et recherches | J. Hugues | 73 |
| 2008-2012 | DIAFORUS - Middleware pour réseau de capteurs | Subventionné National - ANR | I. Demeure | 230 |
| 2010-2013 | MOTELI2 - Moteur Telecom Logiciel Libre | Digiteo | E. Najm | 213 |
| 2010-2013 | PARSEC - Atelier logiciel pour systèmes temps rél critiques | | L. Pautet | 130 |
| 2011-2013 | MEDICAL - Middleware pour réseaux de capteurs dans l'habitat | Subventionné National - FCE/Etudes et recherches | A. Diaconescu | 138 |
| 2011-2014 | HADOPI-MEDEI - Mesure et étude des dynamiques des flux des échanges sur internet | Bilatéral public - Entreprise publique/Etudes et recherches | P. Bellot | 205 |
| 2012-2016 | Cluster CONNEXION - Conception et Développement pour le Côntrole Commande de Centrale Nucléaire | Investissement d'avenir | P. Bellot | 1126 |
| 2012-2015 | Thèse Karel de Vogeleer - Optimisation de l'énergie dans les logiciels de communication | IMT - Futur et Rupture | | 106 |
| 2013-2015 | CORAC - Développement de composants de contrôle de flux dans les architectures avioniques | Grand Emprunt | T. Robert | 155 |
| 2013-2014 | PISCO - Plateforme d'Intégration de Services de COnfiance | Subventionné National - Etudes et recherches | J.L. Danger et T. Robert | 75 |
| 2013 | Industrialisation de la plateforme Ramses | IMT - Futur et Rupture | E. Borde | 6 |

### 7.5.3 Private fundings

| Period | Project details | Funding | Principal investigator | Amount (k€) |
|---|---|---|---|---|
| 2009 | EUROCONTROL - INO | Euroncontrol | P. Bellot | 10 |
| 2009-2012 | modélisation pour sysèmes avioniques | Thales - CIFRE | L. Pautet | 45 |
| 2010-2013 | Convergence des services SOA et Telecom | Orange-CIFRE | E. Najm | 30 |
| 2010-2013 | Architecture décentralisées pour systèmes autonomiques à objectifs multiples | EDF-CIFRE | I. Demeure | 45 |
| 2011-2015 | Chaire systèmes complexes | | I. Demeure | 450 |
| 2011 | Evaluation des langages d'orchestration de services | Orange | E. Najm | 30 |
| 2011-2014 | Architectures logicielles à composants pour sysèmes embarqués | Thales-CIFRE | L. Pautet | 28 |
| 2011-2014 | HYPERVISEURS POUR MULTICOEUR PREDICTIBLES CERTIFIABLES | Thales-CIFRE | L. Pautet | 45 |
| 2011-2014 | Bibliothèque de transformation de modèles pour systèmes avioniques | ADACORE-CIFRE | L. Pautet | 45 |
| 2012-2015 | Middleware intelligent et autonome pour l'orchestration des services contextuels | EDF-CIFRE | P. Bellot | 45 |

### 7.5.4 Patents and softwares

- Patent number 11 01017 entitled "Procédé de modélisation, simulation et évaluation en avance de phase d'une plate-forme de calcul" registered on 04/05/2011 by Laurent Pautet from Télécom ParisTech and Marc Gatti, Michael Lafaye and David Faura from Thales.
- RAMSES, is an open source toolkit and a model driven architecture framework dedicated to integrate design patterns as a set of AADL-to-AADL model transformation. It is used for the integration of schedulability, safety, and security design patterns [1583, 1582, 1584] and is now experimented for automating the selection and composition of design patterns from non-functional requirements. It has been officially released as an open-source contribution (with release of sources at the APP - Agence de Protection des Programmes - Ref: IDDN.FR.001.160014.000.S.P.2012.000.20000) and it is now evaluated for a technology transfer with the company Ellidiss. Collaboration with ELLIDISS is now engaged on maturing and industrialisation of the RAMSES toolkit.

  RAMSES is based on OSATE (Open-Source AADL Tool-Suite Environement), developed by the CMU/SEI (Carnegie Mellon University/Software Engineering Institute), who uses RAMSES now to automate non-regression testing of OSATE.
- AADL-BA-FrontEnd is a plugin of the OSATE framework. It is the first implementation of an AADL Behavior Annex editor integrated in OSATE. It was officially released as an open-source project and is used by several national and international entities such as INRIA, Thales, Ellidiss, and Rockwell Collins. As a result of prototyping the Behavior Annex front end, S3 was very active in the standardization process of the AADL Behavior Annex.
- POK (http://pok.safety-critical.net/) provides a real-time kernel which tends to be compliant with many standards of real-time embedded systems. At this time, it supports the main features of ARINC653, an avionics standard for safety-critical systems (in particular time and space partitioning to isolate different partitions) and MILS, an approach to build real-time embedded systems (in particular isolation of devices and partitioning services). This middleware is the only open-source ARINC 653 implementation and several publications cited POK for their experiments (for instance, "A Time-composable Operating System" and authored by Andrea Baldovin, Enrico Mezzetti and Tullio Vardanega).

- Ocarina (ocarina.enst.fr) is a AADL toolsuite used to analyze, instantiate and optimize AADL models. It also has code generation features to automatically create code from AADL models targeting real-time embedded operating system. In the period of time from 2008 up to now, we added to this tools suite a C code generator (for the PolyORB-HI-C runtime), the code generation for ARINC653 compliant systems (for the ?POK runtime) and we enforced the support of both versions of the AADL (version 1 and 2). Ocarina was used in both industry and research domains and was selected with success as a valid prototype platform for several projects (ESA project TASTE, ANR Flex-eWare and so on).
- PolyORB-HI is an AADL runtime used by Ocarina code generators (for several programming languages). It was initially an Ada Ravenscar compliant. It runs on many operating systems (Linux, FreeBSD, Solaris, RTEMS). It has a low complexity (most of the algorithms have a complexity of O(1)) and a reduced memory footprint. During the period from 2008 up to now, we designed PolyORB-HI-C and PolyORB-HI-Java which complies with the Ada Ravenscar limitations (in order to enforce an analyzable execution model). The PolyORB-HI-C was used in the ANR Flex-eware project.
- Cube (http://cube.imag.fr) is a decentralised framework for self-growing and self-managing large-scale, distributed, service-oriented applications. It relies on a multi-agent approach to automatically instantiate, interconnect and adapt software services so as to obtain applications that conform to a formally-defined architectural template. Cube is currently under development in collaboration with the Adĺe team at University of Grenoble. It is partially funded by the Medical research project (Minalogic) and has been the subject of several research publications [1563], [1681], [1600].
- The POPEYE middleware was designed in the IST-POPEYE project. The main goal of POPEYE is to provide the concepts, methods and core services for next generation mobile collaborative working environment with emphasis on P2P information exchange model in the environment of heterogeneous mobile ad hoc networks (GNU Library or Lesser General Public License version 2.0 - LGPLv2).
- Transhumance is a middleware for peer-to-peer applications on mobile ad hoc networks. It provides full communication and deployment facilities (enhanced transport layer, events and groups management systems). Transhumance was designed and prototyped in the ANR Transhumance project (GNU Library or Lesser General Public License version 2.0 - LGPLv2).

## 7.6 PhDs (Appendix 7)

### 7.6.1 Defended PhDs

[1685] K. Barbaria. *Architectures intergicielles pour la tolérance aux fautes et le consensus.* PhD thesis, Telecom ParisTech, Sept. 2008.

[1686] L. Baud. *ROSA: Un Réseau de Recouvrement Adaptable, Auto-Organisant et Extensible*. PhD thesis, Télécom ParisTech, Apr. 2010.

[1687] E. Borde. *Configuration et Reconfiguration des Systèmes Temps-Réel Répartis Embarqués Critiques et Adaptatifs*. PhD thesis, Télécom ParisTech, Dec. 2009.

[1688] M.-D. Dang. *Quantum Primitives for Secure Two-party Computations and Entanglement Attacks*. PhD thesis, TELECOM ParisTech, ENST08D001, Apr. 2008.

[1689] J. Delange. *Intégration de la sécurité et de la sûreté de fonctionnement dans la construction d'intergiciels critiques*. PhD thesis, LTCI, July 2010.

[1690] O. Gilles. *Vers une prise en compte fine de la plate-forme cible dans la construction des systèmes temps réel embarqués critiques par ingénierie des modèles*. PhD thesis, LTCI, Apr. 2010.

[1691] X. Gréhant. *Allocation efficace et non contraignante de ressources de grilles de calcul à l'aide d'environnements virtuels*. PhD thesis, Télécom ParisTech, Sept. 2010.

[1692] H. Ha Duong. *Partage de données en mode pair à pair sur réseaux mobile ad hoc*. PhD thesis, Télécom ParisTech, Sept. 2010.

[1693] I. Hamid. *Automatic Code Generation and Verification of Hard Real-time Systems*. PhD thesis, Telecom ParisTech, May 2008.
[1694] Z.-I. Kazi-Aoul. *Une Architecture orientée services pour la fourniture de documents multimédia composés adaptables.* PhD thesis, Télécom ParisTech, Jan. 2008.
[1695] M. Lafaye. *Ingénierie des modèles pour la conception de plates-formes temps-réel critiques avioniques*. PhD thesis, LTCI, Nov. 2012.
[1696] G. Lasnier. *Une Approche Intégrée pour la Validation et la Génération de Systèmes Critiques par Raffinement Incrémental de Modèles Architecturaux*. PhD thesis, LTCI, Aug. 2012.
[1697] C. Le-Quoc. *Autour des réseaux quantiques et des modèles de relais pour la clé quantique*. PhD thesis, Télécom ParisTech, Oct. 2009.
[1698] Y. Maurel. *CEYLAN : Un canevas pour la création de gestionnaires autonomiques extensibles et dynamiques*. PhD thesis, UNIVERSITE DE GRENOBLE, Dec. 2010.
[1699] G. Nicolas. *Vers une Orchestration Convergente et Sûre des Services Web et de Télécommunication*. PhD thesis, Telecom ParisTech, June 2013.
[1700] I. Perseil. *The C-Method, a Software Engineering Method for Avionic Real-time Systems*. PhD thesis, LTCI, Sept. 2009.
[1701] B. Zalila. *Configuration et déploiement d'applications temps-réel réparties embarquées à l'aide d'un langage de description d'architecture*. PhD thesis, École Nationale Supérieure des Télécommunications, Nov. 2008.

### 7.6.2 Ongoing PhDs

- B. Debbabi (/09 - 12/13), Cube: un canevas autonomique décentralisé et orienté modèle pour l'autogestion de systèmes répartis. Application á la médiation de données.
- C. Castellanos (10/10–09/13), Conception de systèmes partitionnés sûrs et sécurisés à partir d'une modélisation orientée composants
- C. Ngo (05/12–05/15), Middleware intelligent et autonome pour l'orchestration des services contextuels
- Y. Sun (01/13–12/15), Stratégie d'intégration de processus modulaires d'ingénierie des exigences. Application au Contrôle Commande nucléaire
- N. Zhao (03/12–03/15), Mesure et étude des dynamiques des flux et des échanges sur Internet
- X. Jean (05/11–04/14), Maîtrise de la couche hyperviseur sur les architectures multicoeur COTS dans un contexte avionique
- E. Richa (05/12–05/15), Définition formelle et implantation de bibliothèques de transformations de modèles d'architectures pour systèmes avioniques partitionnés temps-réel
- V. Legout (03/11–02/14), Méthode de conception de systèmes et d'applicatifs temps réels embarqués pour une gestion optimale d'énergie
- F. Cadoret (11/09–10/13), Intégration de politiques de sécurité et de sûreté de fonctionnement pour la modélisation, la vérification et la génération de systèmes critiques
- S. Faye (10/11–09/14), Modèles et algorithmes pour le contrôle du trafic routier urbain par un réseau de capteurs
- R. Hu (10/11–09/14), Un système adaptif de publication-abonnement pour des réseaux mobiles
- S. Frey (10/10–09/13), Architectures décentralisées pour systèmes autonomiques à objectifs multiples
- J. Michaux (10/10–10/13), Orchestration sûre de services web
- K. de Vogeleer (02/12 – 02/15), Optimisation de l'énergie de logiciels communicants

# Chapter 8

# Interaction, Cognition and Complexity (IC2)

## 8.1 Executive Summary (Appendix 1)

**Team leader:** G. Hebrail (–12/10), F. Rossi (01/11–08/11), T. Abdessalem (09/11–)

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**Initial staff:** 9 Professors; 1 Research Scientist; 6 PhD Students.

**Staff who left:** 4 Permanent Staff (164 months) ; 13 PhD Students (441 months) ; 9 Postdocs (146 months).

**Staff who were hired:** 1 Associate Professor (Postdoc at Max-Planck-Institut für Informatik, PhD. at Université Paris-Sud) recruited on June 2008, 1 Associate Professor (Postdoc at Université Paris-Sud, PhD at Georgia Institute of Technology) recruited on August 2011, 1 Associate Professor (Senior researcher at Max-Planck-Institut für Informatik, PhD. at La Sapienza University) recruited on October 2011.

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**Scientific Highlights**

- Extensive research on probabilistic XML databases [1750], has made our group the leader in the area: this includes modeling foundations [1704, 1708, 1705, 1767], the theory of query answering [1760, 1829, 1710, 1896] and updates [1828], systems aspects [1875, 1879, 1880], and applications to mining [1749], corpus summarization [1762, 1763], or uncertain version control [1758, 1771].
- We have explored the role of Kolmogorov complexity in the definition of relevance and interest. This new approach to cognitive modeling is based on the minimum-length description principle (simplicity theory, cf. `www.simplicitytheory.org/`). It is potentially crucial for intelligent language-based interaction and Web search.
- Our basic and applied work on gestural interaction has led both to the revision of the traditional theoretical approach to pointing [1721] and to the design of innovating forms of interaction, whose applications span from the very large [1838] to the very small [1860].
- We introduced new principles to enhance the discovery, learning and recall of commands, leveraging on incidental learning through repetition [1725] and on language-based mnemonic associations [1871]. We obtained decisive experimental evidence showing the efficiency of our novel approach.
- We have developed an expertise in domain-focused Web information extraction, from deep Web extraction aspects [1876, 1783, 1850, 1784, 1855] to the extraction of objects from structured Web pages [1702, 1799] to extraction of content generated by content management systems [1853, 1809].

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**Scientific Production** 31 Journals; 23 Articles in $A^+$ conferences [1]; 3 Books; 20 Book chapters; 112 Articles in other Conference Proceedings; 9 Invited talks; 15 Talks in Conferences without Proceedings.

1. CHI, UIST, SIGMOD, PODS, VLDB, CogSci

**Major Publications**

- G. Gottlob and **P. Senellart**. Schema mapping discovery from data instances. *Journal of the ACM*, 57(2), January 2010. [1720].
- **B. Cautis**, A. Deutsch, N. Onose, and V. Vassalos. Querying XML data sources that export very large sets of views. *TODS (Transactions on Database Systems)*, 36(1), January 2011. [1712].
- S. Abiteboul, **E. Kharlamov**, W. Nutt, T.-H. H. Chan, and **P. Senellart**. Capturing continuous data and answering aggregate queries in probabilistic XML. *TODS (Transactions on Database Systems)*, 36(4), March 2011.
- **A. Roudaut**, **E. Lecolinet**, **Y. Guiard**. MicroRolls: Expanding Touch-Screen Input Vocabulary by Distinguishing Rolls vs. Slides of the Thumb. CHI 2009. [1870],
- **S. Malacria**, **E. Lecolinet**, **Y. Guiard**. Clutch-Free Panning and Integrated Pan-Zoom Control on Touch-Sensitive Surfaces: the Cyclostar Approach. CHI 2010. [1838],

**Impact and Attractivity**

**Editorial boards and organizational responsibilities:** Y. Guiard appointed associate editor of *ACM TOCHI* in 2009, P. Senellart information director of the *Journal of th ACM*, E. Lecolinet elected in Sept. 2012 at the "Comité national de la recherche Scientifique" (CoNRS, section 07), organization of SIGMOD Programming Contest 2010, participation to the organization of CHI'13.

**Best paper awards** at BCS HCI'12 [1857] and ACM UIST'11 [1806].

**Close international collaborations** with teams in the US (UC San Diego, Google), Asia (NUS Singapore, RUC Beijing), Europe (University of Oxford, Aarhus University, TU Berlin, Max-Planck-Institut für Informatik, Yahoo!) and Israel (Tel Aviv University).

**Invited lectures and tutorials:** 73 invited talks for permanent personnel of the group (excluding ordinary talks in conference and workshops, internal seminars, project meetings)

**Steering committees:** ACM SIGCHI Paris, DigiCosme scientific committe, IHM permanent Board, IMT RT4, AFIHM, LTCI lab Council.

**Interaction with Economic and Social Spheres** Two joint laboratories: BILab with EDF R&D until 2011, and UBIMEDIA lab with Alcatel-Lucent Bell Labs since 2008. Radio interviews for the popular science publications of J-L Dessalles on the principles underlying the language faculty and its origins (RFI, 2010; France Culture, 2011). Talks at the FITG forum which aims to bring together researchers, entrepreneurs and artists (2010 and 2012). Three major projects (FP7 IP project ARCOMEM, Equipex DIGISCOPE and the Cluster CONNEXION), twelve national public fundings (ANR, Investissements d'Avenir . . .).

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**Contributions to Higher Education**

- Teaching and administrative responsibilities in Masters: CogMaster (ENS, EHESS, Paris Descartes), IAD (UPMC), MPRI, COMASIC (Polytechnique, Université de Paris-Sud, ...).
- Textbook on *Web Data Management*, Cambridge University Press, 2012. Available online at `http://webdam.inria.fr/Jorge/`
- Training of PhD candidates (13 PhD defended during the period; 13 PhD students registered as of April 2013)
- Responsibility of twelve teaching modules and four specializations in the Master of Engineering of Télécom ParisTech.
- Full courses at Renmin University of China, the University of Hong-Kong and Cheikh Anta-Diop University in Senegal.

## 8.2 People

**Team leader** G. Hebrail (–12/10), F. Rossi (01/11–08/11), T. Abdessalem (09/11–).

**Faculty** T. Abdessalem (FP), B. Burtschy (FP), B. Cautis (AP), A. Danzart (AP, –12/11), J.L. Dessalles (AP), J. Eagan (AP, 08/11–), Y. Guiard (SRS), G. Hebrail (FP, –01/11), E. Lecolinet (AP), C. Potier (AP, –11/10), F. Rossi (FP, –08/11), P. Senellart (AP, 06/08–), M. Sozio (AP, 10/11–), M. Vazirgiannis (Chair Professor, 05/11–05/13).

**PhD students** M.-L. Ba (04/12–), M. Baglioni (11/08–04/12), I. Ben Dhia (10/10–), R. Chicky (–03/09), N. Derouiche (10/08–03/12), M. Durut (03/09–09/12), M-K. El-Mahrsi (07/09–), M. Faheem (08/11–), N. Gabsi (–05/11), H. Gacem (10/12–), G. Gouriten (10/12–), B. Gueni (–11/09), I.-M. Ileana (10/11–), C. Liu (10/12–), S. Malacria (–05/11), S. Maniu (10/09–09/12), T. Muhammad (–07/09), D. Munch (10/09–11/13), M. Oita (11/09–11/12), S. Perrault (10/09–04/13), A. Roudaut (–02/10), Q. Roy (03/12–), A. Saillenfest (10/11–), A. Souihli (10/09–10/12), D-B. Vo (12/09–09/13).

**Post-docs, engineers and sabbaticals** M.-A. Baazizi (10/12–), G. Bailly (06/09-01/11), N. Benguigui (10/08-09/09), Y. Chabchoub (11/09–09/10), A. Gomes Da Silva (10/09–12/11), V. Gomez Berdugo (12/10–10/11), G. Gouriten (07/11–09/12), K. Jouini (08/08–07/09), M. Luo (10/12–), H. Olafsdottir (10/08–12/11), T. Pietrzak (09/09–12/10), M. Serrano (09/11–09/12), A. Tabard (03/09–10/09), J. Wagner (10/12–04/13).

**Externally funded members of the group** Y. Amsterdamer (PhD Student, Tel Aviv University & INRIA Saclay, 02/11–09/11), C. Giatsidis (PhD Student, Ecole Polytechnique, 06/11–05/13), M. Gueye (PhD student, Cheikh Anta Diop University at Dakar, 01/12–), E. Kharlamov (PhD student, Free University of Bozen-Bolzano & INRIA Saclay, 01/09–09/10), F. Suchanek (Post-doc, INRIA Saclay, 07/10–11/11).

## 8.3 Overview

The IC2 team is working on several research problems in computer science, in the area of human-computer interaction, databases and web data management, cognitive computing and business intelligence. The research activity of the team is organized in three institutional projects: two main projects in the fields of data and knowledge management (DBWeb) and human computer interactions (VIA) and a former joint project on business intelligence (BiLab) with EDF, the main electric utility company in France.

In the DBWeb project, we study the fundamental issues raised in modern data and knowledge systems, especially on the World Wide Web and in collaborative contexts oriented towards peer-to-peer networks. Research interests cover theoretical foundations, as practical solutions, applications, and cognitive aspects of data and knowledge management systems. The main challenges we are interested in are: Web data management, with a special focus on information extraction, Web sources selection, and Web archiving; Query optimization over structured or semi-structured data, possibly with restricted access patterns (deep Web); Probabilistic databases; Relevance in communication and its applications in modern knowledge systems; Social web and social networks, with an emphasis on signed (trust–distrust) networks and collaborative applications, inference of signed links, access control, search and recommendation in social applications.

The VIA project is devoted to fundamental and applied research on Human Computer Interaction (HCI). It focuses on the double challenge of representing and manipulating more and more data, and to allow this not only on standard computers but also on large, small and non traditional devices. Our main contributions take place in the following domains: Novel interaction techniques and principles, which an emphasis on the leveraging of input dimensions that had been overlooked so far; Mobile interaction, with a special effort toward increasing the "interaction bandwidth" between users and their devices; Interactive visualization; Fundamental HCI research on reaching movements, with a project aimed at providing a more general understanding of the

Fitts' law; End-user programming and reverse engineering, specifically with aims at giving end users more control over the functionality of and interaction with their software.

The activity of the BILab Project covers several aspects of the Business Intelligence field in relation to both theoretical approaches and industrial applications. A major activity of the project has been related to data stream processing, Time series and functional data mining, Graph exploratory analysis and Large scale data analysis. The project was linked to a joint research laboratory with EDF, the main electric utility company in France (see the BiLab activity at `http://bilab.enst.fr`). It was completed in late December 2011.

## 8.4 Research Themes

### 8.4.1 Databases and the World Wide Web (DBWeb)

**Faculty** T. Abdessalem, B. Cautis, J.-L. Dessalles, P. Senellart, M. Sozio, M. Vazirgiannis (40%)

**Highlights: Scientific Production**

[1720], [1712], [1705], [1710], [1821].

**Highlights: Impact**

*Projects and public funding*: one FP7 IP project, Five national public fundings (ANR and Investissements d'Avenir), one Digiteo Chair (co-affiliated Professor), participation in three Advanced ERC Projects (Webdam, DIADEM, MoDaS).

*International collaborations*: UCSD (B. Cautis, A. Deutsch), RUC Beijing (T. Abdessalem, B. Cautis, P. Senellart, J. Lu), University of Oxford (P. Senellart, M. Benedikt, G. Gottlob, D. Olteanu), NUS (T. Abdessalem, B. Cautis, P. Senellart, S. Bressan, T. W. Ling), Tel Aviv University (P. Senellart, T. Milo).

*Invited lectures and tutorials*: Brazilian Symposium on Databases 2010 (B. Cautis), École thématique Masses de données distribuées 2012 (B. Cautis and P. Senellart), Collège de France 2012 (P. Senellart), tutorials at BDA'08 and IC'09 (T. Abdessalem and P. Senellart), BDA'11 (P. Senellart), EDBT 2011 (P. Senellart), DASFAA 2009 (P. Senellart).

*Sabbaticals*: Tokyo University of Foreign Studies (J.-L. Dessalles, 6 months), University of Hong Kong (Pierre Senellart, 6 months).

**Highlights: Interactions with Society**

*Radio interviews*: for the popular science publications of Jean-Louis Dessalles on the principles underlying the language faculty and its origins (RFI, 2010; France Culture, 2011).

**Theoretical foundations of Web data management.** A number of DBWeb research works deal with the querying of data sources that expose limited querying capabilities, either because they are defined by sets of queries (*views*) or because they have access constraints; this is the case of querying through Web services, the deep Web [1784], or even crowd-sourced data. This has led us to investigate querying relational data through expansions of potentially recursive Datalog programs [1711, 1788], querying XML sources accepting only a limited set of XPath queries [1789, 1712], answering queries under access pattern restrictions [1819] (a problem that we connect to a fundamental question on containment of recursive queries [1782]), or mining association rules by querying individuals from the crowd [1768].

We have done extensive research on the management of probabilistic databases, and probabilistic XML in particular [1750]. This includes developing a common framework for probabilistic data modeling [1704], support for aggregate queries and continuous distributions [1760, 1705], support for trees of arbitrary depth and width, or generation of probabilistic trees from XML corpora [1762, 1763]. We also researched the complexity of a number of other probabilistic XML data management problems: updates [1828], join queries [1829], mining [1749], answering queries using views [1710, 1896]. Finally, we looked at practical aspects of implementing a probabilistic XML database engine, in particular with the help of approximation algorithms [1875, 1879, 1880].

**Data management systems and emergent applications.** We propose in [1702, 1799] a novel approach for extracting structured data from the Web, whose goal is to harvest real-world items from template-based HTML pages (the structured Web). We study in [1844, 1843] the inference of a signed network (a "web of trust") from interactions on user-generated content in Wikipedia. We investigate mechanisms by which relationships between Wikipedia contributors – in the form of signed directed links – can be inferred based on their interactions. This trust network can then be used to annotate Wikipedia articles with confidence information in each revision, a task that we handle using probabilistic XML [1758, 1770]. Similar graph mining algorithms are also applied to determining truth values of facts stated by independent sources [1816] and to a probabilistic approach to the matching of very large ontologies [1732].

We considered in [1841, 1842, 1759] top-$k$ query answering in social applications. We propose in [1759] a sound and complete algorithm, called TOPKS, which addresses important applicability issues of existing techniques. As a complementary direction for efficient, online answering, we considered in [1841] the materialization and exploitation of previous query results (views). Extensive experiments on both synthetic and real-world data show that our techniques have the potential to scale and meet the requirements of real applications, as demonstrated in a social-aware search prototype [1842].

We proposed in [1756, 1781] an access control model for online social networks, where access control rules are expressed as reachability constraints. Our work generalizes access constraints by taking into account the properties of the users, the indirect connections between these users, and is able to express complex relationships. We proposed in [1823, 1824] a matrix factorization technique that aims at improving the accuracy of recommender systems; our solution combines clustering and users' biases in order limit the computational cost. In [1798], we studied the problem of distributing Web content from information suppliers to information consumers. We develop efficient algorithms to match pictures and users from Yahoo! Flickr as well as questions and users of the Yahoo! Answers portal. Finally, we have conducted a number of research works in the field of Web archiving, in particular about efficient crawling and extraction of relevant content in Web sites, using RSS feeds [1853, 1854], alignment with an ontology [1855], or application-aware crawling [1809].

**Cognitive computing.** We propose in [1716, 1743, 1904, 1715, 1800, 1714, 1741, 1742, 1744, 1717, 1718] a model of optimal investment in social signaling. This model highlights the role played by communication in building and preserving of social networks. In [1903, 1801, 1802, 1803], we develop "simplicity theory" (see `http://www.simplicitytheory.org/`). The theory correctly predicts which events will raise interest and are likely to be communicated.

Additional and up to date information on DBWeb main results and publications can be found on the project web page `http://dbweb.enst.fr/`

### 8.4.2 Advanced Interaction and Visualization (VIA)

**Faculty** E. Lecolinet, Y. Guiard, J. Eagan

**Highlights: Scientific Production**

[1867], [1721], [1806], [1725], [1860][2].

**Highlights: Impact**

*Projects and public funding:* EQUIPEX (Digiscope), ITEA-2 (Twirl), OSEO (Quaero), ANR (XWiki), FUI (Quatro2, Eneide), BGLE 2 (Connexion), Futurs et Ruptures (PhD funding).

*Awards and Positions:* E. Lecolinet is part of "Comité National de la Recherche Scientifique" (CoNRS, section 07) since Sept. 2012; Y. Guiard was appointed associate editor of the ACM TOCHI journal in 2009; E. Lecolinet and J. Eagan are officers (Chair and Treasurer) of the ACM SIGCHI Paris Chapter. Best paper awards at BCS HCI'12 and ACM UIST'11.

2. Note that CHI and UIST are exceptionally high-quality conferences with the best scientific impacts in the domain.

*Collaborations:* Aarhus University (J. Eagan), TU Berlin (E. Lecolinet), University of Canterbury (NZ) (E. Lecolinet, Y. Guiard, J. Eagan), National University of Singapore (J. Eagan), LIG (E. Lecolinet), INRIA InSitu (J. Eagan, E. Lecolinet, Y. Guiard).

*Conferences:* Strong contribution to the organization of the prestigious ACM CHI conference (April 2013, 3400 attendees). Local organization of the Program Committee (+200 attendees).

**Highlights: Interactions with Society**

*Projects and patents:* The VIA team has been involved in the Ubimedia joint lab. between Alcatel-Lucent Bell Labs and Institut Télécom since September 2008. One patent have been field, another one is currently being filed.

*Talks:* Y. Guiard and E. Lecolinet have given talks at the FITG forum (Lille, 2010 and 2012) which aims to bring together researchers, entrepreneurs and artists.

**Novel interaction principles and techniques.** Our work on new forms of interaction have led us to explore various dimensions of gestural interaction for increasing the interaction bandwidth between users and their devices. Among these input dimensions, we have studied how the shape and the kinematics of gestures can be exploited for activating and controlling commands in an efficient and intuitive way on touch-sensitive surfaces such as tabletops, large interactive displays and mobile touch screens. This research lead to the conception, implementation and evaluation of several innovative techniques such as MicroRolls [1870], that rely on small, rolling and frictionless, gestures of the thumb, or Motion-Pointing [1810] and Cyclostar [1838] that take advantage of elliptical oscillatory gestures for selecting targets or controlling multiple continuous variables.

**Discovery, learning and memorization of gestures.** Part of our research work on interaction principles and techniques was dedicated to the discovery, learning and memorization of gestures. This first led us to conceive and develop new kinds of Marking menus [1776, 1869, 1812] that solve various limitations of the original approach. These techniques help users making a smooth transition from novice to expert and allow remembering a large set of gestural shortcuts. We then improved this concept by considering additional dimensions such as finger counting [1778, 1725] or bezel taps [1877], hence leveraging on sensors and multimodal input for improving performance. In addition, we have studied the augmentation of gesture-based techniques by natural, language-based mnemonic associations [1871], a novel approach that outperforms the state-of-the art.

**Mobile interaction.** Mobile interaction, with smartphones or smaller objects, is an ideal application domain for novel interaction forms. We first studied the acquisition of small targets on mobile touch screens and proposed efficient ways for solving this problem [1867]. We then considered how 3D gestures could serve to improve user interaction with smartphones [1868, 1773] and gesture-aware remote controls [1779]. In [1780, 1725] we used the Kinect for investigating mid-air free-hand gestures in the context of interactive TV. In addition we also considered other input dimensions that have been overlooked so far such as pseudo-pressure [1774]. More recently, we conducted studies on user interaction with small personal devices such as electronic jewelry and watches [1860, 1912, 1859].

**Augmentation.** Another part of our research on mobile interaction focused on the augmentation of physical and digital artifacts using digital pen and paper. One project aimed at augmenting pupils' notebooks for digital classrooms [1862, 1839]. This system captures what happened when working at home and during the class, paper serving as a flexible and mobile mean for linking events and digital objects. Conversely, another project was devoted to the augmentation of mobile devices with digital paper [1840].

**End-user programming.** We have also expanded our research focus into the area of end-user programming and reverse engineering, particularly with regards to aiding end-users and third-party programmers at modifying the functionality and interaction of existing software applications to better suit their needs. This direction is off to an auspicious start with the first prototype system, Scotty [1806], having received a notable paper award at UIST 2011.

**Theoretical Study of Pointing.** We have cast new light on Fitts' law, a famous empirical regularity of experimental psychology that describes simple rapid aiming — or pointing, a fundamental act of graphical user interfaces. We have clarified in what sense Fitts' law constitutes an instance of a speed-accuracy tradeoff [1826]. We have shown that the traditional definition of the so-called index of difficulty, the law's independent variable, suffers a high degree of indeterminacy [1721]. Introducing a more rigorous definition of the basic dimensions of the problem [1825], we have undertaken to revisit the mathematical foundations of the problem [1727, 1728, 1857].

### 8.4.3 Business Intelligence (BILab)

**Faculty** B. Burtschy, A. Danzart, G. Hebrail, C.Potier, F. Rossi.

**Highlights: Scientific Production**

[1730], [1722], [1729], [1797], [1793].

**Highlights: Impact**

*Projects and public funding*: Two ANR projects (MDCO and MIDAS).

**Highlights: Interactions with Society**

*Collaboration with the industry*: A joint research laboratory was created for four years (2007-2011) with EDF R&D, and an industrial collaboration was set up with Orange Labs (1 CIFRE PhD student), and with Lokad (`www.lokak.com`, 1 CIFRE PhD student).

**Data stream management.** Our main activity related to data stream processing focuses on summarizing structured data streams. We developed several approaches [1746, 1901, 1796, 1813, 1808, 1791] and designed solutions to query the summaries [1814, 1793, 1815]. We have extended the temporal sampling approach called 'Master' developed in 2008, which builds an optimized summary of a large number of distributed streams produced by remote sensors. A clustering strategy was introduced to Master and gave rise to Clusmaster (clustering on master). Experiments with time series from electric power meters were carried out and are described in [1797, 1713]. We have also analyzed data streams describing the working phases of a nuclear power plant [1739]. The goal is to detect periods of dysfunctional states. The approach applied is a clustering based on non-overlapping windows to monitor system and detect changes in evolving data [1734]. Finally, a new approach has been designed for forecasting the generation of photovoltaic (PV) electric power [1818, 1909]. The goal is to forecast local production at a very short term (a few hours).

**Time series and functional data mining.** We provide exploratory analysis of functional datasets via a combined clustering and segmentation approach. The complexity of the prototype set is globally optimized by an efficient dynamic programming scheme [1827, 1753, 1722]. Related work include [1830] in which a piecewise constant approximation of functional data is built in a supervised manner. We have continued our work on supervised modelling of functional data, in particular on the use of derivatives to capture some shape aspects of functional data [1899, 1730]. Finally, in [1738], we handle time varying data in a quite different manner, we study the evolution through time of an unique system (a web server).

**Graph exploratory analysis.** We have been developing graph/network exploratory analysis techniques, with a focus on social networks. We have proposed in [1865, 1898, 1729] a new

topological quality measure for graph clustering, inspired by the self organizing map algorithm. We have used this method and similar graph clustering techniques to analyze successfully real world networks in the genetic domain [1831], in the epidemic domain [4062, 4061] and in the historical domain [1913]. We have also modelled information propagation in social networks and used similar technique to visualize local propagation in important clusters [3986].

**Large scale data analysis.** A distributed storage framework for massive data analysis, based on HDFS (Hadoop distributed file system) and Hadoop ecosystem (Pig, Hive, Hbase) has been designed and tested in a private cloud at EDF R&D. In addition, cloud based implementation of data mining techniques have been studied in collaboration with Lokad [1805, 1905].

# 8.5 Achievements (Appendix 6)

## 8.5.1 Scientific productions

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### Invited Talks

[1891] T. Abdessalem and P. Senellart. Concepts et modèles des webs communautaires. In *BDA*, Guilherand-Granges, France, Oct. 2008.
[1892] T. Abdessalem and P. Senellart. Concepts et modèles des webs communautaires. In *AFIA 2009*, Hammamet, Tunisie, May 2009.
[1893] S. Abiteboul, T.-H. H. Chan, E. Kharlamov, W. Nutt, and P. Senellart. Agrégation de documents xml probabilistes. In *BDA (Bases de Données Avancées)*, Namur, Belgium, Oct. 2009.
[1894] S. Abiteboul, S. Amer-Yahia, A. Galland, A. Marian, and P. Senellart. Birds of a tag flock together. In *SSM (Search in Social Media)*, New York, USA, Feb. 2010.
[1895] B. Cautis. Tutorial: Xpath rewriting using views: The more the merrier. In *The Second International Workshop on XML Data Management (with APWeb 2011))*, Pekin (Chine), Apr. 2011.
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### Talks in Conferences Without Proceedings

[1900] T. Abdessalem and P. Senellart. Gestion de données dans les réseaux sociaux. *Telecom*, 156: 56–58, Jan. 2010.
[1901] R. Chiky and G. Hébrail. Spatial and temporal sampling of distributed data streams. In *Conference of International Federation of Classification Societies (IFCS)*, Dresde, Allemagne, Mar. 2009.
[1902] J.-L. Dessalles. L'altruisme, enfant de la guerre ? *Cerveau & Psycho*, 26:24–28, Feb. 2008.

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[1905] M. Durut and F. Rossi. K-means on azure. In *LCCC: NIPS 2010 Workshop on Learning on Cores, Clusters and Clouds*, Whistler, Canada, Dec. 2010.
[1906] J. Eagan, C. Klokmose, and E. Lecolinet. What are applications in multi-surface environments? In *Powerwall international workshop on interactive, ultra-high-resolution displays, ACM CHI '13*, page 6, Paris, France, May 2013.
[1907] Y. Guiard. Langage ordinaire et modélisation mathématique: quelle fonction d'échange dans la loi du mouvement canalisé d'accot et zhai ? In *IHM, conference francophone d'interaction homme-machine*, pages 11–18, IRCAM (Paris, France), 2007.
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[1914] P. Senellart, S. Abiteboul, and R. Gilleron. Understanding the hidden Web. *ERCIM News*, (72): 32–33, Jan. 2008.

### 8.5.2 Public fundings

| Period | Project details | Funding | Principal investigator | Total (k€) |
|---|---|---|---|---|
| 2008–2011 | MDCO MIDAS – New methods for summarizing data streams | ANR | G. Hebrail | 140 |
| 2008–2011 | ISICIL – Information Semantic Integration through Communities of Intelligence on-Line | ANR | T. Abdessalem | 134 |
| 2008–2010 | LPOD – Language and Platform Open-Document | ANR | T. Abdessalem | 72 |
| 2008–2012 | DataRing – P2P Data Sharing for Online Communities | ANR | P. Senellart | 128 |
| 2010–2013 | Quatro 2 – Terminal multi-usage | FUI | E. Lecolinet | 249 |
| 2010–2011 | VMS3D – Version Management System for Domain Dependent heterogeneous Data | COOPOL, French Embassy at Beijing | T. Abdessalem | 25 |
| 2011–2013 | ARCOMEM – From Collect-All ARchives to COmmunity MEMories | FP7-IP | P. Senellart | 606 |
| 2011–2013 | Digiscope – Infrastructure haute performance pour la visualisation interactive et collaborative | EQUIPEX-ANR | E. Lecolinet | 322 |
| 2011–2013 | DROD – Distributed Revisions for Open Document | FEDER | T. Abdessalem | 160 |
| 2012–2014 | TWIRL – Twinning virtual World (on-line) Information with Real world (off-Line) data sources | Eureka-ITEA | E. Lecolinet | 198 |
| 2013–2015 | CCIPX – Curating and Crowdsourcing information using probabilistic XML | STIC-Asie | P. Senellart | 36 |
| 2013–2028 | Digipods – Interaction collaborative à distance entre plateformes de visualisation hétérogènes | SESAME, Region Île-de-France | E. Lecolinet | 156 |

### 8.5.3 Private fundings

| Period | Project details | Funding | Principal investigator | Total (k€) |
|---|---|---|---|---|
| 2008–2013 | ADR Alcatel NIU – Nouvelles Interactions Et Nouveaux Usages | Alcatel | E. Lecolinet | 294 |
| 2009–2012 | Cifre DURUT – Prévision simultanée d'un ensemble très volumineux de séries temporelles | LOKAD | F. Rossi | 15 |
| 2009–2010 | EDF GD – Gestion de données en environment distribué | EDF | T. Abdessalem | 10 |
| 2011–2015 | MODIM – Modélisation des Imaginaires | Chaire MODIM portée par Pierre Musso | J.-L. Dessalles | 51 |

### 8.5.4 Patents

[1915] J. Robinson, M. Ribière, M. Baglioni, E. Lecolinet, and J. Daigremont. Servers, display devices, scrolling methods and methods of generating heatmaps. US20130155118 A1, June 2013.

## 8.6 PhDs (Appendix 7)

### 8.6.1 Defended PhDs

[1916] M. Baglioni. *Interactions physiques sur dispositifs mobiles*. PhD thesis, Telecom ParisTech, Apr. 2012.
[1917] R. Chiky. *Résumés de flux de données distribués*. PhD thesis, Telecom ParisTech, Mar. 2009.
[1918] N. Derouiche. *Recherche des Objets Complexes dans le Web Structuré*. PhD thesis, Telecom ParisTech, Mar. 2012.
[1919] M. Durut. *Parallélisation d'algorithmes de clustering sur une plateforme de Cloud Computing*. PhD thesis, Telecom ParisTech, Sept. 2012.
[1920] M.-K. El-Mahrsi. *Analyse et fouille de données de trajectoires d'objets mobiles*. PhD thesis, Telecom ParisTech, Sept. 2013.
[1921] N. Gabsi. *Extension et interrogation de résumés de flux de données*. PhD thesis, Telecom ParisTech, May 2011.
[1922] B. Gueni. *Optimization of Nested XQuery Queries*. PhD thesis, Telecom ParisTech, Mar. 2009.
[1923] E. Kharlamov. *A probabilistic approach to XML data management*. PhD thesis, Free University of Bozen – Bolzano, Mar. 2011.
[1924] S. Malacria. *Conception et évaluation de techniques d'interaction pour surfaces tactiles et papier interactif*. PhD thesis, Telecom ParisTech, May 2011.
[1925] S. Maniu. *Data Management in Social Networks*. PhD thesis, Telecom ParisTech, Sept. 2012.
[1926] T. Muhammad. *Tangible and tactile interaction techniques for multimedia systems*. PhD thesis, Telecom ParisTech, July 2009.
[1927] D. Munch. *Un modèle dynamique et parcimonieux du traitement automatisé de l'aspect dans les langues naturelles*. PhD thesis, Telecom ParisTech, Nov. 2013.
[1928] M. Oita. *Deriving semantic objects from the structured Web*. PhD thesis, Telecom ParisTech, Nov. 2012.
[1929] S. Perrault. *Techniques d'interaction pour les dispositifs miniaturisés de l'informatique mobile*. PhD thesis, Telecom ParisTech, Apr. 2013.
[1930] A. Roudaut. *Conception et évaluation de techniques d'interaction pour dispositifs mobiles*. PhD thesis, Telecom ParisTech, Feb. 2010.
[1931] A. Souihli. *Querying Probabilistic XML*. PhD thesis, Telecom ParisTech, Oct. 2012.
[1932] D.-B. Vo. *Conception et évaluation de nouvelles techniques d'interaction pour la télévision interactive*. PhD thesis, Telecom ParisTech, Sept. 2013.

### 8.6.2 Ongoing PhDs

- **A. Amarilli** (09/13 – ), Uncertainty in intensional data.
- **M.-L. Ba** (04/12 – ), Probabilistic approaches in integrating social Web data.
- **I. Ben Dhia** (10/10 – ), Gestion des grandes masses de données dans les graphes réels.
- **M. Faheem** (08/11 – ), Intelligent content acquisition in Web archiving.
- **H. Gacem** (10/12 – ), Intégration du numérique dans l'analogique : augmentation d'objets tangibles.
- **M. Gueye** (10/11 – ), Large scale recommender systems.
- **G. Gouriten** (10/12 – ), Knowledge-based content suggestions on the social Web.
- **C. Liu** (10/12 – ), Navigation multi-échelle : des dispositifs mobiles aux murs d'écrans collaboratifs.
- **I.-M. Ileana** (10/11 – ), Extracting and archiving rich content from the Web: the ARCOMEM approach.

- **Q. Roy** (03/12 – ), Manipulation et analyse d'images médicales 3D via des interactions gestuelles sur surfaces tactiles.
- **A. Saillenfest** (10/11 – ), Modélisation de l'intérêt dans le récit fictionnel – Application au récit automatique.

# Chapter 9

# Network and Information Security (SR)

## 9.1 Executive Summary (Appendix 1)

**Team Leader** Jean Leneutre and Isabelle Zaquine

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**Initial Staff** 7 Professors; 2 Research Scientists; 1 Engineer; 0 Postdocs; 19 PhD Students.

**Staff who Left** 2 Permanent Staff (90 months) ; 36 PhD Students (1211 months) ; 12 Postdocs (144 months) ; 17 CDD (275 months) ; 9 sabbaticals (75 months) .

**Staff who Were Hired** 1 Permanent Staff (TSI); 2 Research Scientists.

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**Scientific Highlights**

- SEQURE was an ANR project aiming at the integration of quantum key distribution on a telecommunication link secured by industrial classical encryptors manufactured by Thales. The paper[1954] reports on the successful demonstration of a 18 km link between Massy and Palaiseau, over more than 6 months.
- Successful application for a competitive funding of Region Ile de France, SESAM in 2008. This has allowed to set up a new platform, focused on quantum optics and quantum cryptography and therefore to extend our activity in experimental quantum information.
- In January 2012 and 2013 the IEEE COMSOC society selected two demonstrations dealing with the emerging NFC technology applied to the IoT for a public presentation on the IEEE booth during the CES 2012 and 2013 show in Las Vegas ( IEEE press release)
- RFC4279: Pre-Shared Key Ciphersuites for Transport Layer Security (TLS). This RFC specifies three sets of new ciphersuites for the Transport Layer Security (TLS) protocol to support authentication based on pre-shared keys (PSKs).
- P. Jouguet, S. Kunz-Jacques, A. Leverrier, P. Grangier, E. Diamanti, "Experimental demonstration of long-distance continuous-variable quantum key distribution", Nature Photonics (2013). [1956] P.Jouguet was awarded the Best Student Paper Award in QCRYPT 2012 for this work.

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**Scientific Production** 62 Journals; 5 Books; 6 Book chapters; 119 Articles in Proceedings; 15 Invited talks; 58 Talks

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**Major Publications**

- Z. Wang and D. Markham, 'Non-locality of symmetric states', Physical Rev. Lett., **108**, 210407 (2012).[1993] We develop novel techniques to show how a large class of states can be used for quantum information tasks via their novel non-local features.
- J. Ghalbouni, I. Agha, R. Frey, E. Diamanti, and I. Zaquine. Experimental wavelength division multiplexed photon pair disptribution. Optics Letters, 38(1):34, January 2013.[1948]
- A. Pappa, A. Chailloux, S. Wehner, E. Diamanti, and I. Kerenidis. Multipartite entanglement verification resistant against dishonest parties. Physical Review Letters, 108(26):260502, June 2012.[1976]

- V. Toubiana, H. Labiod, L. Raynaud, and Y. Gourhant. A global security architecture for operated hybrid wlan mesh networks. Computer Networks Journal, 54(2):218-230, February 2010.[1989]
- R. He, M. Lacoste, and J. Leneutre, “Virtual security kernel: A component-based OS architecture for self-protection”. In Third IEEE International Symposium on Trust, Security and Privacy for Emerging Applications (TSP-10) , Best Paper Award, Bradford, UK, July 2010[2048].

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**Major Documents**

- In fall 2009, the ANR project T2TIT (Things to Things in the Internet of Things), which ended in the beginning of 2010, won the CARTES 2009 Best Software Award.
- In January 2010, the demonstration detailed in the paper [2101] received the Best Demonstration award from the IEEE CCNC conference, and demonstrated the first OPENID infrastructure based on smartcards.
- Expertise report on numerous projects : ITEA E-Confidential, ANR CONTINT (2013), ANR JCJC SIMi3 (2012), ANR TDM-CE-TDM (2012), INFRA (2011), Futur et Ruptures (2011,2013)).
- Anthony Leverrier received the ParisTech PhD prize in 2010.
- Patent WO2010130807 2010-11-18 : Method for securing documents by applying them a specific identification number, and apparatus for authenticating this identification number

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**Impact and Attractivity**

- JLR Future Internet Security & Trust , a common lab created between Telecom ParisTech and Jiatong SISE (Shanghai Jiaotong S School Of Information Security Engineering) in 2012.
- In June 2012, Telecom ParisTech signed a Memorandum of Understanding with the School of Informatics, University of Edinburgh, based on the ongoing collaborations In recognition of commitment from both sides, Kashefi has been made an associate lecturer at TPT and Markham is an Honorary Fellow of the school of Science and Engineering in UoE.
- Organization of several international and national conferences/workshops/seminars: IFIP NTMS (New Technologies Mobility and Security) (2008, 2009, 2011), SAR-SSI (Sécurité des Architectures Réseaux et Systèmes d’Information) (2011), N2S(International Conference on Network and Service Security) (2009) , REVE (réseaux vahiculaires) (2012), workshop ParisTech-NTU (2009).
- E. Diamanti is a member of the steering committee of the Groupe de Recherche "Information Quantique: Fondements et Applications", 2010 - 2013, and responsible for the ’Quantum communications’ thematic research axis.
- “Investissements d’avenir” program winner : the IEED VeDeCoM project about a communicating decarbonated vehicle and its mobility

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**Interaction with Economic and Social Spheres**

- SeQureNet first commercial product : SeQureNet is a start-up company founded par Romain Alléaume, and is a spin-off of Telecom ParisTech . A continuous-variable quantum key distribution system has been sold and deployed in NICT in Japan in 2013.

- In the context of the VELCRI project (Véhicule Electrique à Charge Rapide Intégrée) funded by the “Agence de l’Environnement et de la Maîtrise de l’Energie”, Telecom Paristech contributed to secure the communication between the electric vehicles and the charging stations. The close collaboration with Renault aimed to show that the technical solution is secure and economically viable for different recharging infrastructures.
- The EtherTrust spinoff created in 2007 won the OSEO award in fall 2009. Main industrial achievements are prepayment system designed for a big player, and mobile identity model (SIMply Me!) developed in partnership with the company Morpho.
- The research activity on quantum cryptography has lead to develop close ties with several important industrial partners such as Thales Research and Technologies, and Thales Communications, who are indeed at the forefront of the R&D activity on continuous variable quantum key distribution: a technology invented in the team of Philippe Grangier and developped in partnership with Thales.
- A common laboratory between Télécom ParisTech and EDF has been created in 2012, to work on Internet of things and cybersecurity of electric systems.

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**Contributions to Higher Education**

- Summer Schools Invited lecture series, ’Secret sharing in a quantum world’ in Imperial College, UK, to the Doctoral Training Centre for Controlled Quantum Dynamics (March 2011) and QUISCO quantum information program, University of Edinburgh, (July 2011).
- Courses on quantum information have been organized in various contexts : a full day addressing teachers from “classes préparatoires”, a full week addressing europeen students from partner universities and 120 hours for the engineering students.
- Continuing education : 3 specialized masters : CAR (conception et architecture de réseaux), SSIR (Sécurité des systèmes informatiques et des réseaux ), ATOMS(Architecte Télécom orienté multiservices)
- Research masters in networks (Paris 6) : course responsibilities and teaching
- J. Leneutre and I. Zaquine were appointed "Chevalier de l’Ordre des Palmes Académiques" (a decoration for services to education)

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## 9.2 People

**Team leader** Jean Leneutre and Isabelle Zaquine.

**Faculty** R. Alléaume (AP), H. Aissaoui (Eng), E. Diamanti (JRS), A. Hecker (AP, –01/13), H. Labiod (AP), J. Leneutre (AP), D. Markham (JRS), M. Riguidel (FP, –03/10), A. Serhrouchni (AP, –11/11;FP 12/11–), P. Urien (FP), I. Zaquine (AP).

**PhD students** A. Al Mamou (02/06–01/10), M. Aljnidi (10/05–12/09), L. Aranda (11/07—-), A. Bocquet (07/08–12/11), G. Bovet(12/12—-), H. Dau (11/09–08/11), S. Delamare (10/06–06/10), Z. Drias(12/12—-), D. Elkouss(01/08–07/08, 09/08–12/08), S. El Sawda (10/07–03/11), A. Fadlallah (11/03–01/08), A. Famulari (03/11—-), M. Faycal (04/05–05/10), I. Feki(02/04–09/08), D. Fotue Fotso (10/10—-), A. Garcia (03/13—-), J. Ghalbouni (10/10—-), H. Guerid (11/10—-), S. Guilbaud (10/10–01/12), T. Guillet (12/06–09/10), B. Hamdane (01/12—-), R. He (11/07–10/10), Z. Ismail(02/13—-), M. Jemel(04/13—-), P. Jouguet (09/10—-), A.R. Kaced(10/04–09/08), M. Kasraoui (05/11—-), C. Kiennert (01/10–07/12), M. Komarova(03/05–05/08), S. Ktari (01/08–12/09), A. Leverrier (08/06–01/10), H. Lin (10/05–01/09), A. Makiou(06/12—-), A. Marin (10/09—-), M. Msahli(12/12—-), R. Moalla (04/11—-), S. Natouri (11/10—-), D. Ngueguia Nyamy (11/07–02/12), T. Nguyen (12/11—-), A. Pappa (11/10—-), X. Qian(03/13—-), H. Qin (11/11—-), B. Rodier (01/09–09/09), R. Saad (11/06 - 09/10), J.L. Smirr (01/07–11/10), M. Sokhn (11/07–09/11), A. Sohbi (11/12–), S. Souissi(06/12—-), C. Tchepnda (10/05–12/08), C. Thibaud (01/09—-), V. Toubiana (10/05–01/09), Z. Wang (10/09–03/13), J. Zhang(04/13—-), Y. Zhao(10/12—-), G. Zhioua (04/11—-).

**Post-docs, engineers and sabbaticals** N. Ababneh (04/09–06/11), I. Agha (10/10–09/11), A. Ahmad (03/10–08/10), P. Albertin (05/07–12/08), J. Aranda Buenos (S,10/10–12/11), I. Aykildiz (S, 05/13–06/13), W. Bellante (10/12–09/13), Y. Benchaib (07/07—-), A. Boukerche (S,11/09–12/09), X. Chen (09/10–12/11), P. Desfonds (10/11–09/12), M.A. Dianati (S,7/08–08/08), S. Elrharbi (11/07–01/11), A. Fadlallah (S,07/12–09/12), S. Felloni (04/10–04/11), S. Haddad (01/09–03/11), K. Haddadou (03/10–04/10), A. Handoura (S,05/12–06/12), Z. Ismail (05/12–01/13), P. Jouguet (03/09–02/10), M. Kaplan (02/12–11/15), C. Kiennert (08/08–12/09), S. Ktari (01/10–7/11), R. Kumar (05/12—-), P. Laurier (05/07–06/11), T. Lawson (10/11—-), A. Mandilara (01/12–06/12), P. Marie (02/09–12/09), R. Moalla (01/11—-), L. Monat (03/12–11/12), M. Morcel (12/06–04/10), N. Nogueira Lima (10/09–11/09), X. Odic (08/06–02/08), N. Oualha (09/09–08/10), R. Parapatil (05/12—-), B. Rai (09/10–06/11), T. Räty (S,01/09–07/10), M. Spina (10/12–09/13), P. Selwyn (S,11/12–04/13), K. Sunghyun (S,05/08–05/09), J. Victor (10/10–10/10), Y. Wue (S,09/12–09/13), S. Zeadally (S, 07/13–07/13), J. Zhang (04/13—-).

**External collaborators** M. Riguidel (Prof. emeritus), E. Kashefi (visiting associate professor, Univ. Edinburgh).

## 9.3 Overview

The Computer Science and Networking department has opted for the creation of a research group dedicated to questions of Networks and Information Security (in French even more explicitly called “Sécurité et Réseaux"). Gathering security-oriented researchers from different other groups, this new research group has been established at January, 1, 2010 at the CS and Networking department with an explicit focus on networks and security.

The objectives of this research group is to produce industrially usable high-quality solutions and academically relevant theoretical approaches to improve the resilience and the security of modern networked IT systems, from the security of links and individual components and mechanisms to the architectural and administrative aspects such as gouvernance. This challenge includes aspects of manageability (operator-centric view) and usability (user-centric view), both of the security provisions and of the resulting IT systems and services.

One part of the group addresses complex security issues and has proposed innovative solutions in internetworking security and its applications, internet of things and wireless and autonomous networks. It has established strong cooperations with various important industrial partners (EADS, DGA, Renault, Orange Labs,...) and with national/international academic teams. It has contributed to the creation of common research labs (Seidolab, JLR) and to very important cooperative projects like IEED VeDeCoM and ANR/FP7/CELTIC/IST. The team is very active in the scientific life of the community (organization of conferences/workshops/seminars) and in terms of delivering expertise (ANR, AERES,...) and participating to standardization.

A second part of the NIS group is focusing its activity on different aspects of quantum information science, ranging from fundamental problems related to entanglement theory or theoretical aspects of quantum cryptographic protocols, to experimental work on quantum communications and practical quantum cryptography, with an important effort towards the development of quantum key distribution technology. The team, composed of four permanent members (see below) is also actively participating in the scientific life of the community, through the organization of scientific workshops and conferences (notably, High Performance Coherent Quantum Communications (HIPERCOM) kick-off meeting and Continuous-Variable Quantum Information Processing (CV-QIP'11) workshop held at Télécom ParisTech, Paris in September 2011; and Workshop on Post-Quantum Security Models (PQSM), held at Télécom ParisTech, Paris in October 2010), including the conference series QuPa, which have gathered speakers and participants from research groups interested in quantum information in the Paris area (Quantum Information in Paris (QuPa) workshop series - 8 so far - held with Institut Henri Poincaré and Télécom ParisTech, Paris, May 2009-present). Finally, the dynamism of our activity is also illustrated by an important number of collaborations, as well as the participation in scientific committees at a national and international level (e.g. participation in the Steering committee of the GdR "Information Quantique: Fondements et Applications", program committee for the international conferences such as DCM 2010, DCM 2011, CLEO Europe/EQEC 2011, QCRYPT 2011).

## 9.4 Research Themes

### 9.4.1 Networking security

**Faculty** A. Hecker (left in Feb. 2013), H. Labiod, J. Leneutre, A. Serhrouchni, P. Urien, H. Aissaoui .

**Highlights: Scientific Production** P. Urien. Openid identity service for android, based on usim secure elements. In Mobicase 2012, Seatle, USA, October 2012. Springer.

RFC4279: Pre-Shared Key Ciphersuites for Transport Layer Security (TLS). This RFC specifies three sets of new ciphersuites for the Transport Layer Security (TLS) protocol to support authentication based on pre-shared keys (PSKs).

C. Tchepnda, H. Moustafa, H. Labiod, and G. Bourdon. On analyzing the potential of a layer-2 multi-hop authentication and credential delivery scheme for vehicular communications. Wireless Personal Communications (WIRE); Springer Journal, 2008.

L. Chen and J. Leneutre ; "A game theoretical framework of distributed power and rate control in IEEE 802.11 WLANS", IEEE Journal on Selected Areas in Telecommunications, 26 : 1128-1137, 2008.

A. Hecker ; "On System Security Metrics and the Definition Approaches" Second International Conference on Emerging Security Information, Systems and Technologies, 2008. SECURWARE '08.

**Highlights: Impact** Ruan He received the honorific mention of CONET AWARD 2011 for his PhD work.

Pr Selwyn Piramuthu (from the University of Florida) has been awarded by the Paris Research program, and got a grant for a six month stay (november 2012- april 2013) in the SR team, in order to works on the NFC technology applied to the IoT.

ANR TRAFIC, ANR VELCRI : we address in these projects end-to-end routing in vehicular networks and securing V2V and V2I (vehicle to infrastructure ) communications.

SecFuNet : FP7 europeen project to design and develop a coherent security architecture for virtual networks and cloud accesses.

DYNARIS : a STIC Asia project "Towards a real time risk management in complex information systems".

A. Serhrouchni has been appointed Chairman of IFIP TC 6.5 ;

H. Labiod is co-founder of IFIP NTMS conference

Organization of Intl Future Internet Security and Trust workshops in 2009 and 2011; co-organization with RMS of EuroNF NGI 2010 conference at TPT in June 2010.

Expertise AERES (2012, 2013): evaluation of research unit TR MOTIVE (Modèles, systèmes d'information et gestion viable de l'environnement) of Irstea (ex Cemagref).

**Highlights: Interactions with Society** THALES CIFRE ROSERO

Ines Ayadi, Ahmed Serhrouchni et Guy Pujolle : IETF-Draft: "Integrity Cookie Management" (oct. 2010)

WO2010130807A2 , pp. 20 : Method for securing documents by applying a specific identification number thereto, and apparatus for authenticating said number (2010-11-18)

#### Security of Internetworking and Its Typical Applications

We introduce an innovative security architecture and authentication and credential delivery mechanisms for vehicular networks taking into consideration both ITS and non-ITS services. Our approach illustrates for the first time the concept of layer-2 multi-hop authentication and credential delivery in vehicular networks environments. The proposed solution comprises a trust and security infrastructure, the AUCRED authentication protocol for authentication and credential delivery, and the EGEMO protocol for layer-2 multi-hop transport of authentication messages.

We design a global security architecture aiming at securing the main network operations that may exist in both pure ad hoc or hybrid WLAN mesh networks. Our main contributions are the design of the Adaptive Secured Multipath for Ad hoc networks (ASMA) architecture, the Multipath Trust based Routing Protocol (MTRP) and the On-demand Multipath CERTification (OMCERT) protocol.

#### Internet of Things, M2M and Identity Management with Trustworthy Devices

The goal of this research team is to tackle security and trust issues for networks, for the Internet of Things (IoT), and for the emerging Machine to Machine (M2M) infrastructures. The tentative solutions rely on tamper resistant devices, based on secure microcontrollers such as smart cards or more generally speaking Secure Element (SE).

#### Infrastructureless, Wireless and Autonomous Networking

This research activity is dedicated to the infrastructure-less, wireless and autonomous networks and their specific needs in terms of organization, security, management, etc. This also explicitly includes vehicular networks (VANET), ad hoc networks or sensor networks (WSN). These networks are formed by independent nodes and often have to be self-organized, even though a portal connection to an infrastructure may be available in more specific scenarios. The self-organization in a changing environment spanned over simplistic nodes requires secure and robust yet rapid and simple mechanisms for mobility management, routing, sensing, data plane organization and application APIs. Yet, the security in these environments is hard to establish, mainly because of the performance constraints (bandwidth, calculation, energy), and because of lacking security anchors (usually, no individual device can be presumed physically integer or secure).

### 9.4.2 Quantum information

**Faculty** R. Alléaume, E. Diamanti, D. Markham, I. Zaquine.

**Highlights: Scientific Production** Z. Wang and D. Markham, 'Non-locality of symmetric states', Physical Rev. Lett., **108**, 210407 (2012).[1993] We develop novel techniques to show how a large class of states can be used for quantum information tasks via their novel non-local features.

J. Ghalbouni, I. Agha, R. Frey, E. Diamanti, and I. Zaquine. Experimental wavelength division multiplexed photon pair disptribution. Optics Letters, 38(1):34, January 2013.[1948]

P. Jouguet, S. Kunz-Jacques, A. Leverrier, P. Grangier, E. Diamanti, "Experimental demonstration of long-distance continuous-variable quantum key distribution", Nature Photonics (2013). [1956] P.Jouguet was awarded the Best Student Paper Award in QCRYPT 2012 for this work.

P. Jouguet, S. Kunz-Jacques, T. Debuisschert, S. Fossier, E. Diamanti, R. Alléaume, R. Tualle-Brouri, P. Grangier, A. Leverrier, P. Pache, and P. Painchault, "Field test of classical symmetric encryption with continuous variables quantum key distribution," Opt. Express 20, 14030-14041 (2012).[1954]

A. Pappa, A. Chailloux, S. Wehner, E. Diamanti, and I. Kerenidis. Multipartite entanglement verification resistant against dishonest parties. Physical Review Letters, 108(26):260502, June 2012.

**Highlights: Impact** ANR project EQUANET: embryonic quantum network; ANR FREQUENCY, ANR SEQURE, CEE-CHIST-ERA HIPERCOM, ANR CIQWII.

A quantum information experimental platform has been set up following the successful application to the SESAM project by the Region Ile de France in 2008. Telecom ParisTech and Institut Telecom strongly supported this project, both financially and by granting square meters.

Anthony Leverrier received the ParisTech PhD prize in 2010.

**Highlights: Interactions with Society** We have organized several scientific events in the past few years, in particular a workshop on Post-Quantum Security Models in 2010, the 2011 Continuous-Variable Quantum Information Processing workshop, the Japan-France Laboratory for Informatics meeting in 2013, and an international workshop on Physics and Information, also in 2013. We have also initiated the Quantum Information in Paris (QuPa) tri-annual seminar series, which has played an important role as a federator of the quantum information scientific community in and around Paris and attracts renown international speakers. Finally, our group was selected among several candidate cities to host and organize the major conference in the field of quantum crytography, QCRYPT, in 2014.

Our research activity on quantum cryptography has lead us to develop close ties with several important industrial partners: Thales Research and Technologies, and Thales Communications, are indeed at the forefront of the developpment of the continuous variable quantum key distribution that was invented in the team of Philippe Grangier. It is now licensed to our spin-off SeQureNet and we have an important R&D activity on this topic and many interactions and partnership with industry [2274, 2275]. In the FP7 contract Q-CERT we collaborate in particular with IdQuantique, the leading company in quantum cryptography, while the FEDER contract QVPN, done in collaboration with SeQureNet and CityPassenger aims at wavelength multiplexing quantum and classical (encrypted) traffic on one single fiber.

#### Quantum key distribution (QKD)

Distributing secret keys with information-theoretic security is arguably one of the most important achievements of the field of quantum information processing and communications. The rapid progress in this field has enabled quantum key distribution (QKD) in real-world conditions

and commercial devices are now readily available. In our team we are interested in a QKD protocol, in which the key information is encoded on so-called continuous variables, such as the quadratures of coherent states. This protocol offers the major advantage that it only requires standard telecommunication components. After initial implementations of continuous-variable QKD (CVQKD) systems in the context of network deployments [2270, 1983, 1933], we studied the properties of the error-correcting codes employed in such protocols, which were the main limiting factor with respect to the communication range of the implementations. Advancements in this direction [1954] together with the development of new systems with improved optical stability, allowed us to perform key distribution at long distances with maximal security guarantees [1956]. This work was performed in very close collaboration with the spin-off start-up company SeQureNet, and led to the commercialization of the CVQKD product Cygnus by SeQureNet. Our research efforts are currently focused on the practical security of the CVQKD systems, in particular the exploration of potential side channel-based attacks and the proposal of suitable countermeasures, and on their integration in currently deployed network infrastructure using wavelength division multiplexing techniques. The experimental work is taking place in the platform 'Sécurité quantique' developed by our team and supported financially by the Region Ile de France through a SESAM grant, the LTCI and Institut Télécom. This activity is also at the heart of several projects (FREQUENCY, HIPERCOM, QCERT) and national and international collaborations (for instance, with Institut d'Optique, Thales, IDQuantique, Université de Genève, Université Libre de Bruxelles, University of Waterloo).

**Quantum Protocols and Quantum Computation in future Quantum Networks**

Future quantum networks will comprise users with varying power, from totally classical, through partially quantum (such as the ability to prepare or measure in a limited way, probably includes most users) to fully quantum with the power to do universal quantum computation (probably very few quantum 'servers'). Such a global scenario demands new protocols and promises new unexplored advantages. In the same way that the internet is more powerful than any one protocol or algorithm, we may expect the development and interplay of new protocols to propel quantum information to unknown limits. We study the use of multipartite quantum states for quantum cryptographic protocols beyond QKD, all the way from coin flipping to full blown delegated quantum computation, to this end. We have developed novel protocols including Quantum Secret Sharing [1959], Quantum Coin flipping[1975], quantum entanglement verification[1976] and non-local games [1993]. Our approach is to look from two angles at the very core of these questions. From one side we explore the foundations of quantum physics to see what are the key quantum features that can enable some quantum enhancement (for example the study of fundamental non-locality[1994]). From the other side by developing protocols such as those described we build our understanding of how these features can be used, extended and new features sought out. This long term, broad ranging research project has led us to develop a series of international and interdisciplinary research collaborations and programs, notably resulting in founding an MoU with the university of Edinburgh, as well as our participation in the Japan-France Laboratory for Informatics and several long term collaborations for example with the University of Vienna and University of Bristol, where we also collaborate on experiments.

**Entangled-photon sources**

In order to be truly useful for technological applications, future quantum communication networks will require a large number of high quality entangled photon pair sources. We have been working on the limitations to the quality of entanglement produced by spontaneous down conversion (SPDC) [1984], in various contexts : narrowband sources to be compatible with the future quantum memories [1985], long distance communications in telecom optical fibers [1986] and wideband multiplexed sources for multi-user entanglement distribution [1948].

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# 9.5 Achievements (Appendix 6)

## 9.5.1 Scientific Productions

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### Invited Talks

[2126] E. Diamanti. Implementation and topology of quantum key distribution networks. In *Présentation invitée "International Conference on Quantum Information and Technology (ICQIT)"*, Tokyo, Japon, Dec. 2009.
[2127] E. Diamanti. Present and future of coherent-state continuous-variable qkd in optical fibers. In *Présentation invitée "Continuous-variable quantum information processing (CV-QIP'11) Workshop and HIPERCOM Meeting"*, Paris, France, Sept. 2011.
[2128] E. Diamanti. Implementation of quantum cryptographic protocols in realistic photonic systems. In *Présentation invitée "Quantum Security Meeting, Quisco - Télécom ParisTech"*, Édimbourg, Ecosse, Nov. 2012.
[2129] E. Diamanti. Implementation of quantum cryptographic protocols in practical photonic systems. In *Présentation invitée "JFLI (Japanese-French Laboratory for Informatics) Meeting on Quantum Information and Computation"*, Paris, France, Mar. 2013.
[2153] E. Diamanti, R. Alléaume, A. Leverrier, F. Roueff, N. Lutkenhaus, S. Fossier, T. Debuisschert, R. Tualle-Brouri, P. Grangier, P. Jouguet, and S. Kunz-Jacques. Quantum cryptography and network security. In *Présentation invitée "Updating Quantum Cryptography and Communications (UQCC) Conference"*, Tokyo, Japon, Oct. 2010.
[2131] E. Diamanti, S. Fossier, T. Debuisschert, A. Leverrier, R. Tualle-Brouri, and P. Grangier. La cryptographie quantique à variables continues: garantir le secret sans compter les photons. In *Présentation invitée "Journée Mesures, Lasers, et Applications"*, Paris, France, June 2010.
[2132] E. Diamanti, A. Pappa, A. Chailloux, and I. Kerenidis. Practical quantum coin flipping. In *Présentation invitée "Quantum Information in Scotland (Quisco) Workshop"*, Édimbourg, Ecosse, July 2011.
[2133] H. Labiod. Routing and security, in ad hoc networks. In *Workshop ParisTech-NTU*, Paris, France, June 2009.
[2134] H. Labiod. Routing and security in manets/vanets. In *Secan-Lab, University of Luwembourg*, Luxembourg, June 2009.
[2135] A. Marin and D. Markham. Reed solomon codes for secret sharing protocols. In *Workshop on aspects of coding theory*, Laussane, Switzerland, July 2011.
[2136] D. Markham. Overview of measurement based qip. In *JST-CNRS*, Paris, France, Sept. 2008.
[2137] D. Markham. Entanglement and flow in measurement based qip. In *QICS*, Obergurgl, Austria, Sept. 2008.
[2138] D. Markham. Information flow in secret sharing protocols. In *ICQIT*, Tokyo, Japan, Dec. 2009.
[2139] D. Markham. Accessing information locally. In *Bellairs Workshop on Information Theory, Quantum Mechanics and Security*, Barbados, Mar. 2010.
[2140] D. Markham. Security from quantum encoding. In *Workshop on Physical Layer Security*, Paris, France, Sept. 2010.

[2141] D. Markham. N-party hardy proofs for symmetric states. In *SCQI 2011*, Bhubaneswar, India, Dec. 2011.
[2142] D. Markham. An introduction to quantum cryptography. In *ISQW*, ISI Kolkata, Mar. 2012.

### Talks in Conferences Without Proceedings

[2143] R. Alléaume. From academic research to the development of a commercial quantum key distribution system. In *L'innovation, de la sphère universitaire au monde académique*, Paris, Dec. 2012.
[2144] J. Clarke, M. Riguidel, N. Suri, and A. Pasic. Building a long term strategy for international collaboration in trustworthy ict - security, privacy and trust in global networks and services. In *1st SysSec Workshop*, Amsterdam The Netherlands, July 2011.
[2145] T. Debuisschert, S. Fossier, R. Tualle-Brouri, P. Grangier, E. Diamanti, A. Leverrier, R. Alléaume, P. Pache, P. Painchault, P. Jouguet, and S. Kunz-Jacques. Renforcer la sécurité du chiffrement en couplant cryptographie quantique et cryptographie classique. In *COLOQ'12*, Marseille, France, July 2011.
[2146] T. Debuisschert, S. Fossier, R. Tualle-Brouri, P. Grangier, E. Diamanti, A. Leverrier, R. Alléaume, P. Pache, P. Painchault, P. Jouguet, and S. Kunz-Jacques. Field implementation of symmetric encryption with quantum key renewal. In *Continuous-variable quantum information processing (CV-QIP'11) Workshop and Hipercom Meeting*, Paris, France, Sept. 2011.
[2147] T. Debuisschert, S. Fossier, R. Tualle-Brouri, P. Grangier, E. Diamanti, A. Leverrier, R. Alléaume, P. Pache, P. Painchault, P. Jouguet, and S. Kunz-Jacques. Strengthening classical symmetric encyption with continuous-variable quantum key distribution. In *Conference on Lasers and Electro-Optics (CLEO)*, San Jose, Etats-Unis, May 2012.
[2148] T. Debuisschert, S. Fossier, R. Tualle-Brouri, P. Grangier, E. Diamanti, A. Leverrier, R. Alléaume, P. Pache, P. Painchault, P. Jouguet, and S. Kunz-Jacques. Continuous-variable quantum key distribution strengthening classical symmetric encryption. In *Second GdR "Information Quantique: Fondements et Applications" Workshop*, Grenoble, France, Nov. 2012.
[2149] E. Diamanti. Securiy and implementation of continuous-variable quantum key distribution systems. In *Séminaire Clarendon Laboratory, Oxford University*, Oxford, Grande Bretagne, Mar. 2009.
[2150] E. Diamanti. Long-distance continuous-variable quantum key distribution. In *Séminaire Laboratory for Quantum Photonics, Columbia University*, New York, Etats-Unis, Apr. 2012.
[2151] E. Diamanti. Long-distance continuous-variable quantum key distribution. In *Séminaire Universidad Complutense de Madrid*, Madrid, Espagne, Nov. 2012.
[2152] E. Diamanti, R. Alléaume, F. Roueff, and N. Lutkenhaus. Topological optimization of quantum key distribution networks. In *International Conference on Quantum Communications and Quantum Networking (QuantumComm)*, Vico Equense, Naples, Italie, Oct. 2009.
[2153] E. Diamanti, R. Alléaume, A. Leverrier, F. Roueff, N. Lutkenhaus, S. Fossier, T. Debuisschert, R. Tualle-Brouri, P. Grangier, P. Jouguet, and S. Kunz-Jacques. Quantum cryptography and network security. In *Présentation invitée "Updating Quantum Cryptography and Communications (UQCC) Conference"*, Tokyo, Japon, Oct. 2010.
[2154] E. Diamanti, P. Jouguet, S. Kunz-Jacques, and P. Grangier. Experimental demonstration of long-distance continuous-variable quantum key distribution. In *International Conference on Quantum Information and Technology (ICQIT)*, Tokyo, Japon, Jan. 2013.
[2155] J. Ghalbouni, I. Agha, E. Diamanti, R. Frey, and I. Zaquine. Source de photons intriqués large bande pour distribution multiutilisateurs. In *GDR - IQFA, 1st Colloquium CNRS GDR 3322*, page 19, Nice, France, Mar. 2011.
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[2157] J. Ghalbouni, I. Agha, E. Diamanti, and I. Zaquine. Distribution of photon pairs in a wdm environment. In *GDR - IQFA, 2nd Workshop CNRS GDR 3322*, page 30, Grenoble, Nov. 2012.
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[2161] S. Guilbaud, J. L. Smirr, I. Agha, E. Diamanti, R. Frey, and I. Zaquine. Narrowband entangled photon pair source at 1550 nm for future quantum networks. In *GDR - IQFA, 1st Colloquium CNRS GDR 3322*, page 20, Nice, France, Mar. 2011.

[2162] S. Guilbaud, J. L. Smirr, I. Agha, E. Diamanti, R. Frey, and I. Zaquine. Source de photons intriqués de faible largeur spectrale pour les communications quantiques du futur. In *COLOQ'12*, page 109, Marseille, July 2011.

[2163] Q. He, I. Zaquine, R. Andre, G. Roosen, and R. Frey. Bragg diffraction regime in thin semiconductor 2d refractive index gratings. In *PR 09*, Bad Honnef, Allemagne, June 2009.

[2164] P. Jouguet, S. Kunz-Jacques, A. Leverrier, and E. Diamanti. Improving the performance of continuous-variable quantum key distribution : study of practical imperfections and high-performance reconciliation. In *Second Annual Conference on Quantum Cryptography (QCRYPT 2012)*, Singapore, Sept. 2012.

[2165] P. Jouguet, S. Kunz-Jacques, A. Leverrier, P. Grangier, and E. Diamanti. Experimental demonstration of long-distance continuous-variable quantum key distribution. In *Second GdR "Information Quantique: Fondements et Applications" Workshop*, Grenoble, France, Nov. 2012.

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[2167] P. Jouguet, S. Kunz-Jacques, A. Leverrier, P. Grangier, and E. Diamanti. Experimental demonstration of long-distance continuous-variable quantum key distribution. In *Topical Research Meetings on Physics: Quantum technologies: taking concepts through to implementations*, Londres, Grande Bretagne, Dec. 2012.

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[2169] R. Kumar, H. Qin, and R. Alléaume. Balanced homodyne detection as a coherent mode selector for quantum communications in wdm environment. In *QCRYPT 2012*, Singapore, Sept. 2012.

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### 9.5.2 Public Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008–2010 | SEQURE - Symmetric Encryption with QUantum key REnewal | ANR | R. Alléaume | 45,5 |
| 2008–2011 | BUGYO BEYOND | Europe | M. Riguidel | 92,5 |
| 2009 | Expertise | ITEA E-CONFIDENTIAL | J. Leneutre | 183,7 |
| 2009–2011 | COCQ - | ANR Domaines Emergents | D. Markham | |
| 2009–2013 | eQUANET - embryonic Quantum Network | ANR | I. Zaquine | 60 |
| 2010–2013 | Sécurité quantique | SESAM 2009 (Région Ile de France) | R. Alléaume (coord.) | 35 |
| 2010–2012 | GENEPHY - Génération de paires de photons corrélés dans des fibres hybrides | Cnano Ile de France | I. Zaquine | 9 |
| 2010–2013 | Q-CERT Cryptographic security evaluation and certification | FP7 | R. Alléaume(coord.) | 92 |
| 2010–2013 | FREQUENCY, Fundamental research for quantum networks and cryptography | ANR | E. Diamanti, (coord.) | 53 |
| 2011–2013 | BIC | FP7 | M. Riguidel | 24 |
| 2011–2013 | SecFuNet coherent security architecture for virtual networks and cloud accesses | FP7 | P. Urien | 134 |
| 2011–2013 | On Demand Secured virtual networks on demand | | A. Serhrouchni | 64 |
| 2011–2014 | QLNCC Quantum nonlocality and communication complexity | Digiteo | E. Diamanti | 76.6 |
| 2011–2014 | HIPERCOM High performance coherent quantum communications | Europe CHIST-ERA | E. Diamanti | 22.4 |
| 2011–2014 | HAKA Technological platform for the analysis of level 2/3 to 8 | | A. Serhrouchni | 10 |
| 2012–2013 | MSSTB Risk management, information systems security | | J. Leneutre | 66.5 |
| 2012–2013 | QUICHE Quantum information system characterization and experimentation | Digiteo | E. Diamanti | 59 |
| 2012–2015 | G-SAFE Protection, cloud computing | | A. Serhrouchni | 60 |
| 2012–2015 | NLQCC Quantum non-locality, computing and cryptography | ANR | M. Kaplan (coord.) | 22 |
| 2013–2015 | CIQWII Cryptography in a Quantum world | Ville de Paris Emergence | D. Markham, (coord.) | 45 |
| 2013–2014 | QUANTUM-WDM ; WDM compatible quantum key distribution | ANR | R. Alléaume (coord.) | 96 |

### 9.5.3 Private Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008–2011 | CIFRE ROSERO Flexible models of private life in the digital sphere | THALES | M. Riguidel | 45.5 |
| 2008–2010 | NFC CONTAINER | | P. Urien | 20.5 |
| 2008–2009 | NFC and Chip card security | SAMSUNG | P. Urien | 30 |
| 2008–2010 | LEMON WAY | Security mobile bank applications | A. Serhrouchni | 20 |
| 2009 | OSEO - IP CINE | | M. Riguidel | 117.5 |
| 2009 | IP mobility protocols | EDF | H. Labiod | 14.5 |
| 2009–2010 | EMV bank cards | XIRING | P. Urien | 20 |
| 2009–2010 | M-SCARF Mobile Secure Accessible Rich media Finances | | P. Urien | 73.5 |
| 2010–2012 | CIFRE Digital identity adapted to convergence | Ethertrust | P. Urien | 12 |
| 2010–2013 | CIFRE Network security | Orange Labs | A. Serhrouchni | 10 |
| 2010–2013 | CIFRE Security and performance of quantum key distribution systems | Sequrenet | E. Diamanti | 10 |
| 2011–2012 | Security demonstrator | REGIENOV | H. Labiod | 10 |
| 2011–2014 | CIFRE Network security | Orange Labs | A. Serhrouchni | 10 |
| 2011 | Wireless vehicle communication | RENAULT | H. Labiod | 15 |
| 2011–2014 | CIFRE Security architecture for transportation systems | RENAULT | H. Labiod | 15 |
| 2012 | VE communication security | REGIENOV | H. Labiod | 22 |
| 2012–2014 | QVPN Highly secure communication network | | R. Alléaume | 30 |
| 2012–2013 | OPEN DTEX | | A. Serhrouchni | 0.7 |
| 2012–2016 | SEIDO Laboratory | EDF | J. Leneutre | 16 |
| 2013–2015 | DYNARIS Dynamic risk management in complex information systems | STIC Asia | J. Leneutre, (coord.) | 16 |

### 9.5.4 Patents and software

- Ahmed Serhrouchni : FR2945650A1 - WO2010130807A2 , pp. 20 : Method for securing documents by applying a specific identification number thereto, and apparatus for authenticating said number, 2010.
- Ahmed Serhrouchni : FR2945175A1 , pp. 15 : Method enabling phone users to check the phone invoices emitted by an operator, 2009.
- Mustapha Adib et Ahmed Serhrouchni : EP2210363 (A2) : Method for cryptographic key distribution in a hierarchized network, 2010.
- Ahmed Serhrouchni, Thomas Guillet et M. Badra : FR2928798 : Authentication process, 2009.

# 9.6 PhDs (Appendix 7)

## 9.6.1 Defended PhDs

[2201] A. Al Mamou. *Analyse de performances des réseaux de capteurs sans fil*. PhD thesis, Télécom ParisTech, Dec. 2009.

[2202] M. Aljnidi. *Modèles, architecture et protocoles de sécurité pour les réseaux autonomes mobiles*. PhD thesis, Télécom ParisTech, Dec. 2009.

[2203] A. Bocquet. *Modèles de sécurité réalistes pour la distribution quantique de clés*. PhD thesis, Télécom ParisTech, Dec. 2011.

[2204] L. P. Cambacédès. *Des relations entre sûreté et sécurité*. PhD thesis, Télécom ParisTech, June 2010.

[2205] H. Dau. *Sécurité dans les réseaux véhiculaires*. PhD thesis, Télécom ParisTech, Aug. 2011.

[2206] S. Delamare. *Routage pair-à-pair pour la fiabilité des communications*. PhD thesis, Télécom ParisTech, July 2010.

[2207] A. A. Diallo. *Sécurisation des infrastructures critiques : modélisation des interdépendances, simulation et détection des propagations des défaillances*. PhD thesis, Télécom ParisTech, Sept. 2010.

[2208] M. Fayçal. *Optimisation du trafic P2P sur les réseaux d'opérateurs*. PhD thesis, Télécom ParisTech, May 2010.

[2209] T. Guillet. *Sécurité de la téléphonie sur IP*. PhD thesis, Télécom ParisTech, Oct. 2010.

[2210] Q. He. *Diffraction de Bragg dans des réseaux minces à deux dimensions*. PhD thesis, Université Paris-Sud 11, Oct. 2008.

[2211] R. He. *Architecture et mécanismes de sécurité pour la conception et la réalisation de systèmes embarqués auto-protégeables évoluant dans des environnements pervasifs*. PhD thesis, Télécom ParisTech, Sept. 2010.

[2379] B. Kindarji. *Questions de sécurité et de vie privée autour des protocoles d'identifciations de personnes et d'objets*. PhD thesis, Télécom ParisTech, 2010.

[2213] S. Ktari. *Approche de distribution du plan de contrôle dans les réseaux de capteurs sans fil*. PhD thesis, Télécom ParisTech, Dec. 2009.

[2214] A. Leverrier. *Etude théorique de la distribution quantique de clés à variables continues*. PhD thesis, Telecom ParisTech, Nov. 2009.

[2215] N. Ngueguia. *Architecture de communications pour RFIDS actifs*. PhD thesis, Télécom ParisTech, Feb. 2012.

[2216] B. Rodier. *Intégration des cartes de paiement EMV aux systèmes d'authentification*. PhD thesis, Télécom ParisTech, Sept. 2009.

[2217] R. Saad. *A Service Provider oriented Peer to Peer architecture*. PhD thesis, Télécom ParisTech, Sept. 2010.

[2218] J. L. Smirr. *Vers une source de photons intriqués en polarisation de spectre étroit à 1550 nm : apports théoriques et expérimentaux.* PhD thesis, EDOM, Nov. 2010.

[2219] M. Sokhn. *Ontology driven framework for multimedia information retrieval in P2P network*. PhD thesis, Télécom ParisTech, Aug. 2011.

## 9.6.2 Ongoing PhDs

- L. Aranda (11/07—-) Modèles de sécurité pour la protection de la sphère privée
- G. Bovet(12/12—-) Architectures intelligentes et durables du Web des objets appliquées aux bâtiments intelligents
- Z. Drias(12/12—-) Cyber sécurity des systèmes de controle indystriels
- A. Famulari (03/11—-) Utilisation de réseaux en superposition malléables pour la distribution des média dans les réseaux sociaux en ligne
- Fotue Fotso (10/10—-) Routage et Aggregation dans les Reseaux de Capteurs sans Fils
- A. Garcia (03/13—-) Définition et conception de services de sécurité dans le Cloud Computing
- J. Ghalbouni (10/10—-), New concepts of entangled photon sources.
- H. Guerid (11/10—-), Etude des systèmes coopératifs décentralisés de supervision et de contremesure des incidents et attaques sur les réseaux

- B. Hamdane (01/12—-) Internet du futur : sécurité et nommage
- Z. Ismail(02/13—-) Architectures et mécanismes de sécurité pour la mise en place de stratégies de défense réactives optimales multicritères : application au réseau intelligent de distribution d'électricité
- M. Jemel(04/13—-) Définition, spécification et conception d'un coffre fort numérique
- P. Jouguet (09/10—-) Security and performance of continuous variable quantum key distribution devices
- M. Kasraoui (05/11—-)
- A. Makiou(06/12—-) Règles de sécurité et analyse du trafic
- A. Marin (10/09—-) Flot d'information et intrication dans le traitement quantique de l'information. Utilisation, sécurité et extension des réseaux "graph states" de l'information quantique.
- M. Msahli(12/12—-) Déploiement dynamique des services réseaux sécurisés
- R. Moalla (04/11—-) Etude d'une architecture de sécurité de bout en bout pour les systèmes de transports intelligents
- S. Natouri (11/10—-) Résilience des réseaux et services : détection, réaction et reprise.
- T. Nguyen (12/11—-) Validation de protocoles de sécurité dans des environnements ouverts et mobiles
- A. Pappa (11/10—-) Multi-party quantum cryptographic primitives in realistic environments
- X. Qian(03/13—-) Contrôle d'accès basé sur l'organisation pour une meilleure intégration des ressources et des services dans le contexte du «cloud computing»
- H. Qin (11/11—-) Sécurité pratique de systèmes de cryptographie quantique : étude d'attaques et développement de contre-mesures.
- A. Sohbi (11/12–)Protocoles d'information quantique basés sur l'intrication multipartite
- S. Souissi(06/12—-) Highly accurate kernel analyser
- C. Thibaud (01/09—-) Confiance, résilience et assurance dans les grands systèmes numériques et informatiques
- J. Zhang(04/13—-)
- Y. Zhao(10/12—-) Architecture et mécanismes de sécurité dans l'internet du futur
- G. Zhioua (04/11—-) Evaluation de l'impact de l'intégration des réseaux ad hoc dans les réseaux cellulaires

# Chapter 10

# Mathematics of Information, Communications, and Computation (MIC2)

## 10.1 Executive Summary (Appendix 1)

**Team Leader** L. Decreusefond (01/09–12/11), O. Hudry (01/06–12/08, 01/12–)

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**Initial Staff** Faculty: 5 PR, 4 MC, 1 DR, 1 CR; 3 Postdocs and sabbaticals; 13 PhD students.

**Staff who Left** Permanent Staff: 4 persons (total of 150 months).

**Staff who Were Hired** : 1 person (former post-doctoral student at the EPFL)

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**Scientific Highlights**

- In tight collaboration with P. Martins of RMS team, topological algebra and stochastic geometry have been combined to develop a whole new mathematical paradigm to characterize the geometry of cellular networks. It resulted in 4 co-directed PhD thesis, a tenth of papers, a grant from Orange Labs and a collaboration with Tsinghua University (Beijing, China).
- Inauguration on April 20, 2011 of a joint research laboratory Morpho-Telecom Paristech (ISA), dedicated to meeting the technological challenges associated with identity protection and data security. This lab will develop knowledge in biometry, computer security, cryptography, component security and identity-management systems among others.
- Hugues Randriambolona initiated the study of *multiplicative properties of codes*. This led to many advances both in pure coding theory as well as in various other fields such as algebraic complexity theory, extremal combinatorics, cryptography, and multi-party computation.
- Our expertise in identifying codes and watching systems results in a dozen of articles, one PhD thesis, invited talks in international conferences, reviews for international journals, participation to PhD theses defenses, and a collaboration with the university of Turku (Finland).
- The so-called Kailath innovation conjecture of non-linear filtering has been solved by A.S. Üstünel.

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**Scientific Production** 85 articles in Journals; 4 Books; 6 Book chapters; 48 articles in Proceedings

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**Major Publications**


- I. Camilier, L. Decreusefond: Quasi-invariance and integration by parts for determinantal and permanental processes, Journal of Functional Analysis, vol. 259 (2010).
- J. Bringer, H. Chabanne, G. Cohen, B. Kindarji, G. Zémor: Theoretical and practical boundaries of binary secure sketches, IEEE Transactions on Information Forensics and Security, vol 3, (4) 673-683 (2008).
- H. Randriambololona: Bilinear complexity of algebras and the Chudnovsky-Chudnovsky interpolation method, J. of Complexity 28 (4), 489–517 (2012).
- I. Charon, I. Honkala, O. Hudry, A. Lobstein: Minimum Sizes of Identifying Codes in Graphs Differing by One Vertex, Cryptography and Communications - Discrete Structures, Boolean Functions and Sequences 5, 2013, 119-136.

- J. Sakarovitch: Elements of Automata Theory, Cambridge University Press, 2009.
- A.S Üstünel: Entropy, invertibility and variational calculus of adapted shifts on Wiener space. Journal of Functional Analysis 257(11), 2009.

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**Major Documents**

- The development of VAUCANSON, a C++ platform for computing with weighted automata and transducers written in collaboration with a team from EPITA, has been carried on. A first stable version, VAUCANSON 1.4, has been released in July 2011 and will serve both as a test suite and a milestone for future versions.
- Patent pending: Homomorphic encryption for the exclusive OR and secure computation of Hamming distance with Herve Chabanne and Alain Patey (Morpho).
- Thomas Fuhr (PhD student of Hugues Randriambololona) was part of the team that designed the Shabal hash function, which went up to the semi-final round of the NIST SHA-3 competition meant to define the next-generation standard of cryptographic hash functions.

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**Impact and Attractivity**

- G. Cohen has become IEEE Fellow in 2013. He is also the chairman and founder of the IEEE French Chapter in Information Theory (1993-) and the Telecom ParisTech expert for "Identity and Security Alliance" (joint laboratory with Morpho).
- The members of the team organize international conferences (for ex.: SING7 or EMPG in 2011) or are members of scientific committees of such international conferences. Special issues devoted to these events have been published, with members of the team as the editors.
- On June 2010, we organized an international colloquium in the honor of the 60th birthday of A.S. Üstünel. Around 60 participants came to hear the talks of the most prominent researchers in stochastic analysis and related fields. We edited proceedings of these memorable days [2310].
- Besides the publication of special issues devoted to international conferences (see above), members of the team are also involved in journals as a chief editor ("Mathematics and Social Sciences") or an associate editor (IEEE-IT, RAIRO, AMC).
- J. Sakarovitch has been elected Chair of the Technical Committee 1 (Foundations of Computer Science) of IFIP in January 2013. He is a member of the TC since its establishment in 1989.

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**Interaction with Economic and Social Spheres**

- In the framework of ISA, supervision of 3 PhD Thesis related to biometry, secure distributed computations and security of programs, supported by Morpho CIFRE scholarships.
- L. Decreusefond was responsible of the sub-group MAIRCI of the French society of applied mathematics (SMAI). He co-organized three workshops between 2010 and 2012, see `http://smai.emath.fr/spip.php?article227`.
- Presidency of the French society of operational research (ROADEF) in 2008-2009 (Olivier Hudry).
- Hugues Randriam was part of the DIOPHANTE Jeunes Chercheuses et Jeunes Chercheurs ANR project (2006-2010).
- A.S. Üstünel was scientific counselor of Natixis bank in 2007-2008.

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**Contributions to Higher Education**

- O. Hudry contributed to the creation (2011) of the “Master parisien de recherche opérationnelle” (MPR0), involving Polytechnique ParisTech, ENSTA ParisTech, the CNAM and the ENSIIE. He is the representative of Telecom ParisTech for this master.
- I. Charon designed websites devoted to the learning of C and Java languages, which counts more than 100,000 visits.
- J. Sakarovitch is the responsible for the module “Modelisation with finite automata” within the “Master Parisien de Recherche en Informatique” (MPRI). He is the representative of Telecom ParisTech both at the Study Council and at the Board of Directors of the master.
- The course on Malliavin calculus (given by A.S. Üstünel and L. Decreusefond), which is almost unique in Europe, is now part of the Master program in probability of University Paris 6.
- A new set of courses (“parcours”) has been created (2012) for the teaching of operational research at Télécom ParisTech.

## 10.2 People

Team leader (01/09–12/11), O. Hudry (01/06–12/08, 01/12–)

Faculty: P. Bourgade (AP,07/07–09/10), I. Camilier (AP, 07/07–09/10), I. Charon (P, -06/11; Emeritus), G. Cohen (P), L. Decreusefond (P), O. Hudry (P), A. Lobstein (CR CNRS), D. Madore (AP), B. Meyer (AP, 09/11-), H. Randriambololona (AP), J. Sakarovitch (DR CNRS, -06/13; Emeritus), A.S. Üstünel (P).

Postdocs: T. Courtat (04/12-03/13).

PhD students: P.-Y. Angrand (09/08–03/12), D. Auger (10/07–06/10), I. Camilier (07/07–09/10), E. Ferraz (01/09–01/12), I. Flint (11/10–); J.-P. Flori (09/08–02/12), T. Fuhr (10/08–10/11), B. Kindarji (09/07–06/10), R. Lassalle (09/09–06/12), A. Patey (05/11–), J. Valentin (04/09–), A. Vergne (10/10–), L. Riviere (10/12–), T.T Vu (09/08-09/12).

## 10.3 Overview

Our research is devoted to concepts, methods and models coming from mathematics and computer sciences. Our works are twofold: on the one hand, we apply abstract and generic mathematical results to the computer real world (biometry, optical networks, quantum networks, mobile networks). On the other hand, we consider new mathematical problems raised by the applications (differential geometry, algebraic geometry, automata, infinite dimensional calculus). For instance, classic tools of combinatorial optimization, such as graphs and linear programming, are revisited for their applications to the design of optical networks. We also strongly believe in the necessity to develop abstract theories like algebraic geometry or infinite dimensional analysis, in order to forge the tools which will be used in a near future to model and analyze more and more complex phenomena.

## 10.4 Research Themes

### 10.4.1 Probability and stochastic modeling

**Faculty** L. Decreusefond, A.S. Üstünel

**Highlights: Scientific Production**

- I. Camilier, L. Decreusefond : Quasi-invariance and integration by parts for determinantal and permanental processes, Journal of Functional Analysis, vol. 259 (2010).
- L. Decreusefond, E. Ferraz, H. Randriambololona, A. Vergne : Simplicial Homology of Random Configurations, Journal of Advances in Applied Probability, 2013 (to appear).
- R. Lassalle, A.S. Üstünel: Local Invertibility of Adapted Shifts on Wiener Space and Related Topics, Malliavin Calculus and Stochastic Analysis, Springer Proceedings in Mathematics & Statistics Volume 34, 2013.
- A.S. Üstünel : Persistence of invertibility in the Wiener space. Communications on Stochastic Analysis 4(2), 2010.
- A.S Üstünel: Entropy, invertibility and variational calculus of adapted shifts on Wiener space. Journal of Functional Analysis 257(11), 2009.

**Highlights: Impact**

- The workshop in honor of the 60th birthday of A.S. Üstünel attracted about 60 persons in the audience and 8 “academicians” (members of science academies) as speakers.
- L. Decreusefond was invited as plenary speaker at Oberwolfach and the 17th Workshop on stochastic geometry `http://www.sg2013.umk.pl/?q=node/5`

– A.S Üstünel: Entropy, invertibility and variational calculus of adapted shifts on Wiener space. Journal of Functional Analysis 257(11), 2009.

**Highlights: Interactions with Society**

– Orange Labs grant (180 k €), realization of a simulator of radio wave propagation in a random urban environment

– L. Decreusefond was responsible of a group of the French applied mathematics society and as such organized three workshops dedicated to interactions of maths between industry and academics.

The optimal transportation problem dates back to the eighteenth century. Its modern approach was introduced in the forties by Kantorovitch as an optimization problem in a space of probability. A full solution for the quadratic cost was found in the nineties by Y. Brenier. Because of its numerous applications, for instance to functional inequalities, it is sensible to look at a generalization of this problem to infinite dimension spaces. The optimal transportation problem for a singular quadratic cost on the Wiener space was solved a few years ago. We are now in position to develop consequences and applications. In particular, we found necessary and sufficient conditions for a perturbation of the identity to be invertible in the Wiener space. We also gave some applications to filtering theory. In [2305], Üstünel found a simple result: a causal process on the Wiener space is the unique strong solution of a SDE (stochastic differential equation) if and only if the kinetic energy of its drift is equal to the relative entropy of the law of the process with respect to the Wiener measure. Applications and extensions of this result is the subject of the PhD of R. Lassalle . During last year, Üstünel also extended Talagrand's transport inequality to general diffusion processes with Lipschitz continuous diffusion coefficient and with a very singular drift coefficient, in such a way that this inequality applies to Wigner process which is of fundamental importance in the topics of random matrices and Riemann's conjecture. In financial mathematics, the quasi-linear inequality for American options pricing has already been solved by Üstünel a couple of years ago in the hypoelliptic case with smooth coefficients, using the stochastic calculus of variations of Paul Malliavin [2304]. In his Ph.D. thesis, J. Valentin extended these results to the diffusions whose (degenerate) coefficients possess only some Sobolev regularity by making some deep applications of harmonic analysis in this frame.

The mathematical properties of point processes are well known only for a very few number of processes. Unfortunately, in real life, it is seldom true that the real phenomenon can be modeled precisely by one of the known processes. It is thus of the utmost importance to increase the set of "known" point processes. In [2262], we established the basis of the stochastic calculus with respect to determinantal and permanental point processes. In particular, we computed an integration by parts formula in the sense of Malliavin calculus. This work is now continued in the thesis of I. Flint who is interested in the further properties of these point processes.

Several years ago, we started a collaboration with P. Martins (NMS team) on new mathematical paradigms for the performance evaluation of telecommunication systems. Using concentration inequalities (see [2308] for an introduction to this formula in the context of point processes), we developed robust dimensioning formulas for LTE radio-systems like OFDMA [2350] and then further evaluated the energy consumption of such systems (see the thesis soon to be defended of T.T. Vu). Another line of thought is the usage of algebraic topology for sensor and cellular networks. For randomly located points, representing either mobiles, base stations or sensors, etc. we construct not only its proximity graph (there is an edge between two nodes if they are less than some distance apart) but also its *proximity complex*. A proximity complex is a list 3-uples, 4-uples and so on such that an $n$-uple $[x_1, ..., x_n]$ belongs to this list if and only if the intersection of the balls centered on the $n$ points $(x_1, ..., x_n)$, with the previous distance as a radius, is not empty. Such a construction contains much more information on the underlying topology of the cloud of points. We know from algebraic topology that we can then recover the number of connected components but also the number of *holes*: the number of domains of the plane which are not *covered*. E. Ferraz in his thesis, computed some characteristics of such random complexes using Malliavin calculus formulas [2263] and concentration inequality. The thesis of A. Vergne continues this work. We devised an algorithm based on these ideas to optimally switch off some

sensors in order to save some power with coverage maintained [2368]. The complexity of this algorithm has been shown to be polynomial in several typical situations (Erdös-Renyi and Poisson random geometric graphs for instance)

### 10.4.2 Combinatorics and Optimization

**Faculty** I. Charon, O. Hudry, A. Lobstein

**Highlights: Scientific Production**

- D. Auger, I. Charon, O. Hudry, A. Lobstein, On the sizes of graph and their powers: the undirected case, Discrete Applied Mathematics 159, 2011, 1666-1675.
- I. Charon, O. Hudry, A. Lobstein, Extremal values for identification, domination and maximum cliques in twin-free graphs, Ars Combinatoria 101, 2011, 161-185.
- O. Hudry, NP-hardness of the computation of a median equivalence relation in classification (Régnier's problem), Mathematics and Social Sciences 197, 2012, 83-97.
- I. Charon, O. Hudry, A. Lobstein, Extremal values for the maximum degree in a twin-free graph, Ars Combinatoria 107, 2012, 257-274.
- I. Charon, I. Honkala, O. Hudry, A. Lobstein, Minimum Sizes of Identifying Codes in Graphs Differing by One Vertex, Cryptography and Communications - Discrete Structures, Boolean Functions and Sequences 5, 2013, 119-136.

**Highlights: Impact**

- Organization of workshops or of conferences: "Mathématiques discrètes : théories et usages" (2009), "Optimisation des réseaux" (2010), workshop in honor of Jean-Pierre Barthélemy (2011), "7th Spain-Italy-Netherlands Meeting on Game Theory" (2011), "2011 Meeting of the European Mathematical Psychology Group" (2011), "Algorithms and Permutations 2012" (2012).
- Edition of special issues of journals: Discrete Applied Mathematics 156 (8), 2008; RAIRO - Operations Research 42 (4), 2008; Mathematics and Social Sciences 187, 2009; Mathematics and Social Sciences 190, 2010; Mathematics and Social Sciences 197, 2012; Mathematics and Social Sciences 199, 2012; Electronic Notes in Discrete Mathematics, 2013.
- Participations to international conferences as invited speakers in plenary sessions.
- Contributions to encyclopedies.

**Highlights: Interactions with Society**

- O. Hudry was the elected president of the French society of operational research (ROADEF) in 2008-2009.
- O. Hudry was a member of the board of the "Fédération des associations françaises des sciences et technologies de l'information" (ASTI) from 2007 to 2011.
- Contribution to the creation (2011) of the "Master parisien de recherche opérationnelle" (MPR0), involving Polytechnique ParisTech, ENSTA ParisTech, the CNAM and the ENSIIE.

Any technological system will eventually suffer errors or failures. Then it is necessary to develop tools to handle such events. For instance, in a multiprocessor architecture, we may want to locate the malfunctioning processors. The so-called identifying codes in graphs are one of the best possible ways to achieve this goal. Hence, we studied the properties of these codes, as well as the ones of the graphs admitting identifying codes, called twin-free graphs. Different aspects are considered: structural and combinatorial properties, generalization to watching systems, study of special graphs, complexity and algorithmic issues [2225, 2226, 2254, 2248, 2227, 2228, 2230, 2257, 2256, 2235, 2255, 2240, 2239, 2229, 2258, 2233, 2232]. The study of identifying codes of a graph $G$ for a radius $r$ greater than 1 can be related to the study of identifying

codes of the $r$-th power of $G$ for a radius equal to 1. This led us to study the powers of graphs and their properties [2231, 2234].

Another direction of research deals with mathematical aspects of the aggregation of binary relations, through the linear ordering problem for tournaments and consensus procedures. This includes complexity issues and comparisons between different methods [2249, 2278, 2237, 2279, 2280, 2252, 2285, 2251, 2282, 2283, 2253, 2281, 2284, 2361, 2345, 2360].

A last topic is about combinatorial optimization and more generally operations research [2321]. This includes works on the design of exact methods or of some metaheuristics [2343, 2318, 2344, 2250, 2319] in order to solve NP-hard problems [2313]. Applications can be found in [2326, 2325, 2238] for the resolution of the so-called Routing and Wavelength Assignment Problem and for the problems depicted above [2346].

Besides the publications associated with these works, we may mention also the organization of conferences (2010 workshop Optimization in networks; 7th Spain-Italy-Netherlands Meeting on Game Theory (SING7), 2011; workshop to the memory of Jean-Pierre Barthélemy, 2011; 2011 conference of the European Mathematical Psychology Group (EMPG 2011)) or of special issues of journals [2316, 2315].

### 10.4.3 Coding theory

**Faculty** G. Cohen, D. Madore, B. Meyer, H. Randriambololona

**Highlights : scientific production**

- E. Brier, J.-S. Coron, T. Icart, D. Madore, H. Randriam, M. Tibouchi. Efficient indifferentiable hashing into ordinary elliptic curves. CRYPTO 2010, Springer LNCS 6223, pp. 237–254.
- J. Bringer, H. Chabanne, G. Cohen, B. Kindarji, G. Zémor: Theoretical and practical boundaries of binary secure sketches, IEEE Transactions on Information Forensics and Security, vol 3, (4) 673-683 (2008).
- F.N. Castro, H. Randriam, I. Rubio, H.F. Mattson Jr. Divisibility of exponential sums via elementary methods. J. Number Theory 130 (2010), no 7, 1520–1536.
- G. Cohen, E. Fachini, J. Korner. Skewincidence. IEEE Trans. Inform. Th. vol 57 no 11, 7313-7316 (2011)
- H. Randriambololona. Bilinear complexity of algebras and the Chudnovsky-Chudnovsky interpolation method. J. Complexity 28 (2012), no 4, 489–517.

**Highlights : Impact**

- G. Cohen has become IEEE Fellow in 2013. He is also the chairman and founder of the IEEE French Chapter in Information Theory.
- Invitations as plenary speaker in various international conferences.
- Editorial responsabilities in various international journals.

**Highlights: Interactions with Society**

- Creation of the “Identity and Security Alliance” (joint laboratory between Telecom ParisTech and Morpho).

Our research encompasses both the fundamental aspects of coding theory and related mathematical fields (combinatorics, algebraic geometry, number theory), as well as their applications (digital communications, cryptography, biometry).

Part of our research can be classified as combinatorial coding theory. This includes our study of identifying codes, of witness sets, of zero-error capacity, or of codes with weight constraints. Also, mainly in the framework of the ISA joint laboratory with Morpho, we studied applications in biometry, for example with B. Kindarji’s PhD thesis. Another work motivated by applications in

cryptography is the study of certain combinatorial properties of carries in modular addition. Still in cryptography, T. Fuhr's PhD thesis was on the design of hash functions, and A. Patey is now working on secure multi-party computation.

Another part of our research uses more sophisticated tools from algebraic geometry and number theory, although it is still directly motivated by coding theory. This includes our construction of intersecting codes and separating systems, as well as estimates on divisibility of exponential sums. More related to cryptography is our work on hashing on elliptic curves. Also, in his PhD thesis, J-P. Flori studied bent functions, Kloosterman sums, and the construction of elliptic curves by the complex multiplication method. In another direction, we worked on algebraic complexity theory, with major advances on the construction of multiplication algorithms in finite fields. Last, we're also interested on links between theoretical computer science and algebraic geometry, with problems such as the computability of étale cohomology.

### 10.4.4 Automata theory

**Faculty** J. Sakarovitch

The activity in this domain is conducted by J. Sakarovitch, together with his PhD students: R. de Souza (2004-2008), P.-Y. Angrand (2008-2012) and V. Marsault (2012-2015) and with several external collaborators, mainly S. Lombardy. It may be described under three themes: monographic work, research, and construction of software for handling finite automata (cf. Major documents).

Two chapters ([2320, 2323]) in collaborative books have been published, in addition to the English corrected version of the monography on automata ([2317]).

The research activity may be illustrated by works on finite valued transducers ([2300]), on weighted transducers ([2363]) on the study of a variant of the derivation of expressions ([2290]) and on the definition of the validity of weighted automata ([2291]).

# 10.5 Achievements (Appendix 6)

## 10.5.1 Scientific Productions

### Articles in Journals


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### 10.5.2 Public fundings

| Period | Project details | Funding | Principal investigator | Amount (k€) |
|---|---|---|---|---|
| 2006–2010 | ANR Diophante | ANR | H. Randriambololona | 18 |
| 2011–2014 | VAUCANSON 2 | ANR International | J. Sakarovitch | 73 |
| 2012–2015 | SECULAR Techniques biométriques pour renforcer les niveaux de sécurité de l'indexation multimédia | Autre programme national | G. Cohen | 20 |

### 10.5.3 Private Fundings

| Period | Project details | Funding | Principal investigator | Amount (k€) |
|---|---|---|---|---|
| 2007–2010 | CIFRE B. Kindarji *Protocoles d'identifications de personnes et d'objets* | Morpho | G. Cohen | 45 |
| 2011–2014 | Dimensionnement et qualité de service pour réseaux OFDMA dans un environnement réel - Application au LTE | Orange Labs | L. Decreusefond | 150 |
| 2011–2014 | CIFRE A. Patey *Matching biométrique distribué sécurisé* | Morpho | G. Cohen | 45 |
| 2012–2013 | Modélisation du path-loss dans les réseaux cellulaires | Orange Labs | L. Decreusefond, P. Martins | 70 |
| 2012–2015 | CIFRE L. Riviere *Contribution à la théorie de la sécurisation d'algorithmes cryptographiques* | Morpho | G. Cohen | 45 |

## 10.6 PhDs (Appendix 7)

### 10.6.1 Defended PhDs

[2372] P.-Y. Angrand. *Contributions à l'étude de la dérivation des epxressions rationnelles et à l'étude des systèmes de numération abstraits*. PhD thesis, Telecom ParisTech, Oct. 2012.
[2373] D. Auger. *Problèmes d'identification combinatoire et puissances de graphes*. PhD thesis, Télécom ParisTech, Feb. 2010.
[2374] P. Bourgade. *On random matrices and L-functions*. PhD thesis, Jan. 2009.
[2375] I. Camilier. *Etude des taux d'interet long terme Analyse stochastique des processus ponctuels determinantaux*. PhD thesis, Télécom ParisTech, 2010.
[2376] E. Ferraz. *Analyse stochastique des complexes simpliciaux aléatoires*. PhD thesis, Telecom ParisTech, Oct. 2012.
[2377] J.-P. Flori. *Questions de Sécurité et de Vie Privée autour des Protocoles d'Identifications de Personnes et d'Objets*. PhD thesis, Telecom ParisTech, Oct. 2010.
[2378] T. Fuhr. *Conception, preuves et analyse de fonctions de hachage cryptographiques*. PhD thesis, Télécom ParisTech, 2011.
[2379] B. Kindarji. *Questions de sécurité et de vie privée autour des protocoles d'identifciations de personnes et d'objets*. PhD thesis, Télécom ParisTech, 2010.
[2380] R. Lassalle. *Optimal transportation on Wiener spaces*. PhD thesis, Telecom ParisTech, Oct. 2012.

[2381] R. Medeiros. *Zero-error quantum capacity*. PhD thesis, École Nationale Supérieure des Télécommunications, ENST08, Sept. 2008.
[2382] J. Valentin. *Formule d'Itô faible et applications*. PhD thesis, Telecom ParisTech, Oct. 2012.
[2383] T.-T. Vu. *Géométrie aléatoire pour l'étude des systèmes de communications sans fil*. PhD thesis, Telecom ParisTech, Oct. 2012.

### 10.6.2 Ongoing PhDs

- A. Vergne (10/10–), Topologie algébrique pour le sensing en radio-cognitive.
- I. Flint (12/10–), Analyse stochastique des processus ponctuels à dépendance.
- A. Patey (10/11–), Matching biométrique distribué sécurisé.
- K. Hartmann (09/12–), Calcul variationnel sur l'espace de Wiener et applications.
- L. Riviere (10/12–), Contribution à la théorie de la sécurisation d'algorithmes crytographiques.
- K.C. Low (09/13–), Analyse stochastique des processus déterminantaux (co-tutelle avec l'Université de Singapour).
- F. Maunoury (09/13–), Analyse stochastique des processus permanantaux (co-tutelle avec Paris VII).

# Part IV

# Detailed activities: Signal and Image Processing

# Chapter 11

# Audio, Acoustics and Waves (AAO)

## 11.1 Executive Summary (Appendix 1)

**Team Leader** G. Richard

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**Initial Staff** 7 Professors; 1 Research Scientist;

**Staff who Left** 3 Permanent Staff (89 months) ; 16 PhD Students (450 months) ; 5 Postdocs (103 months) ; 1 Engineer (24 months).

**Permanent Staff who Were Hired** A. Gramfort (09/2012), (PostDoc, CEA)

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**Scientific Highlights**

- *International Projects:* Participation in 5 European projects including 2 Networks of excellence: IST Kspace (*Knowledge Space of Semantic Inference for Automatic Annotation and Retrieval of Multimedia Content*) and 3DLife (*Bringing the Media Internet to Life*)); Obtention of a 3 years Marie Curie Grant for a research fellow exchange between AAO and Columbia University (Prof. D. Ellis).
- *Publications:* 224 publications (56 journals, 141 conferences, 11 book chapters, 17 PhD thesis) for a global H-number of the group for this period of 25 (e.g. 25 papers published in [2008-2013] are cited at least 25 times). The ten most cited papers gather an average of 89 citations (source: Googlescholar).
- *Patents:* 3 new patents were filed and one previous patent was transfered to the SME Invoxia. (Patent transfer and scientific support for the development of a hands-free IP telephone, including microphone array and loudspeaker array).
- *Open source software:* Lead participation in Scikit-Learn (the corresponding journal paper published in 2011 is cited 265 times) and full development and distribution of YAAFE (*Yet Another Audio Features Extractor*) with a growing impact with over 2300 downloads since March 2010 (463 downloads in 01-03/2013) from 79 different countries.
- *Award:* PhD prize in 2010 (jointly awarded by EEA club, GRETSI and ISIS) (N. Bertin, who is now a permanent CNRS researcher);

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**Scientific Production** 56 Journals; 11 Book chapters; 141 Articles in Proceedings; 17 PhD thesis ; 32 Talks

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**Major Publications**


- G. Richard, S. Sundaram and S. Narayanan, "An overview on Perceptually Motivated Audio Indexing and Classification", Proceedings of the IEEE, Vol. 101, n°9, September 2013.
- A. Gramfort, D. Strohmeier, J. Haueisen, M. Hämäläinen, M. Kowalski, Time-frequency mixed-norm estimates: Sparse M/EEG imaging with non-stationary source activations, Neuroimage, 15;70:410-22, April 2013
- V. Emiya, R. Badeau and B. David, "Multipitch estimation of piano sounds using a new probabilistic spectral smoothness principle", IEEE Transactions on Audio, Speech and Language Processing, vol. 18, n° 6, pp. 1643 1654, 2010.

- S. Essid and C. Févotte. Smooth nonnegative matrix factorization for unsupervised audiovisual document structuring. IEEE Transactions on Multimedia, 15(2):415–425, Mar. 2013.
- R. Badeau, N. Bertin et E. Vincent, "Stability analysis of multiplicative update algorithms and application to non negative matrix factorization", IEEE Transactions on Neural Networks, vol. 21, n° 12, pp. 1869 1881, 2010.

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**Major Documents**

- S. Essid et al. A multi-modal dance corpus for research into interaction between humans in virtual environments. Journal on Multimodal User Interfaces, pages 1–14, Aug. 2012.;
- A. Gramfort is one of the lead developer of *scikit-learn* which is a widely used machine learning toolbox and of the *MNE-python* toolbox for M/EEG data analysis. These two projects are open to students in the framework of the Google Summer of Code program.
- Database production and public release which includes 3 databases for music separation and transcription (MAPS, ENST-Drums, QUASI), 1 for robot audition (ROMEO-HRTF) and 1 for multimodal scenes analysis (ACM Grand Challenge).

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**Impact and Attractivity**

- *Editing activities:* Editor and Associate editors of journals (A. Gramfort for *Jour. FBMIM*; G. Richard for IEEE Trans. on ASLP (2007–2011) and R. Badeau for EURASIP Jour. on AMSP (since 2012)); Guest editors of special issues in journals (B. David, Lead Guest Editor - IEEE Trans. on ASLP 2010; G. Richard, Guest Editor - IEEE JSTSP 2011 ; G. Richard Lead Guest Editor of EURASIP JASP 2013).
- *Organization of International conferences and workshops :* 14th edition of the International Workshop on Image and Audio Analysis for Multimedia Interactive Services (WIAMIS) 2013 (S. Essid, G. Richard : General Co-chairs); IEEE MMSP (Y. Grenier: Technical Co-chair); CFA 2010 (B. David, Technical co-chair); Acoustics08 (B. David, Technical Co-chair)
- Participation to technical committees of Scientific bodies (G. Richard, IEEE AASP TC), Major conferences (A. Gramfort, PRNI; G. Richard, ICASSP, Interspeech; S. Essid ACM MM, ICME; Y. Grenier, IWAENC; R. Badeau, ISSPA) and International PhD committees (G. Richard in 7 European countries).
- *National and International collaborations:* 65 % of published journal papers are co-authored with external collaborators; 5 European projects ; Collaboration with other research groups of LTCI in projects(OSEO-Quaero, FP7-VERVE, FP7-REVERIE, FP7-3Dlife) and PhD thesis supervision (3 joint PhDs with STA including 2 ongoing; 1 starting with MM).
- Invitation of tutorial/Keynotes talks in conferences (A. Gramfort, PRNI'2013, S. Essid and G. Richard at WIAMIS'2012, G. Richard at ACM Multimedia'2011) and in major international research labs.

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**Interaction with Economic and Social Spheres**

- Public scientific conference at "Espace Pierres Gilles de Genes, ESPCI" ("Does the computer has the sense of rythmn ?") by B. David and G. Richard.
- 6 CIFRE PhD theses with Orange (1), INA (2), Arkamys (1), Parrot (1), Audionamix (1)).
- A patent from AAO was transfered to the SME Invoxia (Patent transfer and scientific support for the development of a hands-free IP telephone, including microphone array and loudspeaker array).

- Serving as experts for funding agencies : ANR-CONTINT (G. Richard, member of Programme committee), OSEO (S. Essid), Dutch Technology Foundation STW (S. Essid), European Union (G. Richard)
- Technology transfer to instrument makers: for more than 10 years now, AAO regularly attends the JFIS workshop (ITEMM) with the goal to tackle applied science projects with the stringed instruments luthiers. Leads to the PAFI ANR-project (B. David) where a software and hardware platforms have been developed and used in the today practice of the craftsmen.

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**Contributions to Higher Education**

- Participation in University Masters *Méthodologie en Imagerie Médicale-Paris Descartes* (A. Gramfort), *Informatique-UPMC* (A. Gramfort, Y. Grenier, G. Richard (resp. of 1 UE)), *MVA-Paris Descartes/ENS Cachan* (Y. Grenier, G. Richard (resp. of 1 UE)), *ATIAM-UPMC* (R. Badeau, B. David (both resp. of 1 UE), G. Richard).
- Introduction of a new course of Signal processing based on active learning (e.g. problem and project based learning) for the 1st year of Telecom ParisTech engineering studies (B. David).
- Leading role in the reshape of the 1st year of study at Telecom ParisTech and in the proposal and then coordination of the newly introduced 6 months collaborative project (PACT, coord. B. David, [2470, 2474]).
- PhD students coordination: 17 PhDs awarded in the period. Amongst the 23 Phds students awarded in [2005 - 2011], 10 are now permanently employed in Academia, 2 at the European Patent office, 6 have permanent position in industry and 1 has started his company.
- Sessions for the benefit of "classes préparatoires" teachers, aka LIESSE: two sessions of a 2-day course on Python (A. Gramfort, S. Essid), 1 session on High Resolution Method (Y. Grenier, B. David, M. Maazaoui)

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## 11.2 People

**Team leader** G. Richard (FP)

**Faculty** R. Badeau (AP), B. David (AP), Y. Grenier (FP), C. Févotte (–12/09), N. Moreau (FP, –03/2010), S. Essid (AP), J. Prado (AP,-02/2011); A. Gramfort (AP,10/2012-).

**PhD students** M. Betser (–06/08), N. Bertin (10/05-10/09), J-L. Durrieu (01/07-05/10), M. Ramona (10/06-06/10), C. Joder (11/07-09/11), L. Oudre (10/07-11/10), F. Vallet (11/07-09/11), S. Gulluni (02/08-12/11), R. Hennequin (10/08-11/11), M. Maazaoui (01/09-), S. Fenêt (01/10-); B. Fuentes (10/09-03/12); R. Foucard (10/09-); M. Moussalam (10/09-12/12); F. Rigaud (10/10-); A. Liutkus (01/10-11/12);N. Lopez (05/11-) A. Masurelle (10/11-); X. Jaureguiberry (10/11-); C. Fox (10/10- ); A-C Conneau (01/12- ); H. Bai (10/12-); N. Seichepine (10/12-).

**PostDocs, engineers and sabbaticals** M. Lagrange (Postdoc,10/08-09/09), A. Ozerov (02/08-07/09), T. Fillon (Postdoc,10/08-04/13), B. Mathieu (Engineer,10/08-12/10), H.Takeugming (12/11-11/12), A. Dielmann (PostDoc, 11/10-03/11), A. Drémeau (PostDoc, 09/11-08/13), C. Damon (PostDoc, 01/12-), D. Mauro (Post Doc, 01/13-)

**External collaborators** L. Daudet (Institut Langevin, Paris), O. Derrien (LMA-Marseille), E. Vincent (INRIA Nancy), L. Devillers (LIMSI-CNRS, Orsay), L. Girin (GIPSA-Lab, Grenoble), R. Boyer (LSS, Orsay), A. Ozerov (Technicolor), S. Marchand (Univ. de Bretagne occidentale), N. Bertin (CNRS-IRISA, Rennes), F. Gautier (LAUM, Le Mans), X. Boutillon (LMS, Polytechnique), N. Evans (Eurecom), T. Sikora (Technical Univ. of Berlin), N. O'Connor (Dublin City University), E. Izquierdo (Queen Mary Univ., London), P. Daras (CERTH, Thessaloniki), B. Thirion et G. Varoquaux (INRIA-Saclay), M. Hamalaïnen (Harvard), M. Descoteaux (Sherbrooke Univ.), Y. Hua (Univ. of California), D. Ellis (Columbia Univ., New York).

## 11.3 Overview

The overall objective of this research group is to develop digital signal processing methods with applications to audio, music, multimodal and biomedical signals. Its activities range from theoretical work on machine learning for signal processing, signal models and sparse representations to computational optimization of algorithms.

An increased effort was in particular dedicated to adaptive methods for high resolution sinusoidal components tracking [2387, 2388, 2386] and sparse signal representations with a specific interest on those based on Matching Pursuit (MP), Probabilistic Latent Component Analysis (PLCA) or Non-negative Matrix factorization (NMF), that allow to decompose a signal using a limited number of atoms or basis functions. Several very interesting results were for example obtained for NMF concerning the stability of multiplicative update algorithms [2389, 2462], or the description of beta-divergence as a subclass of Bregman divergence [2412]. Several extensions of the NMF were also explored including the introduction of a new generalized model for High-Resolution NMF [2455], the extension to multichannel [3936], the presentation of a novel geometric algorithm based on single-class Support Vector Machines [2487], and the proposal of a general formulation of underdetermined source separation of Gaussian Processes [2422]. The applicability of these methods to generic problems such as audio indexing in the (scalable) compressed domain [2434], audio source separation or music signal indexing was demonstrated by introducing specific constraints deduced from the audio signal properties (use of harmonicity or temporal constraints for music transcription [2390, 2465, 2439], use of source production or timbre models for source separation [2396, 2397], use of time-frequency activations to model non-stationary audio events [2411],...). This methodological effort explores both deterministic and statistical approaches.

*Source separation* also appears to be at the heart of this research group with applications in nearly all the individual research themes.

Besides this methodological axis, the research tackled by the group can be organized in three main themes (which will be further discussed in section 11.4):

1. *Machine listening and audio source separation:* The objective of this theme is to improve the capability of machines to analyse and interpret complex audio situations by developing specific digital signal processing methods. This is the main research theme of the group.
2. *Audio and multimodal signal processing:* The objective of this theme is first to develop novel generic models and approaches for audio signal representation and compression and second to automatically process multimodal data streams (segmentation, structuring,...).
3. *Biomedical signal analysis:* is dedicated to the analysis of biomedical signals, in particular electroencephalographic (EEG) and magnetoencephalographic (MEG).

In terms of bibliometry (source GoogleScholar), the group's faculty members have co-authored over 200 papers including 56 journal papers, 141 conference papers and 11 books or book chapters. Considering that each faculty is at most half-time on research, the group staff is 3.25 Equivalent Full Time (EFT) researchers and which leads an average number of 11,5 papers per year per EFT researcher. The H-number of the group for this period is 25 (e.g. 25 papers published in the period 2008-2013 are cited at least 25 times) and the ten most cited papers gather an average of 89 citations (ranging from 56 to 280).

Besides publications, the group promotes whenever possible research reproducibility by distributing open source software or by participating to open source software initiatives (for example, one of the members of the group is one of the lead developer of the scikit-learn which is a widely used machine learning toolbox and of the MNE-python toolbox for M/EEG data analysis). Recently, the group has been preparing jointly with with ENS-Cachan, with the support of the LMH (Hadamard) Labex, the launch of a new journal for reproducible research currently named *Audio and Signal Processing Algorithms Reviews*. This new journal will follow the spirit of an existing journal for image processing (IPOL).

In terms of attractivity and impact, the team is particularly visible at the international level with the participation in 5 European projects and the participation to international campaigns such as MIREX. Besides all members of the group are particularly active in Editing and Reviewing activities for major journals and conferences (editing activities in some of the most prestigious journals in this field including IEEE Transactions on Audio Speech and Language Processing, IEEE Journal on Selected Topics in Signal Processing, EURASIP journal on Advances in Signal Processing, Journal Frontiers in Brain Imaging Methods,... ). Some members of the group are also particularly active in scientific bodies (SFA, IEEE Audio and Acoustic signal Processing TC) and are regularly invited to international PhD committees, area chair in major conferences such as ICASSP for example. The group is also regularly receiving visits from researchers from all around the world and candidacies for sabbatical. As an example, following a previous 2 months visit of Dr. Mads Christensen, Professor Juan Pablo Bello (New York University) will come to the AAO group for a one year sabbatical starting in January 2014 on a Fullbright grant.

The group has also strong interactions with the socio-economic world. First the group is involved in a variety of collaborative projects with industry. Then, the group is also developping bilateral collaborations with industry in particular through CIFRE PhD thesis (2 with INA, 1 with Orange, 1 with Arkamys, 1 with Audionamix, 1 with Parrot). In parallel of an active publication activity, the AAO group has also filed three new patents in the period. One of the patents previously filed was also transferred to the SME Invoxia in this period along with a scientific support for an efficient technology transfer.

## 11.4 Research Themes

### 11.4.1 Machine listening and audio source separation

**Faculty** B. David, Y. Grenier, S. Essid, R. Badeau, G. Richard, C. Févotte (–12/09);

**Highlights: Scientific Production** [2426] (collaboration with Fraunhofer, Columbia Univ. and Tampere University, cited 50 times), [2402] (cited 75 times), [2389] (collaboration with INRIA, theoretical results, cited 21 times), [3933] (collaboration with STA), [2414] (cited 23 times)

**Highlights: Impact**

- ANR projects: DReaM (*Active music listening*) and DESAM (*Audio object decomposition with application to music*).
- CapDigital-ROMEO (*a project within "pôle de compétitivité" CapDigital, led by Aldebaran Robotics and aiming at creating a humanoid robot*), ROMEO2 (*a PIA "Projet d'Investissement d'Avenir", a follow-up to ROMEO aimed at bringing learning skill to a humanoid robot*)
- PhD prize in 2010 (jointly awarded by EEA club, GRETSI and ISIS) (N. Bertin);
- Organisation of a special issue in Eurasip Journal on Advances in Signal Processing on Informed Acoustic source separation analysis (2013, collaboration with Tampere Univ. of Techn., Bogazici Univ., Dublin Institute of Technology and Technicolor).
- OSEO-QUAERO (*Towards multimedia and multilingual search engines for professional and general public applications*), a very large scale French/German project.

**Highlights: Interactions with Society**

- Technology transfer to SME Invoxia (Patent transfer and scientific support for the development of a hands-free IP telephone, including microphone array and loudspeaker array).
- 2 patents filed including 1 in 2013 on Audio Fingerprinting.
- The open-source software YAAFE (*Yet Another Audio Features Extractor*). Growing impact (with over 2300 Downloads since March 2010 and 463 downloads between 01/01/2013 and 01/04/2013 from 79 different countries (mainly France, United States, Germany and United Kingdom)).
- Public scientific conference at "Espace Pierres Gilles de Genes, ESPCI" ("Does the computer has the sense of rythmn ?").
- 3 CIFRE PhD theses (with INA on Electro-acoustic music segmentation and transcription, Arkamys on speech dereverberation and with Parrot on noise reduction).

The objective of this theme is to improve the capability of machines to analyse complex audio situations by developing specific digital signal processing methods. This research theme encompasses a variety of situations ranging from speech signal dereverberation using a single microphone to complex audio and music scene analysis using one or several sensors.

#### Music analysis and audio source separation

A topic of major interest to the group is *Music transcription and source separation*, which are two intricate problems. Indeed, efficient source separation facilitates the transcription of the resulting sources and vice-versa. In music signal transcription, the group is directly interested in the four main problems which are *multiple fundamental frequencies estimation* (e.g. detection of simultaneous notes in a polyphonic musical recording [2402, 2439, 2505]), *rhythmical information tracking* (tempo and beat estimation [2526], *harmonic information estimation* (recognition of the chords sequence [2591, 3933, 3934]) and *timbre recognition* (musical instrument recognition [2413, 2532]). Whenever possible, the results obtained are submitted to national or international evaluation campaigns. In particular in 2011, our group has obtained the best results in several

subtasks of the Quaero competitive internal evaluation campaigns. Further, source separation approaches were developed for specific music transcription tasks such as piano transcription [2402] and main melody estimation (by the use of a NMF-based source-filter model for separating the singing voice from the musical accompaniment [2397]) but also for specific audio rendering tasks such as stereo signal remastering [3936].

Another topic of interest in the group, related to the recognition of musical audio events discussed above, is the so-called audio fingerprinting problem. The objective of audio fingerprinting is to identify a given audio excerpt (e.g. obtaining metada such as title and artist identification in the case of a musical song) using the sole audio signal. Our work in this domain has concentrated on the introduction of simple *audio fingerprints* which are highly robust to the major signal degradations observed in broadcast streams [2494] and on its capacity to scale up to very large databases or dynamically growing databases [2495]. More recently, a major extension was introduced which led to a versatile system capable of identifying not only identical excerpts but also "semantically similar" excerpts with large acoustical variations (such as re-recording, live/studio versions and in some cases cover versions recorded with complete different musicians). A patent was recently filled on this topic.

Another topic of interest to the group is *multimodal music classification* where the focus is on the incorporation of prior knowledge on the nature and structure of music data into discriminative classifiers, both at the signal level and the semantic level, using all the available data, including ancillary information possibly attached to the content (available meta-data, tags...) and/or user interaction (*relevance feedback*). As such, efforts have been dedicated to the alternative route to music transcription that consists in achieving *music-to-score-alignment*, given that musical scores have become widely available over the Internet, which has made the approach of using such scores for music transcription highly appealing. Our contributions along this line are mainly the introduction of an effective and scalable statistical framework using *Conditional Random Fields* [2414, 2415]. Further, user-interactive systems have been devised that rely on *active learning* techniques for the analysis of the structure of particular forms of music, namely *electro-acoustic music*, which cannot be envisaged without taking into account the viewpoint of a human analyst [2510, 2511, 2512]. Finally, in view of music similarity analysis [2418, 2499], the task of music auto-tagging (that is predicting user-tags for musical pieces) has been addressed, where multi-level, especially multi-scale classification systems have been developed using boosting techniques [2500, 2501].

**Robot audition and blind source separation**

A strong focus in robot audition is on multiple microphone techniques: beamforming for microphone arrays and blind source separation, some of these techniques being also applied to single microphone source separation and dereverberation.

Current work addresses the difficult problem of humanoid robot audition which needs, using a limited number of sensors, to be robust to movements of the robot and to highly variable environments. This task is part of the Romeo project that aims at building an humanoid robot (Romeo) that can act as a comprehensive assistant for persons suffering from loss of autonomy. Our approach follows a two-stage blind source separation strategy. The first stage consists in a fixed beamforming preprocessing to reduce the reverberation and the environmental noise. Due to the highly constrained context of robot audition, pre-recorded Head Related Transfer Functions (HRTFs) are used to estimate the beamforming filters. The use of the HRTF to estimate the beamformers allows to capture the head and torso effect on the manifold of the microphone array. The second stage is a blind source separation algorithm based on a $l_1$ norm minimization sparsity criterion. The results obtained highlighted the merit of the fixed beamforming preprocessing for improving the separation performances [2544, 2424]. A recent extension was also proposed by using a modified $l_p$ norm blind source separation criterion based on the source sparsity in the time-frequency domain. We followed a tempered approach where the sparsity constraint could be reinforced by varying the parameter $p$ of the $l_p$ to dynamically change from $l_1$ to $l_0$ norm. This variation is driven by a sigmoid function which allows to obtain smooth transition and to avoid

the divergence of this tempered approach. The merits of this method were demonstrated and compared to more classical schemes [2545].

Our cooperation with Invoxia has permitted to develop a combination of a microphone array and a loudspeaker array that allows hands-free communications with high quality of the captured speech, and a 3D restitution of various distant speakers in a local listening room. The transfer of a patent (Y. Grenier inventor) to Invoxia was the conclusion of this study. Invoxia has already designed two products using our technology (they call it In Vivo Acoustic: http://www.invoxia.com/fr/technologies/invivoacoustic), and the first of these products NVX 610 received a Best Innovation Award in CES 2012 (Las Vegas).

Another axis in this domain relates to signal capture in reverberant environment using a single sensor and a dedicated collaboration with the company Arkamys has permitted to develop novel dereverberation algorithms, based upon an estimation of the reverberation time [2542].

### 11.4.2 Audio and multimodal signal analysis

**Faculty** R. Badeau, S. Essid, G. Richard, N. Moreau (–03/2010 );

**Highlights: Scientific Production** [2433] (2008, cited 37 times; collaboration with Institut Langevin); [2425] (collaboration with Institut Langevin); [2438] (collaboration with INA), [3888] (collaboration with 5 European partners); [2430] (collaboration with Technicolor, ).

**Highlights: Impact**

- 2 European Networks of Excellence: FP6 Network of Excellence (NoE) IST Kspace (*Knowledge Space of Semantic Inference for Automatic Annotation and Retrieval of Multimedia Content*) and FP7-ICT NoE 3DLife (*Bringing the Media Internet to Life*)
- 1 European Integrated project FP7-ICT REVERIE (*REal and Virtual Engagement in Realistic Immersive Environments*)
- ANR DReaM (*Active music listening*) with collaboration with INPG Grenoble, Institut Langevin, University of Brest, Iklax.
- ACM MM' Grand Challenges: organization and data production for the 2011-2012 3DLife/Huawei challenges on *Realistic Interaction in Online Virtual Environments*;
- Organisation of the 14th edition of the International Workshop on Image and Audio Analysis for Multimedia Interactive Services (WIAMIS) 2013 - technically co-sponsored by IEEE SPS (http://wiamis2013.telecom-paristech.fr).

**Highlights: Interactions with Society**

- 1 Patent jointly filled with INPG Grenoble on Informed source Separation.
- Collaboration with Technicolor on Informed source Separation.
- 1 CIFRE Phd Thesis with INA on Audiovisual document structuring

#### Sound source compression, Acoustics and 3D Audio

In audio compression, the work was mostly dedicated to low to medium bit rate parametric audio coding. For low bit rate music coding applications, parametric coders are an efficient alternative to transform coders. In particular, sinusoidal modeling is widely used in response to the fact that most real-world audio signals are dominated by tonal components. Less used, the exponentially damped sinusoidal model (EDS) combined with a variable-length time segmentation is however considered as more powerful, but at the cost of an increased number of parameters. Our work has shown, however, that it is possible to design a joint scalar quantizer for amplitude, damping and phase parameters and obtain increased coding capabilities compared to the more traditional sinusoidal model. Our model incorporates in particular a dynamic temporal segmentation and psychoacoustic modeling and an asymptotically optimal entropy-constrained quantization method for the four sinusoid parameters (e.g. including damping) [2475, 2395].

On the other hand, investigations were pursued to develop highly scalable transform coders which can seamlessly operate from very low bit rate up to transparency. To that aim, sparse overcomplete representations are used to decompose the audio signals over a redundant union of bases (such as Modified Discrete Cosine Transform bases at different scales)[2433]. It was also shown that the high flexibility of the signal representations used in this coder allows to address various audio indexing tasks (such as beat tracking or musical genre recognition) directly in the transformed domain [2434] or to perform a large variety of music similarity tasks or structural-based audio coding [2557]. More recently, a novel Random Matching Pursuit algorithm was designed which allows to simulate a local search in a larger dictionary while operating at the cost of a search in a sub-sampled dictionary. The approach consists in using a non adaptive random sequence of subdictionaries in the decomposition process, thus parsing a large dictionary in a probabilistic fashion with no additional projection cost nor parameter estimation. Based upon a theoretical modeling exploiting order statistics and experimental evidences, it was shown that the novel algorithm can be efficiently used on sparse approximation problems and successfully applied to signal compression [2425]. On a more transversal axis, a comparative study of sparse greedy algorithms that had been independently introduced in speech and audio research communities was conducted. It was in particularly shown that the Matching Pursuit (MP) family of algorithms (MP, OMP, and OOMP) are equivalent to multi-stage gain-shape vector quantization algorithms previously designed for speech signals coding. Following this unified view, a new family of algorithms was introduced based on cyclic minimization principles and on the recent Cyclic Matching Pursuit [2398].

In parallel, our work on Informed source separation allowed us to propose a novel framework to close the gap between source separation and audio coding domains by exploiting source separation models and principles for multichannel audio coding [2423]. This novel approach, called Coding-based ISS (CISS) encodes the individual sources using not only a model as in source coding but also the observation of the mixture. This approach has several advantages including state of the art performance for multi-source audio coding in terms of rate-distorsion using Nonnegative Tensor Factorization as a source model [2567, 2430].

The group is also pursuing its activity in Acoustics and especially in audio rendering (or Audio3D) and musical acoustics. The audio rendering activity also benefits from the two European projects 3DLife and REVERIE. The group is in particular interested in developing novel hybrid approaches between pure physics-based approaches and perception-based approaches. One of the current lines of research consists in extending radiance-based transfer method to be effective for both the early part of the reverberation (early echoes) and late reverberation for which it was initially designed for. The musical acoustics activity is particularly focused to applying subspace methods and enumeration methods to the modal analysis of musical instruments, where it allows to investigate successfully the mid-frequency range [2401, 2400, 2399, 2575, 2485]. This activity benefited from the ANR PAFI project, a four years project in collaboration with French instrument makers.

**Audio-visual content and human activity analysis**

As far as multimedia content analysis is concerned, the group's efforts are mainly geared towards audio-visual document segmentation and structuring, where the focus has been mainly on radio and TV content analysis [2571, 2588, 2452].

On the methodological level, a special interest has been directed to kernel-based methods (Support Vector Machines, probabilistic distances, kernel change detection...) [2572, 2432, 2438] allowing us to develop original and effective architectures for tasks such as *audio diarization*, that is segmentation into broad classes of events (especially music/speech discrimination) and more specifically *speaker diarization* [2438].

Another line of work, conducted in collaboration with the STA group, is concerned with the development of new matrix factorisation techniques, which turn out to be particularly useful for document structuring [4082, 3889]. More recently, the focus has been on methods allowing a

meaningful joint decomposition of "temporally related" parallel streams of data, especially the audio and visual streams of a video content [4152].

In parallel, the topic of *human activity analysis* has attracted a growing interest within the AAO group, especially as part of its involvement in the 3DLife, EMC$^2$ and REVERIE European projects. The work is centered at the development of machine learning and signal processing techniques [1] amenable to the analysis of data recorded through multiple capturing devices of different natures (microphone and video-camera arrays, inertial measurement units and motion capture devices, depth sensors, physiological sensors...). In general, the originality of our approach lies in the adoption of methodologies whereby the useful information is hunted for by spotting regularities emerging jointly across the concurrent streams of observed data. From the applicative viewpoint the group's work revolves around multimodal action/gesture classification, especially dance gesture analysis, motivated by a use-case that has been promoted by the 3DLife/Huwaei Grand Challenge within ACM multimedia 2011-2013, that is a virtual dance class scenario [3888, 3489, 2489]. Problems of interest include dance performance alignment [2491, 2476], representation [2536] and recognition.

### 11.4.3 Biomedical signal analysis

**Researchers** J. Prado (-02/2011), S. Essid (30%), A. Gramfort (100%);

**Highlights: Scientific Production** [2410] (collobaration with INRIA/Neurospin, Harvard medical school, Ilmenau university, Supelec); [2593] (conference acceptance rate $\leq$ 20%; collaboration with INRIA/Neurospin and Ecole Centrale); [2471] (collaboration with ESPCI).

**Highlights: Impact**
- DGA-DGCIS project MEEGAPERF (*Monitoring EEG pour l'Anticipation des PERFormances*);
- European project FP7-VERVE (*Vanquishing fear and apathy through E-inclusion: personalized and populated Realistic Virtual Environments for clinical, home and mobile platforms*)
- Development of the MNE-Python (http://martinos.org/mne/) package supported by 2 Google Summer of Code student in 2013

The third research direction of the group is dedicated to the analysis of biomedical signals, in particular electroencephalographic (EEG) and magnetoencephalographic (MEG) which are respectively electrical and magnetic signals induced by the electrical activity of active neurons. M/EEG offer a unique opportunity to non-invasively measure the brain activity at a millisecond time scale with clinical applications (epilepsy, sleep disorders) as well as for cognitive neurosciences and brain computer interfaces (BCI).

The team has pursued its long-standing work on asleep subjects recorded using a single pair of EEG electrodes. The developed approach has two technological breakthroughs: an automated analysis pipeline and the use of a single EEG channel. The efficiency and robustness of the developed method have been quantified and experimentally validated in collaboration with a French company called Physip founded by a former PhD student. Another application of interest was the analysis of biomedical data about colonic transit time (CTT). In particular, a dedicated approach was designed to robustly estimate this colonic transit time even in situations where the patient omits to ingest the radiopaque markers for one or two days [2392].

The effort of the group in the domain of biomedical signal processing (especially multichannel EEG analysis) has been strengthened with the acceptance of two research projects. The first project (MEEGAPERF), started in September 2009, is centered at EEG-analysis for the realtime detection of physical performance decrease, using portable and lightweight EEG devices. The most recent work has been on artifact rejection [2471] with specific constraints: noisy experimental setups and limited number of electrodes. The second project (FP7-VERVE) aims at developing dedicated tools to support the treatment of people who are at risk of social exclusion due to fear and/or apathy associated with a disability. The group's work is focused on the analysis

1. often related to the ones developed for multimedia content analysis

of a patient's emotional state as he/she is submitted to a serious game treatment, based on EEG and ECG recordings used to monitor him/her.

The recent arrival of a new associate professor in biomedical signal processing, A. Gramfort, will allow this research topic to be further developed. Current directions are on the use of time-frequency representations for brain source localization [2410], as well as data-driven representation learning using sparse coding and dictionary learning techniques. In his research, A. Gramfort works on the development of statistical machine learning techniques for mining brain imaging data (MEG, EEG and functional MRI). A recent collaboration with Ecole Centrale Paris led to a paper at the IPMI conference [2593], known for being very selective.

# 11.5 Achievements (Appendix 6)

## 11.5.1 Scientific Productions

### Articles in Journals


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### Invited Talks and Tutorial

[2594] B. David and G. Richard. L'ordinateur a-t-il le sens du rythme ? In *Conférence Grand Public, Espace Pierre Gilles de Genes*, Paris, France, Dec. 2008.
[2595] G. Richard. Multimedia music signal processing. In *Tutorial at ACM Multimedia Conference*, Phoenix, USA, Nov. 2011.
[2596] G. Richard. Multimodal music processing. In *Dagstuhl Seminar on Multimodal music processing*, Dagstuhl, Germany, Jan. 2011.
[2597] G. Richard. Indexation des signaux musicaux polyphoniques. In *Keynote aux Journées d'Informatique Musicale*, Rennes, France, May 2011.
[2598] G. Richard. Audio processing research and technologies. In *International Korea university Workshop*, Seoul, Korea, Mar. 2012.
[2599] G. Richard. Audio and multimedia music signal processing. In *Keynote at 13th International Workshop on Image Analysis for Multimedia Interactive Services*, Dublin, Ireland, May 2012.

### Talks and Seminars

[2600] R. Badeau. Analyse spectrale à haute résolution appliquée au traitement des signaux de musique. In *Seminar of SFA at TSI/AAO, Télécom ParisTech*, Paris, France, 2011.
[2601] R. Badeau. Modèles probabilistes de représentations temps-fréquences. application au traitement des signaux de musique. In *Seminar at LIF/LATP, Aix-Marseille Université*, Marseille, France, May 2012.
[2602] R. Badeau. High resolution spectral analysis and nonnegative decompositions applied to music signal processing. In *Seminar at C4DM, Queen Mary University of London*, London, UK, 2013.
[2603] R. Badeau. Probabilistic modelling of time-frequency representations with application to music signals. In *Seminar at C4DM, Queen Mary University of London*, London, UK, 2013.
[2604] R. Badeau. Probabilistic modelling of time-frequency representations with application to music signals. In *Seminar at MLG, City University London*, London, UK, 2013.

[2605] R. Badeau. Probabilistic modelling of time-frequency representations with application to music signals. In *Seminar at SigProC, University of Cambridge*, Cambridge, UK, 2013.

[2606] S. Essid. Classification automatique de signaux multimédia. In *Seminar at IRISA, INRIA*, Rennes, France, Nov. 2009.

[2607] S. Essid. Music-to-score temporal alignment with discriminative graphical models. In *Seminar at the Music and Audio Research Laboratory, New York University (NYU)*, New York, USA, Oct. 2011.

[2608] S. Essid. The 3dlife multimodal dance corpus and applications. In *Seminar at The University of Tokyo*, Tokyo, Japan, Mar. 2012.

[2609] S. Essid. Audio-driven multimedia content analysis. In *Tutorial at MediaSense 2012: Summer School on Multi-modal Data Analytics*, Dublin, Ireland, May 2012.

[2610] A. Gramfort. Supervised and unsupervised learning in brain imaging: from sparsity for the meg inverse problem to dictionary learning for fmri and dmri. In *Athena INRIA Team Group meeting*, Sophia-Antipolis, FR, 2012.

[2611] A. Gramfort. Functional brain imaging: how to use meg and fmri to know the "where" and "when". In *Probabilistic structures of the brain*, Cergy, FR, 2012.

[2612] A. Gramfort. Sparse methods for brain imaging. In *Workshop on Sparse Models and Machine Learning*, INRIA/IRISA, Rennes, FR, 2012.

[2613] A. Gramfort. Decoding in source vs sensor space. In *Neurospin Decoding Symposium*, Gif sur Yvette, FR, 2013.

[2614] A. Gramfort. An introduction to regularized risk minimization for predicting from neuroimaging data. In *Pattern Recognition in Neuroimaging (PRNI) conf.*, Philadelphia, USA, 2013.

[2615] A. Gramfort. Analyse temps-fréquence et parcimonie pour la localisation de sources par eeg et meg. In *Société de mathématiques appliquées et industrielles (SMAI)*, Seignosse, FR, 2013.

[2616] M. Moussallam. Greedy pursuits in random sequential sub-dictionaries. In *Seminar at Columbia University*, New York, USA, Oct. 2012.

[2617] G. Richard. Beyond the bag-of frames approach for musical instrument recognition. In *Seminar at Aalborg University*, Aalborg, Denmark, 2009.

[2618] G. Richard. Beyond the bag-of frames approach for musical instrument recognition. In *Seminar at Dublin Institute of Technology*, Dublin, Ireland, 2009.

[2619] G. Richard. Beyond the bag-of frames approach for musical instrument recognition. In *Seminar at INESC, Porto*, Porto, Portugal, 2009.

[2620] G. Richard. Automatic extraction of the main melody from polyphonic music signals: With application to transcription and separation. In *Seminar at Queen Mary University of London*, London, UK, 2010.

[2621] G. Richard. Greedy pursuits algorithms for representing audio signals: with applications to compression, source separation and audio fingerprint. In *Seminar at ICSI, Berkeley University*, Berkeley, USA, 2012.

[2622] G. Richard. Greedy pursuits algorithms for representing audio signals: with applications to compression, source separation and audio fingerprint. In *Seminar at Los Angeles University*, Los Angeles, USA, 2012.

[2623] G. Richard. An overview of audio research at telecom paristech. In *Seminar at Technical University of Berlin*, Berlin, Germany, 2012.

[2624] G. Richard. Some research in audio, music and multimodal signal processing. In *Seminar at Fraunhofer Institute*, Ilmenau, Germany, 2013.

### 11.5.2 Public Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2011-2014 | REVERIE - Realistic and immersive 3D Environnements | Europe (IP) | S. Essid | 323 k€ |
| 2011-2014 | VERVE - Vanquishing fear and apathy through E-inclusion | Europe (STREP) | S. Essid | 110 k€ |
| 2010-2013 | 3Dlife - Analysis/synthesis of 3D audiovisual content for 3D models animation, virtual humans and virtual environments creation | Europe (NoE) | G. Richard | 272 k€ |
| 2008-2013 | QUAERO - Automatic analysis, indexing of multimedia and multilingual documents | OSEO | G. Richard | 803 k€ |
| 2009-2013 | DREAM - Sound Separation, transformation and watermarking for active listening | ANR | G. Richard | 128 k€ |
| 2008-2011 | ROMEO - Sound capture by microphone arrays for Humanoid robots | Cap Digital | Y. Grenier | 159 k€ |
| 2012-2016 | ROMEO 2 - Sound scene capture for Humanoid robots | OSEO | Y. Grenier | 179 k€ |
| 2008-2013 | PAFI - Modular platform for music instruments | ANR | B. David | 60 k€ |
| 2009-2013 | ARTIS - Articulatory inversion of audiovisual speech for augmented speech | Europe | S. Maeda | 159 k€ |
| 2012-2013 | SPOL : Sound Processing On Line | Labex LMH 2012 | G. Richard | 5 k€ |
| 2011-2014 | MeegaPerf - EEG Monitoring | Contract with Industry | S. Essid | 131 k€ |
| 2011-2014 | EMC2- Support action towards excellence in media computing and communication | Europe | G. Richard | 25 k€ |
| 2013-2016 | Marie Curie IOF Fellowship | Europe | G. Richard | 280 k€ |
| **TOTAL** | | | | 2,3 M€ |

### 11.5.3 Private Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008-2009 | GRANDE PAROISSE 6: sound source localisation | Contract with Industry | Y. Grenier | 35 k€ |
| 2008-2011 | INA - CIFRE PhD (S. Gulluni) on Audio segmentation | Contract with Industry | G. Richard | 20 k€ |
| 2009 | INA - Database collection | Contract with Industry | S. Essid | 3 k€ |
| 2011 | Egonocast - Algorithms | Contract with Industry | S. Essid | 1,3 k€ |
| 2011-2014 | Arkamys - CIFRE PhD on Speech dereverberation | Contract with Industry | G. Richard | 48 k€ |
| 2011-2012 | Audionamix - CIFRE PhD on source separation | Contract with Industry | G. Richard | 16 k€ |
| **TOTAL** | | | | 123 k€ |

### 11.5.4 Patents and software

#### Patents

- Sébastien Fenet, Yves Grenier and Gaël Richard (TSI), *Audiofingerprinting "Generation d'une signature d'un signal audio musical"*, Patent filled under N° FR 13/51752
- Antoine Liutkus, Laurent Girin, Roland Badeau and Gaël Richard, *Procédé et dispositif de représentation et de séparation/filtrage des composantes d'un signal mixé*, Patent filled under N° FR 10/58348
- Nicolas Lopez, Gaël Richard and Yves Grenier, *Procédé de suppression de la réverbération tardive*, Patent filled under N° 26875 FR.

#### Softwares

- Benoit Mathieu, Jacques Prado, YAAFE, (open source) software referenced under N° IDDN.FR.001.100013.000.S.P.2010.000.20000
- Benoit Mathieu, Jacques Prado, YAAFE extension, software referenced under N° IDDN.FR.001.100014.000.S.P.2010.000.20000
- Jacques Prado, Benoit Mathieu, SMARC, sotfware referenced under N° IDDN.FR.001.080018.000.S.P.2010.000.20000
- Jacques Prado, Benoit Mathieu, SMARC (Language C), sotfware referenced under N° IDDN.FR.001.080017.000.S.P.2010.000.20000

# 11.6 PhDs (Appendix 7)

## 11.6.1 Defended PhDs

[2625] N. Bertin. *Les factorisations en matrices non-négatives. Approches contraintes et probabilistes, application à la transcription automatique de musique polyphonique.* PhD thesis, Télécom ParisTech, Oct. 2009.

[2626] M. Betser. *Modélisation sinusoïdale et applications à l'indexation sonore*. PhD thesis, Telecom ParisTech, June 2008.

[2627] J.-L. Durrieu. *Transcription et Séparation automatique de la mélodie principale dans les signaux de musique polyphoniques*. PhD thesis, Télécom ParisTech, May 2010.

[2628] B. Elie. *Caractérisation vibratoire et acoustique des instruments à cordes - Application à l'aide à la facture instrumentale*. PhD thesis, LAUM, Nov. 2012.

[2629] V. Emiya. *Transcription automatique de la musique de piano*. PhD thesis, TELECOM ParisTech, Oct. 2008.

[2630] S. Fontana. *Déconvolution et applications à la technologie binaurale*. PhD thesis, TELECOM ParisTech, July 2008.

[2631] B. Fuentes. *L'analyse probabiliste en composantes latentes et ses adaptations aux signaux musicaux. Application à la transcription automatique de musique et à la séparation de sources*. PhD thesis, Télécom ParisTech, Mar. 2013.

[2632] S. Gulluni. *Un système interactif pour l'analyse des musiques électroacoustiques*. PhD thesis, Télécom ParisTech, Dec. 2011.

[2633] R. Hennequin. *Décomposition de spectrogrammes musicaux informée par des modèles de synthèse spectrale : modélisation des variations temporelles dans les objets musicaux.* PhD thesis, Télécom ParisTech, Nov. 2011.

[2634] C. Joder. *Alignement temporel musique-sur-partition par modèles graphiques discriminatifs*. PhD thesis, Telecom ParisTech, Sept. 2011.

[2635] A. Liutkus. *Processus gaussiens pour la séparation de sources et le codage informé*. PhD thesis, Télécom ParisTech, Nov. 2012.

[2636] M. Maazaoui. *Séparation de sources pour l'audition des robots*. PhD thesis, Télécom ParisTech, May 2012.

[2637] M. Moussallam. *Représentations Redondantes et Hiérarchiques pour l'Archivage et la Compression de Scènes Sonores*. PhD thesis, Télécom ParisTech, Dec. 2012.

[2638] V. S. Nguyen. *Etude de caractéristiques de la langue vietnamienne en vue de sa synthèse et de sa connaissance automatique. Aspects statiques et dynamiques*. PhD thesis, Télécom ParisTech, Dec. 2009.

[2639] L. Oudre. *Reconnaissance d'accords à partir de signaux audio par l'utilisation de gabarits théoriques*. PhD thesis, TELECOM ParisTech, Nov. 2010.

[2640] M. Ramona. *classification automatique de flux radiophoniques par machines à vecteurs de support*. PhD thesis, Télécom ParisTech, June 2010.

[2641] F. Vallet. *Structuration automatique de talk shows télévisés*. PhD thesis, Télécom ParisTech, Sept. 2011.

## 11.6.2 Ongoing PhDs

[2642] H. Bai. *Analyse automatique et synthese dynamique de secenes 3D audio*. PhD thesis, Télécom ParisTech.

[2643] A.-C. Conneau. *Identification automatique et dynamique de l'état émotionnel par analyse de signaux biologiques hétérogènes*. PhD thesis, Télécom ParisTech.

[2644] S. Fenet. *Identification audio par le contenu*. PhD thesis, Télécom ParisTech.

[2645] R. Foucard. *Fusion multi-niveaux pour la recherche par similarité musicale*. PhD thesis, Télécom ParisTech.

[2646] C. Fox. *Reduction de bruit acoustique en environnement automobile*. PhD thesis, Télécom ParisTech.

[2647] X. Jaureguiberry. *Fusion et optimisation de modèles pour la séparation de sources audio*. PhD thesis, Télécom ParisTech.

[2648] N. Lopez. *Méthodes partimonieuses pour la déréverbération des signaux audio*. PhD thesis, Télécom ParisTech.

[2649] A. Masurelle. *Analyse automatique de scènes multimodales par approches discriminatives*. PhD thesis, Télécom ParisTech.

[2650] F. Rigaud. *Apprentissage de modèles génératifs pour un instrument de musique sur des données enregistrées*. PhD thesis, Télécom ParisTech.

[2651] N. Seichepine. *Factorisations multimodales pour la structuration non-supervisée des documents audiovisuels*. PhD thesis, Télécom ParisTech.

# Chapter 12

# Image Processing and Understanding (TII)

## 12.1 Executive Summary (Appendix 1)

**Team Leader** Isabelle Bloch (FP)

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**Initial Staff** Permanent positions : 5 full professors, 5 associate professors, 4 Research scientists (CR1 CNRS).

**Staff who left** One full professor left in 2010, one associate professor left in 2012.

**Staff who were hired** One associate professor (formerly senior scientist at Saarland University) was hired in 2009, two research scientists (CR2 CNRS) (formerly post-docs at Caltech and University of Utah) were hired in 2010 and 2011.

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**Scientific Highlights** The reputation of the team is based on its two main components:

1. Its contributions to modeling, based on formal methods of different natures, with pioneer work, such as (just to name a few):

• stochastic image modeling : non local methods for various noise distribution, texture modeling, a contrario methods for image matching (probabilistic and statistical models),

• optimal transport, with new results on the circle, both in the discrete and continuous cases (analytical models),

• mathematical morphology in various complete lattices, providing a core framework for imperfect knowledge representation and spatial reasoning (algebraic models),

• adaptive meshing and scalable mesh processing (geometrical models),

2. Its contributions to large application domains, with several original results, such as:

• structural anatomical knowledge modeling to drive medical image understanding,

• realistic modeling of the human body (from fetus to adult) from medical images, combining image understanding and computer graphics,

• analysis and indexing of natural textured images,

• analysis of multi-modal (optical, radar) and multi-temporal data in remote sensing,

• efficient visualization and visual search in images, videos and 3D object databases.

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**Scientific Production** 191 Journals; 7 Books; 34 Book chapters; 315 Articles in Proceedings; 62 Phd theses.

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**Major Publications** • L. Bibin, J. Anquez, J. de la Plata Alcalde, T. Boubekeur, E. D. Angelini, and I. Bloch. Whole body pregnant woman modeling by digital geometry processing with detailed utero-fetal unit based on medical images. IEEE Transactions on Biomedical Engineering, 57(10):2346-2358, Oct. 2010.

• I. Bloch. Mathematical morphology on bipolar fuzzy sets: general algebraic framework. International Journal of Approximate Reasoning, 53:1031-1061, July 2012.

• M. Delbracio, P. Musé, A. Almansa, and J.-M. Morel. The non-parametric sub-pixel local point spread function estimation is a well posed problem. International Journal of Computer Vision, Sept. 2011.

• C.-A. Deledalle, L. Denis, and F. Tupin. How to compare noisy patches? Patch similarity beyond Gaussian noise. International Journal of Computer Vision, Feb. 2012.

• J. Rabin, J. Delon and Y. Gousseau. Transportation distances on the circle. Journal of Mathematical Imaging and Vision, 41(1):147-167, Sep. 2011.

• G. Fouquier, J. Atif, and I. Bloch. Sequential model-based segmentation and recognition of image structures driven by visual features and spatial relations. Computer Vision and Image Understanding, 116(1):146-165, Jan. 2012.

• S. Ladjal, J.-F. Aujol, and S. Masnou. Exemplar-based inpainting from a variational point of view. SIAM Journal on Mathematical Analysis, 42(3):1246-1285, Jan. 2010.

• G.-S. Xia, J. Delon, Y. Gousseau. Accurate junction detection and characterization in natural images. International Journal of Computer Vision, to appear, 2013.

• H. Sahbi, J.-Y. Audibert, and R. Keriven. Context-dependent kernels for object classification. In Pattern Analysis and Machine Intelligence (PAMI), 4(33):699-708, Apr. 2011.

• J.-M. Thiery, J. Tierny, and T. Boubekeur. Cager: Cage-based reverse engineering of animated 3d shapes. Computer Graphics Forum, Dec. 2012.

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**Impact and Attractivity**

- Distinctions: Eurographics Young Researcher Award (2012, E. Eisemann), Best student paper at ICIP 2010 (C.-A. Deledalle, F. Tupin), First Price for the Student Paper Award of EUSAR 2008 (A. Ghaleb, L. Vignaud and J. M. Nicolas), Best Paper Award at the Eurographics Symposium on Parallel Graphics and Visualization 2013 (J. Tierny), Honorable mention of the Dirk Bartz Prize for Visual Computing in Medicine (2011, J. Anquez, I. Bloch, T. Boubekeur, E. Angelini), Best PhD Award of Fondation Telecom (B. Buchholz), PhD Award in Signal, Image, Vision 2012 for C.-A. Deledalle.
- Organization: International conferences (MICCAI 2008, ISBI 2008, CIARP 2010, High Performance Graphics 2012, Eurographics, Visu 2012), international workshop Optimal transport, algorithms and applications (IHP 2011, J. Delon), symposium and special sessions (SIAM IS, EGSR 2012, SMAI, Gretsi).
- Editorial duties (associate editors): IEEE TGRS (F. Tupin), IPOL (A. Almansa, Y. Gousseau), CGF (Journal of the Eurographics Association, T. Boubekeur), IEEE SMC (until 2012), FSS and CVIU (I. Bloch), IEEE TBME (E. Angelini, 2008-2012).
- Invited conferences.
- Common Labs and Chairs (WHIST, Isa, Imaginaires), financed international and national collaborations.

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**Interaction with Economic and Social Spheres**

- Collaborations with major industrial actors in our main application fields (biomedical imaging, remote sensing imaging, digital photography, computer graphics).
- Benchmark for evaluating photographic devices (texture quality) used worldwide (NASA, Nikon, Popular photography, FNAC, Chasseur d'images, etc.).
- Stereo algorithm used by CNES to process the most recent Pleiades images.
- The algorithm "Phong tessellation" is included in most 3D middleware of modern video games (Unreal engine, Cry engine).
- Several PhD thesis results included in software platforms used in companies and hospitals (segmentation for oncology applications, retina layers segmentation and quantification), large diffusion of anatomical models for research purposes.

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**Contributions to Higher Education**

- Organization of the "Image" program at Telecom ParisTech, formation of high level engineers mostly dedicated to research and development.
- In charge of the IMA Master 2 program, UPMC (I. Bloch) and lectures (I. Bloch, T. Boubekeur, S. Ladjal, F. Tupin).
- MVA Master 2 program : lectures (A. Almansa, J. Delon, Y. Gousseau, J.-M. Nicolas, F. Tupin) and organization of the Telecom-MVA cursus.
- Launching the biomedical master program BME-Paris, chair of the M1 (E. Angelini).

## 12.2 People

**Team leader** Isabelle Bloch (FP).

**Faculty** A. Almansa (CR1 CNRS, HDR), E. Angelini (AP, HDR in 2011, on leave in Australia at CSIRO for six months in 2010, on leave at Columbia University since January 2012), I. Bloch (FP, on leave from February to July 2013), T. Boubekeur (AP, HDR in 2012), H. Brettel (CR1 CNRS, HDR), M. Campedel (AP), J. Delon (CR1 CNRS, HDR in 2011), E. Eisemann (AP, since 12/09 and until 9/12), Y. Gousseau (FP, HDR in 2009), S. Ladjal (AP), H. Maître (FP, Emeritus since March 2013), P. Memari (CR2 CNRS, since 10/11), J.-M. Nicolas (FP), S. Rital (Research Engineer, until 01/13) M. Roux (AP), H. Sahbi (CR1 CNRS, HDR in 2011), T. Tanzi (FP, until 2010), J. Tierny (CR2 CNRS, since 10/10), F. Tupin (FP).

**PhD students** *Defended (dates are for the defense):* A. Baillard (12/08), N. Bonnier (9/08), M. Costache (9/08), J. Dellière (6/08), T. Hurtut (3/08), A. Kermi (10/08), H. Khotanlou (2/08), I. Kyrgyzov (5/08), P. Lopez-Quiroz (11/08), C. Millet (1/08).
E. Aldea (12/09), J. Anquez (9/09), C. Le Men (9/09), D. Lesage (10/09), J. Rabin (12/09), N. Sabater (12/09, with ENS Cachan).
J. Baussé (10/10), M. Bredif (5/10), D. Cerra (5/10), N. Chenouard (1/10), D. Craciun (7/10), G. Fouquier (2/10), B. Galerne (12/10, with ENS Cachan), G. Lehureau (4/10), C. Mallet (11/10), F. Mosca (10/10), T. Napoléon (7/10), G. Palma (2/10), A. Shabou (11/10), H. Sportouche (12/10), N. Widynski (11/10, with UPMC), J. Wojak (12/10).
S. Audière (12/11), P. Birjandi (9/11), P. Blanchart (9/11), M. Bouali (6/11), E. Bughin (10/11, with ENS Cachan), C. Deledalle (11/11), V. Duval (6/11), G. Hochard (3/11), M. Marim (4/11), B. Petitpas (12/11, with Univ. Marne la Vallée), H. Soubaras (1/11), M. Tepper (3/11, with Univ. Buenos Aires), C. Vanegas (1/11), G.-S. Xia (3/11).
I. Ghorbel (4/12), J. Caron (5/12, with Univ. Amiens), A. Graciano (6/12, with Univ. Sao Paulo), G. Vialaneix (11/12), J.-M. Thiery (11/12), A. Roquel (12/12, with U. Paris Sud), B. Buchholz (12/12), G. Pizaine (12/12).
J. Huang (2/13), M. Höllander (3/13), M. Delbracio (3/13 with ENS Cachan), N. Faraj (6/13).
*Current (dates are for the beginning of PhD):* C. Aguerrebere (4/11, with UdelaR, Montevideo), E. Au (12/11, with LIP6), D. Aubry (9/12), L. Avanthey (10/12, with ESIA), T. Baar (10/12), E. Benhaim (10/11, with Parrot), N. Bourdis (1/10, with EADS), S. Calderon (11/11), I. Cléry (2/12, with IGN), A. Deblonde (4/12, with Morpho), F. Dellinger (10/10, with CNES), K. Falkenstern (2/12), M. Gargouri (11/11), R. Gauriau (6/12, with Philips), N. Geeraert (9/11, with GE), T. Guillemot (10/10), E. Guy (10/12), C. Herold (12/10, with Morpho), P. Irrera (7/12, with EOS Imaging), Q. A. Le (10/09), Y. Le Montagner (10/10, with Institut Pasteur), B. Mazin (9/10), J.-C. Michelin (12/11, with IGN), C. Miloudi (9/12, with ISEP and hôpital des XV-XX), B. Morel (12/12, with hôpital du Kremlin-Bicêtre), A. Newson (9/10, with Technicolor), J.-B. Poisson (10/10), J. Preciozzi (3/11, with UdelaR, Montevideo), G. Quin (9/10, with CEA), A. Roman Gonzalez (9/09), L. Schemali (1/11, with Useful Progress), X. Su (10/11), S. Tabti (10/12), G. Tartavel (10/11), Y. Traonmilin (7/11), U. Verma (10/10), P. Vo (10/10), B. Wang (10/12, with Shondong University), Y. Yang (10/10), F. Yuan (9/10-9/11).

**Post-docs, engineers and sabbaticals** R. de Aldama (3/13–12/13), J. Anquez (1/10–6/10), L. Babou (7/09–2/11), A. Bretto (1/10–8/10), F. Cao (9/10–4/11), S. Chevallier (3/11–8/11), S. Dahdouh (10/11–6/13), J.-P. De la Plata (8/09–7/11), A. El Ghoul (01/12–1/14), D. Günther (05/13–11/14), E. Erdem (7/09–3/10), F. Fayard (5/10–4/11), G. Fouquier (7/09–3/11), M. Horta (4/11–9/11), O. Kyrgyzov (7/12–6/13), S. Lee (7/09–2/11), X. Li (6/09–6/10), M. Lindenbaum (3/11–8/11), K. Loquin (3/10–10/11), A. Marquez (9/9–10/10), M. Moghrani (9/09–8/10), V. Pascucci (6/11–), Y. Pinto (3/11–10/11), E. Provenzi (04/13–03/14), T. Ritschel (5/10–9/11), X. Rondeau (10/09–3/11), Y. Rouchdy (10/09–12/10), A. Serrurier (2/12–12/12), H. Sportouche (4/11–03/12), O. Tankyevych (1/11–8/11), V. Tayanov (10/09-12/09), J.-M. Thiery (12/12–12/13), C. Vanegas (1/11–4/11), I. Yu (04/12–05/13), A. Zureiki (7/09–10/09).

**Associate members** Mihai Datcu (DLR, until June 2010), Hong Sun (Univ. Wuhan), Catherine Adamsbaum (Univ. Paris Sud, CHU Bicêtre).

## 12.3 Overview

The objective of the group is to develop methodologies and theoretical tools for image, scene and 3D object processing and interpretation. This includes analyzing, transforming, representing, understanding and synthesizing images, digital volumes and objects. The main approach consists in solving globally complex problems, based on rigorous theoretical foundations, and integrating multiple and complementary techniques, in order to derive interpretations from data. Applications focus on medical imaging, aerial and satellite imaging, natural image analysis. Contributions of the group can therefore be found at theoretical level (knowledge and information representation and modeling, in 2D as well as 3D, processing, interpretation and reasoning on spatial data), at algorithmical level (in particular to implement the developed models for large and complex data sets), and at applicative level. With a strong theoretical and methodological anchoring, along with close links with applications, the contributions of the group are at the cross-road of applied mathematics, computer science and artificial intelligence. The group is well recognized, in academic, institutional and industrial domains, in particular for his noticeable contributions in mathematical modeling of images, digital geometry and rendering, image retrieval, mathematical morphology and spatial reasoning, radar imaging, medical imaging. It has numerous collaborations with other universities, and is supported by grants and contracts. The different research activities are closely linked together, which is one of the distinguishing features of the group.

The group is involved in several joint labs: CoC with DLR and CNES, which was finished during this period (see Section 12.4.5), WhistLab with Orange Labs and Telecom Bretagne, IDentity & Security Alliance (The Morpho and Telecom ParisTech Research Center), as well as in the "Chaire Modélisation des Imaginaires". It is also involved in the new French Initiatives, such as the Labex Smart and DigiCosme, and the Equipex Digiscope.

Over the period covered by this report, the group has benefited from the appointment of two CNRS researchers (P. Memari and J. Tierny) and one associate professor (E. Eiseman), strengthening research axes mainly in computer graphics, but also in medical imaging. E. Eiseman left in 2012 to be promoted as a professor at the University of Delft. Over the same period, one professor (T. Tanzi) left to join a research team in Sophia-Antipolis at Mines ParisTech. The good reputation of the group and its visibility, in France as well as at an international level, are confirmed by the number of publications, but also by the number of collaborations, mentioned below for each research axis, and by its attractiveness for CNRS candidates, post-docs and PhDs.

The scientific animation of the team includes a general seminar and several specific ones (medical imaging, compressed sensing, radar imaging, 3D and computer graphics...). PhD candidates are invited to publicly present their work at the end of the first year of their PhD, so as to gather comments from the whole team and initiate discussions among them, thus favoring cross-fertilization of ideas. A mid-term evaluation is also organized for all PhD candidates. We also pay attention to the accompanying process of the PhD theses, beside the direct scientific supervision, including a help to prepare their future.

## 12.4 Research Themes

### 12.4.1 Mathematical methods for images

**Faculty** A. Almansa, I. Bloch, J. Delon, Y. Gousseau, S. Ladjal, F. Tupin.

**Highlights: Scientific Production** [2792, 2740, 2762, 2820, 2698, 2837]

**Highlights: Impact Research project funding** : ANR projects (CALLISTO, FREEDOM, LOGIMA, MATAIM, OTARIE), FUI (9th call) CEDCA, ECOS Sud (U06E01), STIC AmSud (MMVP-SCV), CNES PhD funding, ONERA PhD funding, Cifre PhD fundings, DGA/REI MRIS and Tracking.

**Collaborations** : MAP5, LIP6, LRI, CMLA, CEREMADE, Ponts ParisTech, ECP, GREYC, Institut Camille Jordan, Laboratoire Jean Kuntzmann, Université Bordeaux 1, Université

Saint-Etienne, CESBIO, IGN, Institut Pasteur, U. Las Palmas et UPF Barcelone (Espagne), Univ. Dresden (Germany), Technion (Israël), Polytechnique Montréal (Canada), Caltech, UCLA et U. Minnesota (USA), Universidad de la Republica (Uruguay), UBA (Argentine), Univ. Merida (Venezuela), U. Wuhan (Chine), Poncelet Lab. Moscou (Russie).

**Organisation** : Colloque *Optimal Transport, algorithms and applications* (IHP 2011), symposium and special sessions SMAI, GRETSI, SIAM.

**Highlights: Interactions with Society** Industrial collaborations : CNES, DxO, Morpho, Shlumberger, Technicolor.

A stochastic image model developed in our team (Y. Gousseau) has been introduced in the latest version of DxO's *Analyzer* software. As such, it is used by economic actors such as La Fnac, foreign research agency such as the NASA, industrial actors such as Nikon or specialized press such as Chasseur d'images or Popular Photography.

One of our stereoscopy algorithm (A. Almansa) has been implemented by the CNES to process images from his most recent satellites, such as Pleiades and successors.

**Texture and natural images modeling** This research theme deals with the stochastic modeling of natural images. These models (dead leaves, shot-noise, transparent models) are grounded in the theory of marked point processes, whose marks are geometrical structures. The most notable works in this area are concerned with texture synthesis using spot-noise models, see [2740, 2739], sparse modeling [3154], as well as the stochastic modeling of transparency [2738]. Much effort has also been devoted to the study of the impact of various restoration image models on the textured aspects of natural images, as explained below, see [2703, 2719, 2720]. An important achievement is that a model previously developed in our team, the *scaling dead leaves model*, has been retained by the company DxO to evaluate the ability of imaging devices to preserve textures in natural images and is included in the latest version of their software *analyzer* as mentioned above.

**Image analysis and computer vision** These last years, we have developped a large body of work in the field of computer vision. Contributions include both methodological studies and competitive algorithms, in particular for image matching and comparison problems.

A first methodological aspect of our work is concerned with optimal transportation equations. These equations enable the definition of metrics between weighted features and yield elegant ways to compare images. We have proposed several complementary studies on the subject of optimal transportation on the circle, one in a continuous setting [2708] and the other one in a discrete setting [2792, 2794]. This last study compares for different retrieval tasks the transportation metrics with the classical distances used in computer vision. More recently, we have focused on transport problems with concave costs [2709], which are more realistic in many applications, especially in economic situations. In the same research field, a sliced approximation of the optimal transport is introduced in [3113] and used for texture mixing.

Another methodological aspect of our researches deals with *a contrario* methods, developed by Desolneux et al. to automatically fix detection thresholds for image analysis. An attempt to evaluate the collaboration of Gestalt grouping laws in vision using this *a contrario* framework is proposed in [2748]. Another attempt to extend this framework to the interactions between collaborations and conflicts of simple grouping laws was proposed in [2820] in the context of contrast and regularity for edge detection. To a great extent, we also applied these *a contrario* methods to the problem of image matching. We have developed a complete chain for the matching of images from local descriptors (such as SIFTs). This procedure encompasses the descriptors themselves, a transportation metric adapted to circular histograms, an unsupervised matching criterion, and a validation, RANSAC-like step [2792, 3110]. This procedure is adapted to the case of color images in [3070]. A close research direction concerns the accurate detection of junctions in natural images [3188, 2837]. In the particular case of block-matching of epipolarly-rectified stereo pairs, the *a contrario* methodology has proven very efficient to build up semi-dense sets of reliable

matches [2804]. This yields disparity maps computed up to an unprecedented accuracy level, closely matching our theoretical accuracy estimation [2803]. Check also the accompanying online demo [1]. The a contrario methodology also allows for parameterless and unsupervised graph-based clustering [2819] without any shape prior. Applications ranging from high-dimensional data analysis to restoration of images and 3D data are being explored. Another approach for point matching was developed for change detection problems based on a new interest point matching approach combined with the epipolar geometry [2810]. Eventually, we also have developed an extension of the *a contrario* approach, in which the hypothesis of independence classically made for the null hypothesis is alleviated. This is permitted by the use of graphical models and has been applied to alignment and object detection [2782].

Still in a probabilistic framework, new graph-cut based optimization approaches of Markovian models have been proposed. They allow an efficient compromise between memory size and quality of the obtained optimum [2812].

Among the other tools that we have investigated and applied, let us quote hiererarchical morphological image representations. These tools, and in particular the topographic map, turn out to be particularly efficient for perceptual edge detection [2820], for the indexing of satellite images [2769], the indexing of texture through extensions of the classical granulometry from mathematical morphology [2836] or the analysis of artistic line-drawings [2755]. A strong asset of all such approaches is a flexible control on a wide range of geometrical and radiometric changes.

**Restoration of images and image sequences** In the last few years, our group has become quite active in the field of image restoration.

In the case of single-frame restoration, many denoising problems have been tackled. We have proposed several extensions and studies of Non-Local Means methods. In [2720], we proposed an in-depth study of such denoising methods and give a solution for the automatic and local setting of parameters. In [2703], it is proposed to use adaptive and generic patches to improve denoising results. In [2701], the method is extended in a probabilistic approach, allowing to process images for which a distribution of the parameters of interest is available (Poisson, Gamma, Wishart distributions...). This framework also permits to process vectorial data [2702].

We have recently proposed an adaptation of non local approaches for the removal of impulse and mixed Gaussian-impulse noise [2968, 2706]. Still in the domain of impulsive degradations, we have conducted an extensive study of the popular TV-L1 model, showing that it is equivalent to some morphological filtering and acts as a granulometry [2719]. The TV regularization model under local L2 constraints showed effective in the context of irregularly sampled blurred and noisy data [2731, 2887]. It was also shown useful for destriping MODIS images [2774].

In order to restore larger and more extreme degradations of images, we also took interest in image inpainting. We developed an approach relying on the automatic combination of patch-based methods and geometrical interpolation [2683], permitting the restoration of both the texture and the geometry of images over large regions. This subject has also been addressed in a related work on the variational interpretation of copy-paste methods [2762]. Some of the previous works require an accurate knowledge of internal camera parameters like the intrinsic blur kernel (PSF). In [2698] and the corresponding online demo [2700] we showed how accurate estimation of the subpixel PSF from a single aliased photograph becomes a well posed problem: An appropriate white noise image has to be used as a callibration pattern. If a second rescaled snapshot is available, the pattern may be unknown, and some deviations from the optimal pattern are still admissible as shown in [2699] and the accompanying IPOL demo [2].

Recently, we have oriented an important part of our restoration activity toward multi-frame restoration. This research direction is intimately related to different research projects, in particular ANR FREEDOM JCJC (2007-2011) on movie restoration, the collaborative FUI project CEDCA with DxO Labs on protocols for quality enhancement in digital photography, and two PhD theses (one with Technicolor SA and the other in the context of the project CEDCA). As part of the

1. http://dev.ipol.im/~monasse/ipol_demo/bms_binocular_stereo_pipeline/
2. http://www.ipol.im/pub/algo/damm_blind_psf_estimation_from_scaled_image_pairs/

research project FREEDOM, we have proposed two contributions related to contrast and color: the first one concerns the restoration of local radiometric problems in image sequences [2705], and the second one is an efficient method for the removal of artifacts [2793] introduced by contrast and color changes. Another contribution deals with the detection and restoration of occluding defects in movies [2930]. Our recent contributions on the subject of multiframe restoration mainly concern the outlier-resistant enhancement of dynamic and resolution in images. On the creation of *high dynamic range* (HDR) images, we have proposed an a statistical study of the efficiency of HDR algorithms for static scenes. We also adressed the case of dynamic scenes, with a patch-based method for the simultaneous denoising and HDR creation [2884]. Concerning multi-image *super-resolution* our study [3160], extends theoretical bounds on well-posedness of the problem to the case of affine motions, and takes advantage of these predictions to preserve more details by automatic fine-tuning of the required regularization. When the previous study is reformulated in the robust $L^1$ data-fitting framework, it turns out that simultaneous super-resolution and *outlier detection & restoration* is possible [3161] under sparsity constraints on the outlying artifacts, that are closely related to the null-space property commonly used in *compressed sensing*.

**Tracking** Another contribution based on probabilistic methods addresses tracking issues in image sequences, by incorporating different types of information in the probabilistic model [2728, 2727, 2834, 2835] (collaboration with LIP6). Our approach is based on particle filtering, and we have proposed original ways to introduce spatial relations, represented in a fuzzy set framework (see Section 12.4.2), either between different positions of one object during time, or between several objects for multiple object tracking problems (PhD of N. Widynski). In this case, we also proposed a ranked partitioned sampling method, so as to handle the most visible objects first. Multiple appearance models and adaptive fusion of multiple cues have also been proposed. These new models and the associated algorithms provide better results than state of the art methods, in terms of accuracy of tracking, object association, and handling partially occluded objects. Multiple object tracking has also been addressed using multiple hypotheses methods, for biological applications in cluttered environment [2950, 2951, 2952] (collaboration with Institut Pasteur).

Tracking has also been exploited in segmentation problems, in particular for elongated structures such as blood vessels, using particle filters and minimal paths according to adaptive metrics (see also Section 12.4.4). A new project on multi-view tracking has also been launched, based on particle filter, to estimate the shape parameters and the pose of a face for authentication based on face matching (collaboration with LIP6 and Morpho, PhD of C. Herold). The originality is to integrate static parameters in the particle filter [2872, 3022].

**Mathematical morphology** In parallel to the work mentioned above on granulometry and TV restoration, our contribution in mathematical morphology concerns the representation and handling of qualitative and imprecise information in different settings, such as formal logics [2653, 2896], including description logics for ontological reasoning, fuzzy sets [2672], and more recently hypergraphs [2918, 2676, 2919], concept lattices [2898], and bipolar information [2916, 2673, 2674, 3029] to model both positive information (observations, preferences) and negative information (constraints). In all these frameworks, we proposed appropriate complete lattices and connectives, leading to good properties of mathematical morphology operations. These operations can then be used for various tasks, such as preference modeling and spatial reasoning (see Section 12.4.2). This work was partly carried out in collaboration with LRI, ECP, GREYC, university Merida (Venezuela), university Dresden (Germany).

### 12.4.2 Image understanding, learning and spatial reasoning

**Faculty** I. Bloch, H. Brettel, M. Campedel, M. Datcu (until 2010), H. Sahbi.

**Highlights: Scientific Production** [2662, 2737, 2805, 2827, 2844]

**Highlights: Impact** CIARP 2010 conference.

ANR DAFOE, Infomagic, K-Space, ANR DESCRIBE, ANR LOGIMA, CNES PhD thesis and research projects funding, collaboration with J. Atif (LRI), C. Hudelot (ECP), J. Inglada (CESBIO), S. Le Hégarat-Mascle (IEF), R. Cesar (U. Sao Paulo, Brazil), F. Distel (Univ. Dresden).

**Highlights: Interactions with Society** Collaboration with Mondeca, IGN, CNES.

**Spatial reasoning** Our work on modeling spatial relations within the fuzzy set framework has evolved towards complex relations such as *along*, *surrounds*, *to go across*, *parallel to*, both for individual objects and for groups of objects [2817, 3262, 3167]. New fuzzy connections have also been proposed, and applied to filtering problems [2784, 2790]. A new direction of research concerns spatial relations in a bipolar setting. These relations are based on mathematical morphology operators, and their use for spatial reasoning was formalized in different settings (PhD of G. Fouquier, C. Vanegas, A. Graciano). One relies on graph-based reasoning, where a graph modeling the available knowledge about a scene (on objects and their spatial relations) guides a sequential segmentation and recognition process [2737]. The order in which structures are segmented is adapted to each image, by combining spatial relations and saliency information. Another approach relies on the search for a global solution by expressing the recognition as a constraint satisfaction problem [2785, 2786, 2827], or as an inexact graph matching problem [2788]. Finally ontological reasoning was proposed, by introducing mathematical morphology operators in description logics in order to define spatial relation concepts [3029]. In the same line, a method associating description logics, formal concept analysis and mathematical morphology was developed. The first reasoning service we proposed within this framework is abduction, in order to provide the best explanation of a scene according to the available knowledge [2896, 2662]. Extension to fuzzy abduction is currently addressed.

A renewed interpretation of conflict within the belief function framework was developed during the PhD thesis of A. Roquel (in collaboration with IEF), and an original decomposition of the conflict was proposed, to allow interpreting its causes and then adapting the fusion process [3118].

During the ANR project DAFOE4app (2007-2010), an engineering collaboration between Telecom ParisTech and Mondeca has been initiated which received the support of CNES. The goal was to create and develop interactive tools to assist satellite image interpreters through the creation of two OWL ontologies: one to describe the image content and the feature extraction process, the other to manage the land cover classes; these ontologies integrate spatial relationships between image objects as well as other semantic relationships. A prototype of the annotation tool, based on Mondeca technology has also been built. Although it needs further engineering development to make it fully operational, it is ideal to demonstrate the usefulness of both low-level image processing algorithms and semantic reasoning in the context of satellite image interpretation.

Two important projects were completed during this period, Infomagic and K-space, leading to the publications of one book and a significant contribution to a second one [2844, 2869].

This research theme was also developed specifically in the context of remote sensing imaging, as described in Section 12.4.5.

**Machine learning** • Besides recognition and spatial reasoning, spatial relations have also been used in structural learning for image classification, based on original graph kernels including spatial relations [2850] (PhD of E. Aldea).

• In our work on interconnected networks & activity recognition, we improved support vector machines (SVMs) scene annotation and retrieval by using a new class of kernels referred to as context-dependent (CD). The main contributions of our method ly in the variational approach to design the CD kernel and in the proof of convergence of this kernel to positive definite fixed-point. When plugged in SVMs, our CD kernel consistently improves the performance of image annotation and retrieval, compared to context-free kernels, on hundreds of thousands of Flickr

images [3125, 2805, 3126]. We also extended this CD kernel in order to handle logo detection and recognition [2806] as well as activity indexing and recognition in video sequences [3196, 2842].

• We proposed a novel approach for kernel map learning that goes beyond the naive use of existing kernels and their restricted combinations in order to design "model-free" transductive kernels. They are based on the minimization of an energy function mixing a reconstruction term (product of a learned dictionary and a learned kernel map), a fidelity term ensuring consistent label prediction, and a smoothness term. Experiments conducted on object class segmentation and image annotation, show that our kernel achieves at least comparable results with related state of the art methods on different standard databases [3173, 3172].

• Automatic speech analysis is currently evolving towards hybrid systems that combine both visual and acoustic information. We introduced in this work an original visual speech recognition approach including the design of a similarity function, based on string kernels, that models the dynamics as well as the appearance of visual features in talking faces, and a kernel combination procedure based on multiple kernel learning, that makes visual feature selection effective and also more tractable. Experiments conducted on a standard digit database show that the proposed algorithm outperforms current state-of-the-art methods [2902].

• We also proposed a novel superpixel-based framework for object class segmentation using conditional random fields (CRFs). The framework proceeds in two steps: (i) superpixel label estimate, and (ii) CRF label propagation. Step (i) is achieved using multi-scale boosted classifiers over superpixels and makes it possible to find coarse estimates of initial labels. Fine labeling is afterward achieved in Step (ii), using an anisotropic contrast sensitive pairwise function designed in order to characterize the intrinsic interaction potentials between objects according to 4-neighborhoods. Finally, a higher-order criterion is applied to enforce region label consistency of OCS. Experimental results demonstrate the effectiveness of the proposed framework [3053].

• In a process of learning semantic manifolds for mental image search we designed an algorithm based on a novel principle that unmixes semantics from images and maps them from an initial ambient space (related to low level visual features including texture, color and shape) to an output space spanned by a well defined semantic basis. We cast this problem as a convex quadratic programming (QP) optimization, constrained in a simplex spanned by few pure semantic basis vectors. The advantage of the proposed approach is a significant reduction in the input space dimensionality (which is difficult to explore/visualize), and an easier interpretation of retained features. Therefore, searching for a mental target is achieved by simply scanning and targeting image data according to their coordinates in the learned semantic subspace.

• We introduced a complete "2D to 3D object" retrieval framework. Given a (collection of) picture(s) or sketch(es) of the same scene or object, the method allows us to retrieve the underlying similar objects in a database of 3D models. The contribution of our method includes a generative approach for alignment and the application of an efficient and effective matching method used for ranking. The results are reported through the Princeton Shape Benchmark and the Shrec benchmarking consortium evaluated/compared by a third-party. In the two gallery sets, our approach achieves good performance and outperforms the other runs [2783].

**Color perception** Another aspect of the research deals with the human perception [2829, 2883]. In our work on color processing by the human visual system, we have studied the excitation of photoreceptors other than the three types of cone cells in the human eye. Besides being a visual stimulus, light entering the eye may be captured by melanopsin, a photosensitive pigment that has been recently discovered in some retinal ganglion cells. To examine the effects of light on melanopsin, we theoretically decomposed the light spectrum in two components: a fundamental color stimulus that controls the three cone responses and a metameric "black" that has no effect on cones but can drive other receptor responses. Using seven color LEDs, we produced real metamer illuminations and could show that two lights of equal luminance may result in different pupil apertures and thus different retinal illuminance. The results have implications for understanding light effects which are not explained by trichromatic theory, and are practically

relevant to the development of LED lighting and other energy-efficient lighting technologies.

### 12.4.3 Computer Graphics

**Faculty** T. Boubekeur, E. Eisemann (until 10/12), P. Memari (since 10/11), J. Tierny (since 10/10).

**Highlights: Scientific Production** [2724, 2815, 2780, 2715, 2822]

**Highlights: Impact** Eurographics Young Researcher Award (E. Eisemann), D. Bartz Prize for Visual Computing in Medicine, Honorable Mention (T. Boubekeur), Best PhD Award of Fondation Telecom (B. Buchholz), Best Paper Award at the Eurographics Symposium on Parallel Graphics and Visualization 2013 (J. Tierny), 4 (resp. 5) E.U. (resp. national) public grants.

**Highlights: Interactions with Society** Chaire Ubisoft/Dassault Systèmes/PSA/Orange “Modélisation des Imaginaires”, Organization of conferences (High Performance Graphics 2012, Eurographics, EGSR 2012, Visu 2012), CIFRE EDF, CIFRE Renault-PSA, EU project with Disney Research

The algorithm "Phong tessellation" is included in most 3D middleware of modern video games (Unreal engine, Cry engine), as well as in the reference GPU benchmark 3Dmark.

The research activities in computer graphics focus on geometric modeling, rendering and visualization, as well as on some graphics-related aspects of computer vision and imaging. Our expertise covers most of the computer graphics chain, from capture to synthesis of 3D shapes, appearance and motion.

**Geometric Modeling** In computational geometry, the group studied the large space of triangulations [3071] and their dual complexes in arbitrary dimension, showing that compatible dual complexes exist only for a particular type of triangulation which extends the well known (weighted) Delaunay/Voronoi duality. The provided geometric parameterization of this space is particularly valuable in discrete optimization problems such as optimal meshing [2780]. The group also investigated weighted triangulations as discrete, augmented approximations of surfaces [2696], and derived a discrete Laplace-Beltrami operator that preserves core properties of its continuous counterpart, with applications to circle and sphere packing problems.

In geometry processing, the group has developed several fast and scalable mesh processing operators, including a locally separable feature-preserving filtering operator [3169], a stochastic adaptive simplifier [2678] with linear time and memory complexity; a collection of real time mesh upsampling methods ranging from fast visually smooth polygon tessellation [2677, 2863] to high quality subdivision surface synthesis [2656, 3024], with view-dependent control [2924]. The group also introduced the first non-local meshless surface model [3015], which dominates local approaches in self-similar surface structure reconstruction.

In interactive geometric modeling, the group proposed several systems tackling open problems: GeoBrush [2816] for interactive 3D shape fusion; VoxMorph [2733] for interactive volume editing, with application to medical data modeling and physical simulation [2995]; an interactive quad remesher [2825] for polygonal surfaces integrating user constraints on-the-fly [2825] and an alternative approach reusing exemplar databases for generating new quadrangulations from predefined styles [2824].

In geometric analysis, the group has proposed several high level structure extraction mecanisms from raw data, including the CageR system for stable cage-based reverse engineering of animated shapes [2822] and a new parametric curve skeleton model [2821], with applications of these structures to filtering, compression, transfer and modeling. Last, the group has developed a co-dimensional methodology exploiting 2D and 3D lines to analyze and transform 2D and 3D geometry, with application to 3D search [2724], shape learning [2758], 2D painting [2903] and freeform modeling [3134].

**Rendering and Visualization** In realistic rendering, the group has developed new algorithms for efficient global illumination, including ManyLoDs [2749], a fine-grained real time level-of-detail algorithm, as well as a factorized reflectance function learning method [2681]. Screen-space [3501, 2750], object-space [2801] and hybrid-space [3114] techniques have been proposed to quickly approximate complex effects such as ambient/directional occlusion, color blending, (indirect) soft shadows and deferred antialiasing

In expressive and perceptual rendering, the group has worked on the link between the geometry of the scene and its visual impact, focusing in particular on binary shading [2682], animated line drawing [2932], amortized rendering methods [3023] and stereo rendering [2975].

Optical phenomena stemming from virtual cameras model, such as depth-of-field, lens-flare and motion blur, have been studied in detail to improve realism but also to offer artistic control [2764, 2753] in a real time environment. Finally, a remote rendering system has been developed [2789].

Several projects have been conducted on the perceptual component of rendering techniques and have led to new methods offering a higher (perceived) screen resolution than the physical one [2713], and a better detail preservation [2714], as well as higher quality stereo rendering [2715].

In visualization, a new approach was proposed to explore interactively large-scale simulations based on a topology pre-analysis [2679]. Additionally, a new method for topological verification was able to illustrate the shortcomings of various realizations of isosurface-extraction methods that are publicly available [2730]. Finally, a new combinatorial approach for the general simplification of scalar fields on surfaces has been proposed [2823]. This approach improves on previous work by its simplicity, efficiency and generality.

**Vision and Imaging** Beyond modeling and rendering, the group also works intensively at the frontier between computer graphics and other visual computing research fields.

In computer vision, 2D [2722] and 3D [2724] visual search engines were developed, together with dedicated descriptors, benchmarks and user studies, allowing to query interactively images, videos and 3D shapes using rough line drawings. These engines are the state of the art in sketch-based search at the current time and were instrumental in developing a new visual content creation paradigm [2723, 2816] combining large data collections and interactive compositing. At the junction between 2D and 3D vision, another method has been proposed to register photos and 3D terrain models [2901], with applications to automatic geo-localisation, object recognition and to add annotations.

In imaging, a new approach for the stitching of pre-registered images for panorama creation [2815] has been proposed. This approach provides an automatic stitching algorithm that is orders of magnitude faster than previous approaches, while achieving equal, if not better, quality. Being extremely fast, this approach enables new interaction mecanisms, yielding for the first time real-time user interactions on the image seams.

### 12.4.4 Medical and biological imaging

**Faculty** E. Angelini, I. Bloch, T. Boubekeur, J. Delon, P. Memari, J. Tierny.

**Highlights: Scientific Production** [2659, 2660, 2744, 2773, 2790]

**Highlights: Impact** Honorable mention of the Dirk Bartz Prize for Visual Computing in Medicine [2697]. Launch of new International Master of Biomedical Engineering BME-Paris. Participation in Labex SMART on human body modeling. ANR (FETUS, Kidpocket, IPHOT, ReVeal), ANSES ACTE, MINIARA. Visiting Scientist fellowship at CSIRO (Australia) and at University Columbia (USA). Collaborations with Institut Pasteur (J.C. Olivo-Marin), ISEP (F. Rossant), Columbia University (A. Laine), hospitals (Cochin - Saint Vincent de Paul, Bicêtre, Robert Debré, XV-XX, Lariboisière...).

**Highlights: Interactions with Society** Joint Lab with Orange Labs (WHIST). Collaborations with Siemens, Philips, General Electric, Dosisoft, Echosens, Fovea, EOS Imaging, Orange Labs (J. Wiart), CIFRE PhD theses funding.

Several softwares developed by our team are used within hospitals for clinical research (characterization of cerebral tumor evolution in IRM imaging, segmentation for oncology, quantitative analysis of retina layers in optical coherence tomography, etc.)

Our work on segmentation of normal and pathological brain structures is strongly related to our research in spatial reasoning (see Section 12.4.2), where anatomical knowledge is represented using structural formalisms, and used to guide the segmentation and recognition [2737, 2785] (PhD of G. Fouquier). These ideas have also been exploited in other medical applications. A new direction on pathologies focuses on neonatal images (PhD of B. Morel) [3078].

Analysis of longitudinal changes of brain pathologies has been an important focus of research, supported by very active collaborations with several academic and clinical sites. The project on low-grade brain tumor growth has matured [2659, 2889, 2808] and is being pursued. A new collaboration with CSIRO was launched, on the topic of longitudinal analysis of brain white matter lesions on Alzheimer patients.

Quantitative longitudinal image analysis is likely to become a major field of investigation for our group. As an example, a new collaboration with Columbia University and University of Iowa has been initiated, to work on emphysema segmentation and texture analysis, from very large longitudinal US databases of full-lung CT scans acquired on patients suffering from COPD (chronic obstructive pulmonary disease). As a first step, Markov-field segmentation has been demonstrated to be robust to very high noise level involved with varying scanning conditions and tomographic reconstruction algorithms [3019]. Such an automated segmentation solves the current issue of the current clinical paradigm based on simple thresholding of pixel intensities, to quantify emphysema evolution on heterogeneous databases of longitudinal scans. Close links are currently being built with several groups from the University Paris Descartes, specialized in human and small animal vascular and tumoral imaging for longitudinal evaluation and identification of biomarkers.

Anatomical modeling has also benefited from great activities and strong links between the medical imaging and the computer graphics teams (see Section 12.4.3). Several joint supervisions of PhD students, post-doctoral fellows and research engineers have led to the strengthening of this activity, focusing on the segmentation of obstetrical images in US and MRI [2892, 2894, 2893, 2660, 2958] (PhD of J. Anquez), and the design of dedicated modeling tools for the construction of pregnant women bodies from segmented medical images [2665, 2666, 2697], deformed in various positions for dosimetry simulations. Models of the fetus growth were also proposed, as well as an interpolation and deformation method enabling to generate fetus models at any age and in any position [3140]. In the same line, segmentation of whole body MRI children images for anatomical modeling at different ages was addressed [3002]. These works were carried out in close collaboration with Orange Labs, within the joint laboratory WHIST, for numerical dosimetry studies [3176, 3175, 3039]. A recent collaboration was initiated with the car manufacturer Renault and its research laboratory (LAB) for the co-supervision of the PhD thesis of M. Gargouri, focusing on the enrichment of numerical models of the human skeleton based on the segmentation of a large database of whole-body CT scans. An approach exploiting the random forests classifier is pursued, proposing shape-specific descriptors robust to high variability in image quality and patient positioning [3004].

Vascular imaging was also an important focus of research, with a collaboration with Siemens Corporate Research (PhD of D. Lesage) and then Philips Healthcare (PhD of G. Pizaine). Stochastic, discrete and continuous methods were investigated for the segmentation of small and large vessels [3052, 3102, 3104], with various types of geometric constraints and various levels of supervision and training. A new direction of investigation focuses on the combination of geometric constraints and vessel tree labeling constraints. We developed a “topologically correct” segmentation method for two dimensional images of vascular network, starting with a simple geometric model which has the right topology [2658], which is then refined using a “phase field”

segmentation procedure.

The long-term collaboration with Columbia University has led to the graduation of a jointly supervised PhD student working on IVUS images (PhD of A. Katouzian), for the segmentation of coronary vessels [3034, 3035, 3036, 2759, 3037] and the joint supervision of a PhD candidate (PhD of A. Lorsakul) on the quantification of myocardial strain from 3DUS images [3060]. We have also continued the work on the reformulation of deformable models with Active Surface Function [2717, 2718] for real-time segmentation performance.

A new collaboration was initiated with Echosens for the co-supervision of the PhD of S. Audière on impulsional elastography for the assessment of liver fibrosis. Novel algorithms and numerical models were developed for the FEM-based simulation of elastography experiments and the extraction of discriminant spectral parameters toward more robust estimations of liver elasticity from the RF data [4042, 3994]. A new maximum likelihood formalism was also designed to jointly estimate liver elasticity and the angle of the line of sight [3996], paving the way to new impulsional elastography acquisition setups.

A new project on liver segmentation based on models was initiated in collaboration with Philips (PhD of R. Gauriau). Extensions to multi-organ segmentation will then be addressed.

During this period, the MINIARA project on oncological applications was completed, with contributions on the segmentation of tumors and organs at risk, exploiting complementary information from PET and CT data (PhD of J. Wojak), and on the follow-up of patients, using constrained level sets approaches [3182, 3184]. Dedicated registration tools for protontherapy were also developed (PhD of J. Baussé).

In mammography, in collaboration with General Electric, we focused on the analysis of tomosynthesis images and developed original filters [2790] (see Section 12.4.1), and segmentation methods, dedicated to masses, using fuzzy approaches, and spiculated lesions, using *a contrario* approaches [2895, 3095, 3093] (PhD of G. Palma). Recently, questions related to dose assessment and risk were also addressed, based on a physical model and an estimation of the breast density [3006, 3007].

Still in X-ray imaging, a new collaboration with EOS Imaging (PhD of P. Irrera) led to new results on image denoising and enhancement on very low dose acquisitions [3031]. The developed approach relies on adaptive non-local methods, according to the different parts of the body.

Activities on nuclear imaging have been initiated with Columbia University, working on ringing artefact suppression in PET reconstruction using PSF modeling [3072].

A few years ago, a new research track was investigated in biological imaging, in collaboration with Institut Pasteur (PhD of N. Chenouard), with new results on multiple objects tracking in cluttered environment, both in 2D and in 3D [2692, 2950, 2951] (see Section 12.4.1). Regarding the activity in optical imaging, the group has launched a fruitful collaboration with Institut Pasteur and the ESPCI/Institut Langevin for the exploitation of Compressed Sensing in microscopy imaging. The Phd of M. De Moraes Marim has led to breakthrough publications introducing CS-based denoising [3063], temporal acquisition schemes and digital holography imaging [3066, 2772, 2773] for fast image sampling and efficient image reconstruction in realistic microscopy imaging setups[3]. A PhD student (Y. Le Montagner) is working on the optimization of the image reconstruction process dedicated to temporal CS microscopy imaging [3044, 3046, 3047, 3048]. A collaboration with Ecole Polytechnique, UPMC and Mines ParisTech was initiated on the 3D segmentation and analysis of collagen fibrils on multiphoton images [2657].

A close collaboration with ISEP and XV-XX hospital was launched on eye imaging, using multiple modalities. In optical coherence tomography (OCT) we proposed an original method to detect all retinal layers, using parallel deformable models, which applies in normal and pathological cases, and from which quantitative measures are derived, supporting the analysis of retinal structure variability and the early detection of alterations [2744] (PhD of I. Ghorbel). A recent technique based on adaptive optics was then exploited to detect photoreceptors and estimate their density [3058, 3059]. This technique is currently further explored to have a more precise estimation of the photoreceptors using multiple incidence images (PhD of C. Miloudi). Finally,

3. This work has received a best student paper award at the conference ISBI 2010 [3066].

eye fundus images were used for the segmentation of blood vessels and their classification into arteries and veins [2802].

A new topic was recently launched within the WHIST lab, on brain-computer interfaces (BCI), for large public applications. The first contribution concerns the detection of eye movements and blinking in EEG signals [3193], and their use as control signals for BCI tasks (PhD of Y. Yang). Optimal selection of spatial filters and of the number of electrodes has also been addressed [3192, 3191, 3194]. This activity is now moving to AAO team.

### 12.4.5 Remote Sensing

**Faculty** A. Almansa, M. Campedel, M. Datcu (until 2010), J. Delon, Y. Gousseau, H. Maître, J.-M. Nicolas, S. Rital (until 1/13), M. Roux, F. Tupin, H. Sahbi.

**Highlights: Scientific Production** [2804, 2731, 2812, 2704, 2770]

**Highlights: Impact** CNES PhD theses and research projects funding, ANR EFIDIR, REI-DGA, SWOT CNES project, Terra Numerica.

**Collaborations** with DLR (A. Reigber), U. Parthenope II Italy (G. Ferraioli), U. Sao Paulo Brazil (T. Perciano, M. Horta), Univ. Wuhan (H. Sun), Shanghai Jiao Tong University, CEA (R. Binet, B. Puysségur), U. UPEMLV, IGN, Télécom Saint-Etienne (L. Denis), ONERA (H. Oriot).

**Awards:** PhD Award in Signal, Image, Vision 2012 for C.-A. Deledalle. Best student paper at ICIP 2010 (C.-A. Deledalle, F. Tupin and L. Denis, [2965]). Antoine Ghaleb, First Price for the Student Paper Award of EUSAR 2008 (A. Ghaleb, L. Vignaud and J. M. Nicolas, [3008]).

**Highlights: Interactions with Society** CEA-Recalage, Magellium, CIFRE Thales, CIFRE EADS.

Remote Sensing stays an important application field of the group with different sensors (optical images, SAR, SMOS, lidar data, ...) and different applications (denoising and artefacts removal, 3D reconstruction, segmentation and classification, change detection, image visualization and navigation, ...).

**3D point clouds and lidar data** As long as 3D model generation from multiple images is concerned, our focus is in the construction of a low cost system allowing non-specialists to make 3D measurements with a minimal set of constraints on the image acquisition [3252]. The concerned applications are related to surface roughness and dendrometric parameter measurements (PhD of B. Petitpas with UPMLV).

In a study devoted to the analysis of full-waveform lidar data for automatic classification either for urban areas or for littoral scenes, the contribution of radiometric calibration features to obtain a high accuracy was demonstrated [2771, 2770] (PhD with MATIS, IGN).

For automatic plane detection from point clouds, a-contrario based techniques showed a great efficiency [3218, 2933], while in cases where 3D point-clouds are noisy or at low-resolution, non-local methods proved more effective [3015].

New investigations are presently undertaken towards the generation of underwater 3D models with Unmanned Underwater Vehicle (UUV) (PhD of L. Avanthey with ESIEA, DGA funding).

**Stereovision** In stereovision, our research within the MISS project focused on the feasibility of the $\frac{1}{10^{th}}$ to $\frac{1}{100^{th}}$-pixel accurate disparity maps, required for sub-meter-accurate digital elevation models in urban areas from high-resolution low-baseline stereoscopy as provided by Pleiades, and future CNES missions. We showed that such accuracy requirements are close to information-theoretic bounds [2803], and that they can be met at about $50\%$ of the pixels, once unreliable areas have been automatically rejected by a statistical criterion [2804]. The software that implements this technique was found to greatly improve the accuracy of state-of-the-art software used at CNES and IGN [3122]. It also was a key element that allowed our colleagues at IMAGINE (ENPC) to win the PRoVisG Mars 3D Challenge. Such accuracy levels are only possible if

satellite microvibrations are first estimated (PhD of J. Caron ) and the resulting irregular samples restored to produce an image on a regular grid. This is an ill-posed inverse problem requiring advanced variational techniques [2731]. In the process, a precise knowledge of the sub-pixel blur kernel is required. A new calibration pattern makes this estimation problem possible from a single image [2698, 2699, 2700].

**SMOS data (Soil Moisture and Ocean Samlinity)** RFI (Radio Frequencies Interferences) outlying artifacts in **SMOS** images made numerous single snapshots from this earth observation mission completely useless. Our study [3107] shows that automatic detection and removal of such artifacts is possible with high accuracy. The technique combines an accurate image formation model, with TV-$L^0$-$L^2$ minimization (similar to the celebrated geometry-texture decomposition) in order to separate actual image information from outlier artifacts and sensor noise.

**SAR imagery** • At the signal level, works on the statistical modeling of SAR images based on Mellin transform have been completed with the introduction of Meijer distributions which allow the definition of a unifying framework. All usual SAR distributions can be seen as Meijer distributions, and this new formalism is a powerful tool to model geometric, harmonic or arithmetic means.

• We demonstrated the efficiency of non-local means (NLM) for denoising, when properly extended to a probabilistic framework both for amplitude images [2701], or interferometric / polarimetric data [2702] [2704] (PhD of C. Deledalle, see also Section 12.4.1). We extended NLM to multi-temporal series denoising (PhD of X. Su). To solve the "rare patch effect" and for classification purpose, approches based on invariant dictionaries are now being investigated (PhD of S. Tabti). A Markovian formalism and different estimators with adapted optimization approaches define an elegant context for the fusion of multi-channel interferometric data [2736, 2811, 2810, 2812] (PhD of A. Shabou, REI project).

• For pattern recognition and image interpretation, many efforts have been dedicated to the fusion of SAR and optical images (PhD of G. Lehureau, and H. Sportouche) with SVM methods or with explicit object detection and likelihood optimization [2814]. SAR descriptors, adapted to SAR data statistics, have also been defined to propose efficient registration schemes (PhD of F. Dellinger). Network extraction is still an important problem. We adopt Markovian approaches to detect rivers with SWOT images in a CNES project and for road detection in a multi-temporal and multi-sensor framework (PhD of T. Perciano).

• Important efforts have been devoted to multi-temporal series analysis since a new generation of SAR sensors (2 Terrasar-X, 4 CosmoSkymed), with metric resolution images and a short repeat time, has raised new issues. Thanks to different projects (ANR Efidir, DLR or ASI projects), many multi-temporal datasets have been acquired. Novel registration approaches with sub-pixel accuracy have been developed and novel change detection methods, based on statistics, have been proposed. (PhD of G. Quin in collaboration with CEA). They have been used for glacier monitoring (ANR EFIDIR) with adapted similarity criteria [2732] (PhD of R. Fallourd). Man-made corner reflectors have also been positioned on Argentiere glacier to serve as ground truth and help understanding the backscattering mechanisms of metric resolution images. In the PhD of G. Hochard, the analysis of long temporal series on the Serre-Ponçon dam has led to a selection method for interferograms which could also be applied for change detection.

In collaboration with ONERA, the detection of moving target in circular imagery has been investigated (PhD of J.-B. Poisson).

**Aerial video change detection** The detection of significant changes in aerial videos is an interesting problem for various applications. This task is also challenging in many aspects; on the one hand, it is tedious when performed by human operators and on the other hand, most of the existing automatic solutions suffer from the variability related to irrelevant changes (parallax effects due to camera motion, changes in illumination, etc.). In this work, we address these issues and we introduce novel solutions that make change detection resilient to irrelevant changes

while being effective for relevant ones. More precisely, our change detection approach processes videos to recover camera parameters and to build robust appearance models, and it also exploits the redundancy in videos in order to further enhance the performances (PhD of N. Bourdis with EADS).

**Satellite image visualization and navigation** Most of satellite image search engines are based on existing meta-data or precomputed visual indices, and rely on ad-hoc functionalities such as zooming and panoramic navigation. When using large and complex images, provided by high resolution satellite sensors, these basic functionalities become helpless in order to efficiently explore these images. In Vo Dinh Phong' PhD, we address this issue and introduce a new image database visualization and navigation method that relies on learning a mapping from an initial ambient space (related to low level visual features) to an output space spanned by a well defined semantic basis (where data can be easily explored by the user). With this method, searching for a visual target reduces to scanning data according to their coordinates in the learned semantic space.

**Joint CNES-DLR-Télécom ParisTech Competence Center (CoC)** CoC was created in June 2005, and ended in June 2010. Its activities were focused on information extraction and satellite image understanding for optical images. Numerous PhD theses have been defended since 2009 on a high variety of subjects going from low level image description [2667], classification [2766] to (semi-) supervised active learning tools [2668] and knowledge representation [3262].

Even if this project is now finished, strong collaborations with CNES [4] were maintained on specific applicative projects, from 2008 to 2011, in the context of rapid mapping (EXITER project, SAFER European project and KAL-Haïti ANR). Close relationships with expert interpreters from SERTIT [5] were also developed to better promote the competence center results related to the quick production of relevant land cover maps. SERTIT and CNES provided us with rich datasets to precisely evaluate information extraction and classification tools and also to derive new products (as processing softwares) to be used by interpreters, in the context of different disasters (earthquake, flooding and forest fire). As a consequence scientific and applicative evaluations were performed exploiting platforms like KEO (ESA platform) as well as public tools like OTB (Orfeo Toolbox [6]) and GIS (Geographical Information System). Simultaneously to such engineering works, methodological ones were conducted based on consensual clustering [2934] and hypergraph representation [2929, 2680].

4. http://www.cnes.fr
5. http://sertit.u-strasbg.fr/
6. http://orfeo-toolbox.org/otb/

# 12.5 Achievements (Appendix 6)

## 12.5.1 Scientific Productions

### Articles in Journals


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*2013)*, Paris, France, Apr. 2013.
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### Invited Talks

[3199] E. Angelini. 10 open challenges for medical image processors. In *2nd Workshop US-Turkey advanced meeting on Global Healthcare Challenges and Opportunities*, Antalya, Turkey, 2011.
[3200] E. Angelini. Designing fast and robust algorithms for medical image processing. In *Annual Workshop "Large Data Sets in Medical Informatics"*, Institute for Mathematics and Its Applications (IMA), University of Minnesota, USA, 2011.
[3201] I. Bloch. Morphologie mathématique floue, applications en raisonnement spatial et en logique. In *LFA 2008*, pages 2–9, Lens, France, 2008.
[3202] I. Bloch. Fuzzy and Bipolar Mathematical Morphology, Applications in Spatial Reasoning. In *Symbolic and Quantitative Approaches to Reasoning with Uncertainty ECSQARU*, volume LNAI 5590, pages 1–13, Verona, Italy, 2009.
[3203] I. Bloch. Mathematical morphology, lattices, and formal concept analysis. In *8th International Conference on Concept Lattices and Their Applications (CLA 2011) - Invited conference*, page 1, Nancy, France, Oct. 2011.
[3204] I. Bloch. Structural models and spatial reasoning - Application to segmentation and recognition of anatomical structures in medical images. In *International Conference on MEDICAL IMAGING using BIO-INSPIRED and SOFT COMPUTING (MIBISOC) (Invited Conference)*, page 1, Brussels, Belgium, May 2013.

### 12.5.2 Public Fundings

| Period | Project details | Funding | Principal investigator | Total (k€) |
|---|---|---|---|---|
| 2008-2012 | EFIDIR - Displacement measurement through radar imaging | ANR | J.-M. Nicolas | 69 |
| 2008-2012 | CMCU - Radar differential interferometry using minimal cutson image series | UTIQUE | F. Tupin | 2 |
| 2008-2009 | SOFIA | CNES | M. Datcu | 64 |
| 2008-2008 | TEMPO SAR | OSEO | F. Tupin | 1,5 |
| 2008-2009 | Knowledge representation and platform development | CNES | M. Campedel | 48 |
| 2008-2008 | Segmentation | CNES | H. Maître | 10 |
| 2008-2011 | REI - Multi-objects tracking | DGA | I. Bloch | 148 |
| 2009-2013 | MATAIM - Anisotropic texture modeling | ANR | Y. Gousseau | 18 |
| 2009-2013 | CALLISTO - Calibration procedures for multi-image stereo | ANR | Y. Gousseau | 119 |
| 2009-2010 | REI - Radar image regularization using minimal cuts | DGA | F. Tupin | 121 |
| 2009-2010 | CELUM - Turbulence analysis in underwater acoustics | DGA | J.-M. Nicolas | 10 |
| 2009-2009 | ICS - Satellite image classification | CNES | M. Campedel | 18 |
| 2009-2009 | SAFER - Fast cartography for natural disaster monitoring | CNES | M. Campedel | 11 |
| 2009-2009 | Compressed images | CNES | M. Datcu | 9 |
| 2009-2013 | MEDIAGPU - Parallel algorithms for real-time rendering on GPU | ANR | T. Boubekeur | 134 |
| 2009-2011 | IPHOT - Clinical imaging of photoreceptors | ANR | I. Bloch | 134 |
| 2009-2011 | KIDPOCKET - 3D modeling and deformations for analyzing the exposure of children to magnetic vawes | ANR | I. Bloch | 207 |
| 2010-2010 | SIFTI | CNES | A. Almansa | 40 |
| 2010-2011 | SWOT - River extraction for the future SWOT sensor | CNES | F. Tupin | 50 |
| 2010-2011 | TICA | CNES | M. Datcu | 17 |
| 2010-2012 | Venise - Satellite image visualization and exploration | CNES | H. Sahbi | 75 |
| 2010-2012 | SAFER - Fast cartography for natural disaster monitoring | CNES | M. Campedel | 60 |
| 2010-2012 | Hyper-graphs | CNES | S. Rital | 52 |
| 2010-2013 | VISUNET - Object tracking in multimedia sensor networks | Digiteo | H. Sahbi | 4 |
| 2010-2013 | FETUS - Modeling and deformation for fetus and pregnant woman exposure evaluation to telecom new wireless usages and systems | ANR | I. Bloch | 321 |
| 2010-2013 | MLVIS - Machine learning for visual annotation in social media | ANR | H. Sahbi | 182 |
| 2010-2013 | RELIR - Multi-relational machine learning for image retrieval and annotation in large social sharing media | Digiteo | H. Sahbi | 13 |
| 2010-2013 | CEDCA - Embedded correction systems for camera defaults | FUI 9 | Y. Gousseau | 426 |
| 2010- | 3DLife - Real-time modeling and rendering | Europe | T. Boubekeur for TII | 140 |

| Period | Project details | Funding | Principal investigator | Total (k€) |
|---|---|---|---|---|
| 2011-2013 | Registration of Terrasar X images | CEA | J.-M. Nicolas | 223 |
| 2011-2014 | SPACE&TIME - Rendering of urban data | ANR | T. Boubekeur | 119 |
| 2011- | REVERIE - Capture, transmission and interactive rendering | Europe | T. Boubekeur for TII | 180 |
| 2011-2011 | Image information | DLR | M. Datcu | 19 |
| 2012-2016 | LOGIMA - Logic, structural representation, mathematical morphology and uncertainty for semantic interpretation of images and videos | ANR | I. Bloch | 88 |
| 2012-2013 | Benchmark for artifact detection | CNES | M. Campedel | 16 |
| 2012-2013 | ACTE - Analysis and characterization of very young children exposure to telecommunication systems | ANSES - FT | I. Bloch | 166 |
| 2013-2013 | Num2Phy - Pedagogical innovation | IMT | M. Campedel, J.M. Nicolas | 3 |
| 2013-2015 | REVEAL - High resolution imaging of retinian vessels | ANR | I. Bloch | 80 |
| 2013-2015 | DESCRIBE - Online detection of visual events in videos | ANR | I. Bloch | 91 |
| 2013-2015 | UnTopoVis - Visualization of uncertain scalar data | FCS Campus Paris Saclay | J. Tierny | 77 |

### 12.5.3 Private Fundings

| Period | Project details | Funding | Principal investigator | Total (k€) |
|---|---|---|---|---|
| 2009-2012 | OCT retina imaging | FOVEA - CIFRE | I. Bloch | 20 |
| 2009-2010 | Risk measures for decision under uncertainty | Thales | I. Bloch | 10 |
| 2009-2012 | Vascular imaging | Philips - CIFRE | I. Bloch | 45 |
| 2009-2012 | Parallel geometric processing | EDF - CIFRE | T. Boubekeur | 45 |
| 2009-2010 | Segmentation and modeling of children body | FT | I. Bloch | 96 |
| 2010-2011 | Parametrization of animated lines | Adobe | T. Boubekeur | 5 |
| 2010- | Imaginaires Chair - 3D shape and universe modeling | UBISOFT, DS, Orange, PSA, Alcatel Lucent | T. Boubekeur for TII | 45 |
| 2010-2011 | Ingrid - Transfer of image processing tools in the DGA platform | Magellium | F. Tupin | 40 |
| 2010-2011 | Brain-Computer Interfaces | FT | I. Bloch | 40 |
| 2010-2014 | Segmentation and modeling of soft tissues and bones | FT | I. Bloch | 180 |
| 2010-2013 | Content-based colour management for print | Oce - CIFRE | H. Brettel | 20 |
| 2010-2013 | Pose and shape estimation in face videos | Morpho - CIFRE | I. Bloch | 22 |
| 2010-2013 | Aerial image change detection | EADS - CIFRE | H. Sahbi | 45 |
| 2011-2013 | Degraded films restoration and video inpainting | Technicolor - CIFRE | Y. Gousseau | 45 |
| 2011-2013 | | Usefull Progress - CIFRE | E. Eisemann | 16 |
| 2011-2014 | Mammography and dose estimation | GE - CIFRE | I. Bloch | 22 |
| 2011-2014 | Lip-reading and visual speech recognition | Parrot - CIFRE | H. Sahbi | 36 |
| 2011-2015 | Modeling of skeleton from medical images | Renault - CIFRE | E. Angelini | 45 |
| 2012-2013 | BCI | FT | I. Bloch | 30 |
| 2012-2015 | | Morpho - CIFRE | A. Almansa | 45 |
| 2012-2015 | Multi-organ segmentation | Philips - CIFRE | I. Bloch | 45 |
| 2012-2015 | Low-dose X-ray imaging | EOS Imaging - CIFRE | I. Bloch | 45 |
| 2012-2013 | Information fusion for surfaces extraction | CSSI | F. Tupin | 5,5 |
| 2012-2015 | Optimization of print quality with multichannel printing | Oce - CIFRE | H. Brettel | 45 |
| 2013-2013 | Acquisition of ORV for geological survey of India - Expertise for testing sonar IXBLUE | Wartsila - Sonar IXBLUE | J.-M. Nicolas | 3 |

# 12.6 PhDs (Appendix 7)

## 12.6.1 Defended PhDs

[3205] E. Aldea. *Apprentissage de données structuées pour l'interprétation d'images*. PhD thesis, Télécom ParisTech, Jan. 2009.
[3206] J. Anquez. *Modélisation de la femme enceinte à partir d'images 3D ultrasonores et IRM anténatales, pour l'étude de la dosimétrie*. PhD thesis, Télécom ParisTech, 2009.
[3207] S. Audiere. *Traitement du Signal et Simulations pour l'Elastographie Impulsionnelle*. PhD thesis, Télécom ParisTech, Dec. 2011.
[3208] A. Baillard. *Détermination automatique des paramètres morphologiques des galaxies*. PhD thesis, Ecole Nationale Supérieure des Télécommunications, Dec. 2008.
[3209] J. Baussé. *Recalage et planification du traitement en radiothérapie et protonthérapie*. PhD thesis, Télécom ParisTech, Oct. 2010.
[3210] P. Birjandi. *Modelling, Extraction and Description of Intrinsic Cues of High Resolution Satellite Images: Independent Component Analysis based approaches*. PhD thesis, Télécom ParisTech, Sept. 2011.
[3211] P. Blanchart. *Fast learning methods adapted to the user specificities: application to earth observation image information mining*. PhD thesis, Télécom ParisTech, Sept. 2011.
[3212] N. Bonnier. *Contribution aux algorithmes de mise en correspondance de gammes de couleurs spatialement adaptatifs*. PhD thesis, Eco, Sept. 2008.
[3213] J. B. Bordes. *Inférence de connaissances sémantiques : application aux images satellitaires*. PhD thesis, Ecole Nationale Supérieure des Télécommunications, Apr. 2009.
[3214] M. Bouali. *Destriping data from multidetector imaging spectrometers: a study on the MODIS instrument*. PhD thesis, Télécom ParisTech, June 2011.
[3215] N. Bourdis. *Détection de changements entre vidéos aériennes avec trajectoires arbitraires*. PhD thesis, Telecom ParisTech, May 2013.
[3216] M. Brédif. *Modélisation 3D de bâtiments : reconstruction automatique de superstructures de toits et recalage cinétique de toits polyédriques prenant en compte la topologie*. PhD thesis, Télécom ParisTech, May 2010.
[3217] B. Buchholz. *Abstraction and processing of animated 3D data*. PhD thesis, Télécom ParisTech, Dec. 2012.
[3218] E. Bughin. *Vers une vectorisation automatique, précise et validée en stéréoscopie satellitaire en milieu urbain*. PhD thesis, ENS Cachan, Oct. 2011.
[3219] J. Caron. *Restauration en échantillonnage irrégulier - Théorie et applications aux signaux et images satellitaires*. PhD thesis, Université de Picardie Jules Verne à Amiens, Mar. 2012.
[3220] D. Cerra. *Pattern-oriented algorithmic complexity: towards compression-based information retrieval*. PhD thesis, Télécom ParisTech, May 2010.
[3221] N. Chenouard. *Advances in probabilistic particle tracking for biological imaging*. PhD thesis, Télécom ParisTech, Jan. 2010.
[3222] D. Craciun. *Image-laser fusion for 3D modeling of complex environments*. PhD thesis, Télécom ParisTech, July 2010.
[3223] M. Delbracio. *Two Problems of Digital Image Formation: Recovering the Camera Point Spread Function and Boosting Stochastic Renderers by Auto-similarity Filtering*. PhD thesis, ENS Cachan, Mar. 2013.
[3224] C.-A. Deledalle. *Débruitage d'images au-delà du bruit additif gaussien - Estimateurs à patchs et leur application à l'imagerie SAR*. PhD thesis, Télécom ParisTech, Nov. 2011.
[3225] J. Dellière. *Simulation de données SAR en milieu urbain à haute résolution. Etude de faisabilité d'une méthode exacte*. PhD thesis, Ecole Nationale Supérieure de Télécommunications ENST2008E013, June 2008.
[3226] V. Duval. *Méthodes variationnelles et non locales en traitement d'images : une étude géométrique*. PhD thesis, Télécom ParisTech, June 2011.
[3227] R. El-Berbari. *Segmentation d'images de contractions et de rehaussement tardif en IRM cardiaque. Application à l'étude de la fonction contractile et la viabilité myocardique*. PhD thesis, Ecole Nationale Supérieure des Télécommunications, Jan. 2009.
[3228] N. Faraj. *Modélisation, Visualisation et Interaction par Maillages avec les Volumes 3D*. PhD thesis, Telecom ParisTech, June 2013.
[3229] G. Fouquier. *Optimisation de séquences de segmentation combinant modèle structurel et focal-*

*isation de l'attention visuelle. Application à la reconnaissance de structures cérébrales dans des images 3D*. PhD thesis, Télécom ParisTech, Feb. 2010.

[3230] B. Galerne. *Modèles d'image aléatoires et synthèse de texture*. PhD thesis, ENS Cachan, Dec. 2010.

[3231] A. Ghaleb. *Analyse de l'effet micro-Doppler de cibles mobiles en imagerie radar*. PhD thesis, Ecole Nationale Supérieure des Télécommunications, Feb. 2009.

[3232] I. Ghorbel. *Segmentation et quantification des couches rétiniennes dans des images de tomographie de cohérence optique, dans le cas de sujets sains et pathologiques*. PhD thesis, Télécom ParisTech, Apr. 2012.

[3233] A. B. Graciano. *Modeling and recognition of structured objects: a statistical relational approach*. PhD thesis, Université de Sao Paulo, Brésil, June 2012.

[3234] G. Hochard. *Détection de changements en imagerie radar cohérente*. PhD thesis, Télécom ParisTech, Mar. 2011.

[3235] M. Holländer. *Real-time geometry synthesis*. PhD thesis, Telecom ParisTech, Mar. 2013.

[3236] J.-F. Huang. *Rendering models and 3D emotional animation*. PhD thesis, Telecom ParisTech, Feb. 2013.

[3237] T. Hurtut. *Analyse et recherche d'oeuvres d'art 2D selon le contenu pictural*. PhD thesis, TELECOM ParisTech, Mar. 2008.

[3238] A. Kermi. *Reconstructions faciales à partir d'images tridimensionnelles de crânes humains par recalage et modèle déformable pour l'identification de personnes*. PhD thesis, École Nationale Supérieure des Télécommunications, Oct. 2008.

[3239] H. Khotanlou. *Segmentation 3D de tumeurs et de structures internes du cerveau en IRM*. PhD thesis, École Nationale Supérieure des Télécommunications ENST2008E005, Feb. 2008.

[3240] C. Le Men. *Segmentation spatio-temporelle d'une séquence temporelle d'images satellitaires à haute résolution*. PhD thesis, Télécom ParisTech, July 2009.

[3241] G. Lehureau. *Fusion de données optique et radar à haute résolution en milieu urbain*. PhD thesis, Télécom ParisTech, Apr. 2010.

[3242] D. Lesage. *Models, Features and Extraction Schemes for Vascular Segmentation: Application to the delineation of Coronary Arteries from 3D Computed Tomography Data*. PhD thesis, Télécom ParisTech, Mar. 2009.

[3243] P. Lopez Quiroz. *Séries temporelles de la subsidence de la ville de Mexico obtenues par interférométrie radar*. PhD thesis, TELECOM ParisTech, Nov. 2008.

[3244] C. Mallet. *Analyse de données lidar à retour d'onde complète pour la classification en milieux urbains*. PhD thesis, Télécom ParisTech, Nov. 2010.

[3245] M. Marim. *Imagerie Compressée pour la Microscopie Biologique*. PhD thesis, Télécom ParisTech, Apr. 2011.

[3246] C. Millet. *Construction et utilisation de la sémantique dans le cadre de l'annotation automatique d'images*. PhD thesis, École Nationale Supérieure des Télécommunications, ENST2008E021, Jan. 2008.

[3247] F. Mosca. *Synthèse d'émission spatio-temporelle pour l'imagerie acoustique*. PhD thesis, Télécom ParisTech, Oct. 2010.

[3248] T. Napoléon. *Indexation multi-vues et recherche d'objets 3D*. PhD thesis, Télécom ParisTech, July 2010.

[3249] O. Nempont. *Modèles structurels flous et propagation de contraintes pour la segmentation et la reconnaissance d'objets dans les images. Application aux structures normales et pathologiques du cerveau en IRM*. PhD thesis, Ecole Nationale Supérieure des Télécommunications, Mar. 2009.

[3250] G. Palma. *Détection automatique des opacités et distorsions architecturales en tomosynthèse du sein*. PhD thesis, Télécom ParisTech, Feb. 2010.

[3251] X. Perrotton. *Détection automatique d'objets dans des images numériques - application aux images aériennes*. PhD thesis, Ecole Nationale Supérieure des Télécommunications, Jan. 2009.

[3252] B. Petitpas. *Extraction de paramètres bio-geo-physiques de surfaces 3D reconstruites par multi-stéréo-restitution d'images prises sans contraintes*. PhD thesis, Université Marne la Vallée, Dec. 2011.

[3253] G. Pizaine. *Extraction et étiquetage automatique de structures arborescentes en imagerie médicale, application à l'arbre aortique abdominal*. PhD thesis, Télécom ParisTech, Dec. 2012.

[3254] J. Rabin. *Approches robustes pour la comparaison d'images et la mise en correspondance d'objets*. PhD thesis, Télécom ParisTech, Dec. 2009.

[3255] A. Roquel. *Exploitation du conflit entre capteurs pour la gestion d'un système complexe multi-*

*capteurs*. PhD thesis, Université Paris Sud, Dec. 2012.
[3256] N. Sabater. *Reliability and accuracy in stereovision Application to aerial and satellite high resolution images*. PhD thesis, CMLA - ENS Cachan, Dec. 2009. Directeurs de thèse: A. Almansa, J-M. Morel.
[3257] A. Shabou. *Minimisation multi-étiquette d'énergies markoviennes par coupe-minimum sur graphe : application à la reconstruction de la phase interférométrique en imagerie RSO*. PhD thesis, Télécom ParisTech, Nov. 2010.
[3258] H. Soubaras. *Probabilistic and non-probabilistic measures of risk in Markov-type systems for planning under uncertainty*. PhD thesis, Télécom ParisTech, Jan. 2011.
[3259] H. Sportouche. *Extraction et reconstruction des bâtiments en milieu urbain à partir d'images satellitaires optiques et radar à haute résolution*. PhD thesis, Télécom ParisTech, Dec. 2010.
[3260] M. Tepper. *Detecting clusters and boundaries: a twofold study on shape representation*. PhD thesis, université de Buenos Aires, Argentine, Mar. 2011.
[3261] J.-M. Thiery. *Géométrie numérique et géométrie algorithmique pour le design interactif 3D*. PhD thesis, Télécom ParisTech, Nov. 2012.
[3262] C. Vanegas. *Spatial relations and spatial reasoning for the interpretation of earth observation images using a structural model*. PhD thesis, Télécom ParisTech, Jan. 2011.
[3263] G. Vialaneix. *Algorithmes parallèles de manipulation de maillages*. PhD thesis, Télécom ParisTech, Nov. 2012.
[3264] N. Widynski. *Intégration d'informations spatiales floues dans un filtre particulaire pour le suivi mono- et multi-objets dans des séquences d'images 2D*. PhD thesis, UPMC, Nov. 2010.
[3265] J. Wojak. *Analyse d'images multi-modales TEP-TDM du thorax. Application à l'oncologie : segmentation de tumeurs, d'organes à risque et suivi longitudinal pour la radiothérapie*. PhD thesis, Télécom ParisTech, Dec. 2010.
[3266] G.-S. Xia. *Méthodes géométriques pour l'analyse d'images et de textures*. PhD thesis, Télécom ParisTech, Mar. 2011.

### 12.6.2 Ongoing PhDs

- Cecilia Aguerrebere (04/11–), *Restauration multi-images. Création d'images à grande plage dynamique*.
- Emilie Au (depuis décembre 2011, avec le LIP6) Machines d'annotation dans les bases d'images relationnelles.
- Loica Avanthey (depuis octobre 2012, avec l'ESIA) Mosaiquage de données 3D obtenues par des drones hétérogènes à l'interface air/eau.
- Teun Baar (depuis octobre 2012) Optimisation de la qualité d'impression multi-canaux.
- Eric Benhaim (depuis octobre 2011, CIFRE avec Parrot) Analyse visuelle et fusion pour la reconnaissance de la parole.
- Stéphane Calderon (depuis novembre 2011) Capture et modélisation 3D dynamique.
- Isabelle Cléry (depuis février 2012, avec l'IGN) Valorisation géométrique et radiométrique d'un patrimoine de photographies anciennes scannées.
- Antoine Deblonde (depuis avril 2012, avec Morpho) Mise en correspondance et recherche d'empreintes digitales.
- Flora Dellinger (depuis octobre 2010, avec le CNES) Représentation des informations et détection de changements sur des images de télédétection de haute résolution hétérogènes.
- Kristyn Falkenstern (depuis février 2010) Rendu des images imprimées.
- Mariem Gargouri (depuis octobre 2011, avec Renault) Caractérisation des usagers de la route par imagerie.
- Romane Gauriau (depuis juin 2012, CIFRE avec Philips) Segmentation et mise en correspondance de structures anatomiques en imagerie médicale 3D, application aux problématiques inter- et intra-patient, multi-modalité et multi-structures.
- Nausikaa Geeraert (depuis septembre 2011, avec KUL, CIFRE avec GE) Evaluation quantitative de la densité et de la structure fibroglandulaire en mammographie numérique et application à la stratification du risque et à la dosimétrie.

- Thierry Guillemot (depuis octobre 2010) Nuage de courbes : géométrie numérique par la vision.
- Emilie Guy (depuis octobre 2012) Structure de Contrôle de Formes Automatique.
- Catherine Herold (depuis décembre 2010, avec Morpho) Estimation et filtrage temporel de la forme 3D des visages.
- Paolo Irrera (depuis juillet 2012, CIFRE avec EOS Imaging) Traitement d'images de radiographie à faible dose.
- Quoc Ang Le (depuis octobre 2009, ANR GV-Lex) 3D Expressive Gesture Models.
- Yoann Le Montagner (depuis octobre 2010, avec l'Institut Pasteur) Prototypage d'un système d'acquisition de microscopie avec schémas d'acquisition parcimonieuse dans le domaine de Fourier pour l'imagerie optique biologique à très haut débit d'information.
- Baptiste Mazin (depuis septembre 2010) Invariances colorimétriques et radiométriques pour la comparaison d'images.
- Jean-Christophe Michelin (depuis décembre 2011, avec l'IGN-MATIS) Qualification automatique de bases de données 3D de bâtiments.
- Chahira Miloudi (depuis septembre 2012, avec l'ISEP et l'hôpital des XV-XX) Analyse d'images de la rétine en optique adaptative et tomographie de cohérence optique.
- Baptiste Morel (depuis décembre 2012, avec l'hôpital du Kremlin-Bicêtre) Analyse quantitative de pathologies cérébrales en IRM.
- Alasdair Newson (depuis septembre 2010, avec Technicolor) Restauration de défauts persistants dans les films et inpainting spatio-temporel.
- Guillaume Pizaine (depuis juin 2009, avec Philips) Segmentation de vaisseaux sanguins et détection de pathologies.
- Jean-Baptiste Poisson (depuis octobre 2010, avec l'ONERA) Imagerie SAR circulaire.
- Javier Preciozzi (doctorant à l'etranger UdelaR) Restauration d'images satellitaires.
- Guillaume Quin (depuis septembre 2010, avec le CEA).
- Avid Roman Gonzalez (depuis septembre 2009) Détection d'éléments structurés en imagerie satellitaire.
- Leila Schemali (depuis janvier 2011, avec Useful Progress) Visualisation de gros volumes de données et rendu.
- Xin Su (depuis novembre 2011) Exploitation de séries satellitaires multi-temporelles.
- Sonia Tabti (depuis octobre 2012) Nouveaux modèles d'images pour la restauration, la compréhension et la détection de changements en imagerie radar.
- Guillaume Tartavel (depuis octobre 2011) Modélisation parcimonieuse des textures.
- Jean-Marc Thiery (depuis octobre 2009) Géométrie Numérique et Géométrie Algorithmique pour le Design 3D Interactif.
- Yann Traonmilin (depuis juillet 2011) Comparaison entre modèle d'image et supplément d'information pour la super-résolution.
- Guillaume Vialaneix (depuis décembre 2009, avec EDF) Algorithmes parallèles de manipulation de maillages.
- Ujjwal Verma (depuis octobre 2010, avec l'ISEP) Traitement et classification de signaux multimedia et d'images multi-temporelles.
- Phong Vo (depuis octobre 2010) Visualisation et navigation dans les bases d'images par apprentissage des variétés.
- Bebei Wang (depuis octobre 2012, avec l'université de Shondong, Chine) Illumination globale sur des ressources hybrides.
- Ling Wang (depuis janvier 2012) Graphes appliqués aux réseaux sociaux et à la vidéo.
- Yuan Yang (depuis octobre 2010, avec Orange Labs) Interfaces homme-cerveau pour des applications grand public.
- Fei Yuan (depuis septembre 2010, avec l'Académie des Sciences de Chine) Méthodes à base de graphes pour la recherche dans les bases d'images et les séquences vidéo.

# Chapter 13

# Multimedia (MM)

## 13.1 Executive Summary (Appendix 1)

**Team Leader** Béatrice Pesquet-Popescu

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**Initial Staff** 5 Professors; 2 Research Scientists; 8 Engineers; 10 Postdocs; 25 PhD Students.

**Staff who Left** 2 Permanent Staff (103 months); 13 PhD Students (403 months) ; 17 Postdocs (213 months).

**Staff who Were Hired**

- Marco Cagnazzo – Télécom ParisTech – previously post-doc at l'Univ. Nice Sophia-Antipolis
- Catherine Pelachaud – CNRS – previously professor at l'Univ. Paris 8
- Frédéric Dufaux – CNRS – previously research scientist at l'EPFL
- Giuseppe Valenzise – CNRS – previously post-doc at Télécom ParisTech
- Chloé Clavel – Télécom ParisTech – previously research ingineer at l'EDF

**Scientific Highlights**

- F. Dufaux, B. Pesquet, M. Cagnazzo Editors, Emerging technologies for 3D video: content creation, coding, transmission and rendering, Wiley Eds., May 2013
- D. Petrovska, G. Chollet et B. Dorizzi, Guide to Biometric Reference Systems and Performance Evaluation, Springer, 2009, series on Computer Imaging, Vision, PR and Graphics
- GRETA is a real-time platform of an embodied conversational agent,endowed with socio-emotional capabilities, able to communicate verbally and nonverbally with users.
- GPAC is the leading open source software in the academic world for the encoding, the delivery and the playback of multimedia content, ranging from simple audio/video presentations to complex interactive multimedia services.
- F. Temmermans, F. Dufaux and P. Schelkens, JPSearch: Metadata Interoperability During Image Exchange, IEEE Signal Processing Magazine, vol. 29, no. 5, pp. 134-139, Sept. 2012

**Scientific Production** 80 Journals; 9 Books; 28 Book chapters; 270 Articles in Proceedings; 10 Invited talks; 146 standardization contributions

**Major Publications**

- A-L Bianne, F. Menasri, C. Mokbel, R. Al-Hajj, C. Kermorvant, L. Likforman-Sulem, Dynamic and Contextual Information in HMM Modeling for Handwritten Word Recognition, IEEE PAMI, 2011, Vol. 33, no 10
- A. Fraysse, B. Pesquet, J.-C. Pesquet, On the Uniform Quantization of a Class of Sparse Sources, IEEE Trans. on Information Theory, vol.55, issue 7, July 2009, pp. 3243-3263
- C. Pelachaud, Modelling Multimodal Expression of Emotion in a Virtual Agent, Philosophical Transactions of Royal Society B Biological Science, B 2009, vol. 364, 3539-3548
- L. Zouari et G. Chollet, Efficient codebook for fast and accurate low resource ASR systems, Speech Communication, Mar. 2009
- A. Abou-Elailah, F. Dufaux, J. Farah, M. Cagnazzo, and B. Pesquet-Popescu, Fusion of Global and Local Motion Estimation for Distributed Video Coding, IEEE Trans. on Circ. Syst. for Video Tech., vol. 23, no. 1, pp. 158-172, Jan. 2013

**Major Documents**

- C. Pelachaud, T. Boubekeur, Guest Editors, special issue, Digital Human Faces: From Creation to Emotion, IEEE Computer Graphics and Applications, 2010
- Corpus of ancient printed characters: L. Likforman and M. Sigelle, Recognition of degraded characters using dynamic Bayesian networks, Pattern Recognition, Vol. 41, 3092-3103, 2008 (`http://perso.telecom-paristech.fr/lauli/ENST_ANCIENT_CHAR/`).
- Co-Chairs and Co-Editors of the following standards: ISO/IEC MPEG-U, W3C EmotionML, ISO/IEC JPSearch, ISO/IEC JPEG2000 Wireless
- F. Dufaux, Guest Co-Editor of the Special Issue: "Intelligent Video Surveillance for Public Security and Personal Privacy", IEEE Trans. on Inf. Forensics and Security, 2013
- B. Pesquet, Guest Co-Editor of the IEEE Transactions on Circuits and Systems for Video Technology, special issue on " Emerging Research and Standards in Next Generation Video Coding (HEVC)", Dec. 2012

**Impact and Attractivity**

- C. Pelachaud - invited presentation at Royal Academy, Computation of Emotions in Man and Machines, London, April 2009 (`http://royalsociety.org/events/2009/computation-emotions/`)
- F. Dufaux is Editor in Chief of Elsevier Image Communication since 2010, B. Pesquet is member of the Signal Processing Magazine editorial team since 2012
- B. Pesquet elected 2013 Fellow IEEE (youngest woman IEEE Fellow in France)
- B. Pesquet was General Co-Chairs of EUSIPCO2012 (750 participants)
- B. Pesquet was secretary of the Executive Subcommittee of the IEEE Signal Processing Society Conference Board and is member of the IEEE SPS Awards Board

**Interaction with Economic and Social Spheres**

- J. Lefeuvre and C. Concolato pioneered a Digital and Visual Radio receiver (Diabolo, in parternship with a French SME): appearing on the front cover of a national general public science magazine; and demonstrated during the 2010 International Paris Motor Show
- L. Likforman in collaboration with A2iA won the first place among corporations in Arabic and French handwriting recognition competition
- J. LeFeuvre and C. Concolato have a collaboration with Samsung since 2008
- B. Pesquet is Scientific Director of the UBIMEDIA common laboratory with Alcatel-Bell Labs
- B. Pesquet was cited in Apr. 2012 by Usine Nouvelle among the "100 who matter in the digital world" in France

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**Contributions to Higher Education**

- J.-C. Moissinac is responsible for the Master CPM, in collaboration with INA
- L. Likforman and B. Pesquet are responsible resp. for the "parcours" AFA and SAMVA; coordination of the teaching modules SI221, SI222, MDI343, SI350, SI380
- More than 20 modules of continuous education in the field of multimedia
- Responsible for the training module dedicated to "classes prépas" professors, LIESSE 2013, on new challenges in video
- 2 chapters in the E-Reference book on Signal Processing, Elsevier, 2013
- 9 ISO Certificates of Appreciation for standards editing
- 146 documents of contribution to standardization
- 3 presentations in GDR workshops

## 13.2 People

**Team leader** Béatrice Pesquet-Popescu (FP).

**Faculty** M. Cagnazzo (AP, 02/08 –), C. Clavel (AP, 02/13 –), C. Concolato (AP), J. Lefeuvre (AP), L. Likforman (AP), J.-C. Moissinac (AP), M. Sigelle (AP), G. Chollet (SRS, – 07/12, then Emeritous SRS); F. Dufaux (SRS, 10/10 –), C. Faure (JRS, –02/12), C. Pelachaud (SRS, 10/08 –), G. Valenzise (JRS, 10/12 –).

**PhD students** M. Abid (05/09 – 10/12), A.B. Abou El Ailah (12/09 – 12/12), A-L Bianne (09/08 – 11/11), M. Bendris (10/08–07/11), R. Bouazizi (11/12 –), N. Bouzakaria (12/12 –), M. Calemne (11/13 –), G. Chierchia (10/11 –), M. Chollet (11/11 –), M. Decombas (10/10 –), Y. DING (01/11 –), A. Fiengo (11/13 –), N. Fourati (11/11 –), R. Galvao de Oliveira (01/09–09/12), N. Glas (01/13 – ), C. Greco (10/08–06/12), V. Gros (03/12 –), M. Kaaniche (10/08–12/10), Huang (10/09 – 02/13), S.J. Hyniewska (01/09 – 03/13), H. Khemiri (09/10 –), P. Lauga (11/11 –), Q.A. Le (10/08 – 06/13), M. Meddeb (11/13 –), H. Medina (11/10 – ), P. Milhorat (04/12 –), E. G. Mora (11/10 –), O. Morillot (10/11–), I. Nemoianu (11/09 – 06/13), C. Oprean (10/11 –), F. Pecune (12/12 –), G. Petrazzuoli (11/09 – 01/13), P. Perrot (–12/10), B. Ravenet (03/12 –), B. Rodriguez (02/09–02/13), M. Sarkis (04/13 –), Y. Xing (01/12 – ).

**Post-docs, engineers and sabbaticals** V. Atanasiu (08/10–04/11), R. Chiang (08/12–01/13), M. Kieffer (09/09–), M. Trocan (10/11 –), R. Bouqueau (06/09–05/12), L. Daud (01/10 – 12/11), F. de Simone (11/12 –), J. Deslis (09/12 – ), J.C. Dufourd (10/11 –), J. Feldmar (12/11 – 12/12), R. Gaetano (09/10 – 05/13), J. Gorin (01/13 –), C. Greco (07/12 –), M. Kaaniche (12/10 – 10/11), A. KOZ (10/11 –), C.K. Nguyen (01/11–12/11), V. Nguyen (05/12 – 04/13), X.H. Nguyen (05/12-03/13), R. Niewiadomski (10/08 – 04/13), M. Ochs (09/09 –), S. Pammi (01/12–02/13), A.M. Pez (11/08–), P. Philippe (01/11–12/11), K. Prepin (11/08–), B. Rodriguez (03/12 – 03/13), S. Schlögl (12/12 –), S. Selle (01/10 – 11/11), A. Shafiei (10/12 –), A. Sharma (04/12 – 03/13), J. Sillan (01/09 –12/10), S. Thomas (01/10 – 12/11).

## 13.3 Overview

The Multimedia team research activity concerns all the life cycle of multimedia documents and signals: acquisition, coding, transmission, transport, interactivity.

In particular, the team has an intense activity in image and video compression, producing a very consistent track of publications in the major international journal and conferences. In the 2008-2013 period, the team has continued its work on “classical” video coding, a field that has witnessed an uninterrupted activity by the research community, as testified by the deployment of a new video compression standard in January 2013. At the same time, we have been working on compression for emerging formats, frameworks and applications. In particular, we considered the compression of multi-view video and multi-view plus depth video (a format that is particularly suitable for new services as free-viewpoint television), and the processing and compression of high dynamic range video and images. We have had a very intense activity on the emerging framework of distributed video coding, which is particularly attractive for low-complexity applications, sensor networks, robust transmission. Alternative approaches for robust video streaming have been considered, such as multiple description coding, network coding, and their combinations. We have also been active in content-aware video streaming over wired and wireless network, developing robust transmission protocols that take into account the characteristics of compressed video. Within the Multimedia team, research focuses also on various multimodal contents. In particular, the team has developed several HMM-based (Hidden Markov Models) approaches for handwriting recognition looking at word and text-line recognition. Particular attention was given to the restoration of ancient documents. A new approach resulting from the combination of Total Variation and Non Local Means has been proposed. Lately, not only written document but also web pages became a subject of study. Models to decompose web pages

into functional blocks were proposed in view of adapting web pages to small screens and mobile phones. Another important research line of the team regards speech where we studied speech recognition and synthesis, but also silent speech, audio-visual speech analysis, and lately face tracking and spoken dialog system. The latest topic was also approached from the perspective of the development of socio-emotional embodied conversational agents. The platform of the virtual agent Greta was integrated within an interactive system allowing users to dialog with the agents. The behaviors of the agent were further developed to encompass a large set of emotional and social signals such as blend of emotions, different smiles, or even laughter. These researches gave rise to various working systems that are continuously extended as new research questions are tackled. These studies are conducted collaboratively, within several European and National projects. The Multimedia team has been involved in many research projects, both national and international. The excellence of the team scientific production is testified by the several awards received, both for single papers (MMSP Top 10% award, “High quality paper” reocgnition by the review IEEE MMTC-R Letter for one of our articles [3293]) and for personal achievements (B. Pesquet-Popescu has received the IEEE fellowship elevation, F. Dufaux is editor in chief for the Elsevier *Signal Processing: Image communication* journal, other teams members are associate editors for several reknown journals). This has allowed us to keep a high level of attractivity for the team, as witnessed by the recruitement of internationally recognized researchers (F. Dufaux, C. Pelachaud).

The team has also an intense activity in scientific conference organization. In particular, the team members have been involved in the organizations of the following conferences. IEEE MMSP 2010 (150 participants): general co-chair, electronic media chair; EUSIPCO 2012 (750 participants): general co-chair, publicity chair;; IEEE ICIP 2014: general chair and vice-chair, several other key positions (around 1300 participants expected); IEEE ICM22012: panel co-chair (2400 participants); EUSIPCO2011 : tutorial co-chair (650 participants); IEEE ICIP2011: awards co-chair (1100 participants); IEEE VCIP2010 : tutorial and panel co-chair (450 participants); EUVIP2013 : technical chair (200 participants); AAMAS 2013 (Virtual agents track chair; around 700 participants); IVA 2013 (general co-chair; around 120 participants); ACII 2013 (general co-chair; around 150 participants); AAMAS 2012 (Tutorial co-chair; 700 participants); AAMAS 2010 (Demo co-chair; 700 participants); ACII 2009 (Doctorial consortium co-chair; around 150 participants).

### 13.3.1 Robust Compression and Transmission of Visual Data

**Faculty** B. Pesquet-Popescu, F. Dufaux, M. Cagnazzo, G. Valenzise

**Highlights: Scientific Production** 1) J. Garbas, B. Pesquet-Popescu, and A. Kaup. Methods and tools for wavelet-based scalable multiview video coding. IEEE Trans.on Circ. and Syst. for Video Tech., Feb. 2011.

2) M. Kaaniche, A. Benazza-Benyahia, B. Pesquet-Popescu, and J.-C. Pesquet. Vector lifting schemes for stereo image coding. IEEE Trans. on Image Proc., Nov. 2009.

3) C. Greco, M. Cagnazzo, and B. Pesquet-Popescu. Low-latency video streaming with congestion control in mobile ad-hoc networks. IEEE Trans. Multimedia, Aug. 2012. Selected as “High quality paper” by the review IEEE MMTC-R Letter, Jan. 2013.

4) G. Valenzise, M. Tagliasacchi, and S. Tubaro. Revealing the traces of JPEG compression anti-forensics. IEEE Trans. on Inform. Forensics and Sec., Feb. 2013.

5) M. Agostini, M. Cagnazzo, *et al*. A new coding mode for hybrid video coders based on quantized motion vectors. IEEE Trans. Circ. Systems Video Tech., July 2011.

**Highlights: Impact** 1) Organization of conferences such as IEEE MMSP 2010 (General Co-Chair), IEEE ICIP2014 (General Chair, Vice General Chair), Euvip2013 (Technical Chair), 3DRPC IG within ICME2012 (General Co-Chair).

2) B. Pesquet-Popescu is a member of the several IEEE Technical committees : SPS Image, Video and Multidimensional Signal Processing (IVMSP), SPS Multimedia Signal Processing (MMSP), IEEE Comsoc Multimedia Communications, Member of IEEE SPS Awards Board, and of IEEE SPS Seasonal Schools Subcommittee.

3) 2 papers selected in the Top10% at the conference IEEE MMSP2009, Second Best Student Paper Award at IEEE ICIP2011 for G. Valenzise.
4) 5 Projects funded by ANR, 1 by DIGITEO, 4 FUI, 1 ITEA2.
5) 6 special issues organized: IEEE TCSVT, IEEE TIFS, Annals of Telecoms, JASP (2), IEEE JSTSP.

**Highlights: Interactions with Society** 1) CIFRE PhD Theses (SFR, Orange, Amiriel, Thalès)
2) Industrial contracts with AMIRIEL (2013–), SFR (2005-2008)
3) M. Cagnazzo is Area Editor for 2 *Elsevier* journals (SPIC and Sig. Proc.)
4) B. Pesquet-Popescu is member of the Editorial Board for IEEE Signal Processing Magazine, Associate Editor for 3 *IEEE Transactions* (Circ. Systems Video Tech., Image Proc., Multimedia), and Area Editor for one *Elsevier* journal (SPIC).
5) B. Pesquet is Chair of the IEEE Industrial DSP standing committee since Jan. 2013

As far as **video coding** is concerned, our group worked on to 2D and 3D video compression. In the first field, we proposed new and efficient methods based on motion vector quantization [3267, 3424] and competition [3302, 3304], mode information inference [3303], efficient lossless coding [3274], adaptive wavelet coding [3596, 3597], and more theoretical contributions concerning rate-distortion theory [3330] and convex optimization for sparse criteria [3297, 3295]. For 3D and multiview compression and processing, our contributions include stereo compression; novel techniques for disparity estimation and coding [3313, 3281, 3331, 3291, 3275]; multi-view video coding [3448, 3331]; and depth image coding [3331, 3448, 3653, 3567, 3316, 3315]. Finally, we have been the editors of a book on emerging technologies for 3D video [3351]. Regarding the content **trasmission**, we proposed a protocol for real-time video streaming over mobile ad-hoc networks [3292] with rate/congestion optimization [3293] and we developed novel robust transmission techniques based on multiple description coding (MDC) [3492], network coding (NC) [3571, 3572] and the combination of both [3570, 3493]. We have had an intense activity in the emerging framework of **distributed video coding** [3627, 3626] and we have proposed methods to improve the compression performance using high-order motion interpolation [3625, 3623, 3624], fusion techniques for multiview video [3544, 3463, 3332], iterative decoding and combination of global and local motion estimation [3465, 3396, 3399, 3401, 3269].

Other research activities in this theme include: **semantic-oriented** and content-aware compression using seam carving [3453, 3454, 3456] (a patent has been filed); **High Dynamics Range** representation, for which we developped new algorithms for inverse tone-mapping [3523, 3524]. and a specific video coding scheme taking into account the constraints of backward compatibility [3525]; **video quality assessment** [3455, 3285] and interoperability for **image search and sharing** [3337, 3347], contributing to a new international standard.

### 13.3.2 Multimedia Services Adaptation, Transport and Presentation

**Faculty** C. Concolato, J.-C. Dufourd, J. Le Feuvre, J.-C. Moissinac

**Highlights: Scientific Production** Communicating and migratable interactive multimedia documents [3278], Authoring of Scalable Multimedia Documents [3325], Design of an Efficient Scalable Vector Graphics Player for Constrained Devices [3277], Graphics Composition for Multiview Displays [3370], MPEG Multimedia Scene Representation [3372].

**Highlights: Impact** Participation to the EU Network of Excellence (INTERMEDIA), and to more than 15 other funded projects (France and EU), Organization of several international conferences, workshops and events such as DocEng 2012, SVG Open 2010, or Test The Web Forward 2012, Edition of several ISO/IEC and W3C standards [3754] [3712] [3769].

**Highlights: Interactions with Society** First worldwide Open-Source MPEG-DASH framework for content creation and playback (GPAC), Front cover with a Digital Radio Receiver of a general public scientific magazine, First worldwide Open-Source 3D renderer for autostereoscopic displays, 4-year collaboration with Samsung R&D Headquarter.

**Multimedia Adaptation and Multimodal Interaction** The adaptation of multimedia content to its context of use (terminal capabilities, network characteristics, user preference) to facilitate such media consumption is still a challenge. We address the problems related to multimedia adaptations by defining methods and languages facilitating the adaptation of multimedia documents[3325] [3282], as well as by using formal semantics for multimedia and interaction, as achieved in the implementation and extension of the Multimodal Interaction framework proposed by the W3C [3721].

**Interactive Services and Transmedia** The team has studied new ways to structure, package and transport interactive content, such as "widgets" or portable web applications, in particular in the home [3278], and has spearheaded the development of the MPEG-U standard [3712]. The team is now improving the developed concepts, as part of the work in the W3C Web and TV Interest Group and Device API Working Group. The second field investigated is interactive TV: the team is active in the development and promotion of the Hybrib Broadband Broadcast TV standard[3467].

**Multimedia Transport** The team has a strong activity on heterogeneous networking for multimedia, combined usage of broadcast (satellite, terrestrial) and broadband IP networks, Digital TV and Digital Radio [3755], [3445], [3444]. In this area, the team has contributed (more than 80 contributions) and participated to the editing of the following international standards: MPEG-2 Systems and MPEG-4 Systems, MPEG-DASH. The team has also published scientific papers on the topic [3444],[3445], hosted one of the DASH standardization meeting in Paris and created a large set of conformance files, available in the standard [3758] and a dataset for the research community.

**Open Source Software** The team maintains an Open Source platform called GPAC [3536]. This platform offers various tools for the encoding, the delivery and the playback of multimedia content, ranging from simple audio/video to complex interactive multimedia services. The platform is distributed under an LGPL license to the Open Source community or under specific licenses for industrial partners. In 2012, the software was licensed to two companies, including a major US-based company. GPAC is also used by the academic world (more than 50 citations in journals or international conferences) and has been advertised in the ACM SIG MM Newsletter. GPAC is the back-bone of the implementation of the team's work and is often demonstrated in conferences or standardization meetings [3763], [3686].

### 13.3.3 Multimodal Content and Interaction

**Faculty** L. Likforman-Sulem, M. Sigelle, G. Chollet, C. Faure, C. Pelachaud, C. Clavel

**Highlights: Scientific Production** 1) L. Likforman-Sulem, M. Sigelle (2008), Recognition of degraded characters using Dynamic Bayesian Networks, Pattern Recognition, Vol. 41, no 10, Oct. 2008, pp 3092-3103

2) A-L Bianne, F. Menasri, C. Mokbel, R. Al-Hajj, , C. Kermorvant, L. Likforman- Sulem (2011), Dynamic and Contextual Information in HMM Modeling for Handwritten Word Recognition, IEEE PAMI, Vol. 33, Nr 10

3) T. Hueber, EL. Benaroya, G. Chollet, B. Denby, G. Dreyfus, M. Stone, Development of a silent speech interface driven by ultrasound and optical images of the tongue and lips, Speech Communication 52 (4), 288-300, 2010.

4) K. Khurshid, C. Faure, N. Vincent: Word spotting in historical printed documents using shape and sequence comparisons. Pattern Recognition 45(7): 2598-2609 (2012)

5) R. Niewiadomski, S. Hyniewska, C. Pelachaud, Constraint-Based Model for Synthesis of Multimodal Sequential Expressions of Emotions, IEEE Transactions of Affective Computing, vol. 2, no. 3, 134-146, July 2011.

**Highlights: Impact** 1) Contracts: 10 European projects and 15 National projects (DGA (2); ANR (7); PEPS (2); FUI (3); FEDER (1))

2) Invited talks in international conferences: 8 (Royal Academy'09, MIG'09, HCSNet'09, FAA'10, JSMA'11, LREC'12, Tiger'13, Petra'13)

3) Best paper awards in international conferences: 3 (IVA'10)
4) Conference chair of international conferences: 6 (minisymposium in SIAM Conf. on Imaging Science 2010, W3C Workshop on Emotion Markup Language, IVA'10, IVA'13, ACII'13, AAMAS 2013 Virtual agent track chair )
5) International Journal guest editors: 4 special issues (IEEE Computer Graphics and Applications 2010, Journal on Multimodal User Interfaces 2012).

**Highlights: Interactions with Society** 1) 3 Industrial contracts
2) Presentation for large audience: Universcience TV 2011
3 )Interventions in public events: 2 (Musée des arts et métiers, Paris, 2010 and 2013)
4) NATO: invited talk for Machine Translation for Coalition Operations working group
5) C. Pelachaud is Associate Editor for ACM Transactions on Interactive Intelligent Systems,IEEE Transactions on Affective Computing, Journal on Multimodal User Interfaces

**Written Communication:** We have developed efficient segmentation-free approaches for handwritten recognition [3290, 3273] and word spotting [3300]. These approaches include context-dependent Hidden Markov Models [3273], Dynamic Bayesian networks [3305] and Recurrent Neural Networks [3568]. Our developed systems have participated to ICDAR 2009 and 2011 word and text-line recognition challenges. At the document level, our objectives are to restore ancient document images by a combination of powerful filters [3306] or to provide style characteristics of handwritten documents [3395]. Web documents have also been converted to images in order to extract a combination of image and textual-based features, and to decompose them into meaningful blocks [3573].

**Multimodal signal analysis and synthesis**: We have developed several open-source software for the analysis of major biometric modalities (face, voice, audio-visual speaker, signature, iris, hand shape...). This work led to the publication of a reference book ([3356]) and to the development of databases, reference systems and benchmarking protocols ([3477]). Multilingual speech recognition is still a major topic for our team. Languages of interest include french, english, dutch, spanish, german and italian. Speech recognition and synthesis are being experimented in the context of Spoken Dialogue Systems. We are also extending an opensource Dialog system, called DISCO.

**Multimodal modality and socio-emotional interaction**: We have been working on developing a human-agent interaction system able to drive virtual and robotic agents [3582, 3533]. We have defined several computational models to enlarge the virtual agent repertoire [3319, 3589]. A new animation model allows rendering more natural facial and body motion [3462, 3500]. The agents are endowed with socio-emotional capacities [3320, 3318]; they can show their engagement through the emergence of behavior synchronization [3632]. Now we are focusing on enhancing the expressive animation model, on developing a cognitive model for the agent and model of social attitude.

# 13.4 Achievements (Appendix 6)

## 13.4.1 Scientific productions

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[3807] C. Tillier, G. Pau, and B. Pesquet-Popescu. Coding performance comparison of entropy coders in wavelet video coding. Technical Report m12056, Busan, Korea, Apr. 2009.

### 13.4.2 Private Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008-08 | GEODIO | BILATERAL | MOISSINAC JC | 3 |
| 2008-12 | ALCATEL SOA2M | BILATERAL | MOISSINAC JC | 141 |
| 2008-11 | A2ia / BIANNE | CIFRE | LIKFORMAN L | 30 |
| 2008-09 | SAMSUMG | BILATERAL | CONCOLATO C | 113 |
| 2008-10 | SAMSUMG RICH MEDIA WIDGETS | BILATERAL | CONCOLATO C | 105 |
| 2009-10 | NVELLES APPROCHES | AUTRE | PESQUET B | 4 |
| 2009-09 | OSEO EMPREINTES MULTIMEDIA | BILATERAL | CONCOLATO C | 1 |
| 2009-11 | MY PRESENTING AVATAR | AUTRE | PELACHAUD C | 137 |
| 2010-11 | SAMSUMG ADVANCED INTERACTION SYTEMS | BILATERAL | CONCOLATO C | 105 |
| 2010-10 | OSEO-DOC ON DEMAND | BILATERAL | LIKFORMAN L | 3 |
| 2010-15 | CHAIRE IMAGINAIREA | AUTRE | PELACHAUD C | 105 |
| 2010-13 | DGA-MORILLOT | AUTRE | LIKFORMAN L | 50 |
| 2010-13 | FT CIFRE MORA | CIFRE | PESQUET B | 30 |
| 2011-13 | THALES / DECOMBAS | CIFRE | PESQUET B | 45 |
| 2011-13 | DIALONICS - INTELLIGENCE EMOTIONNELLE | BILATERAL | PELACHAUD C | 121 |
| 2011-13 | IMEI - STIC ASIE (Investigating Multicultural, Empathic Interactions between a Human and an Embodied Conversational Agent in a Living Space) | AUTRE | PELACHAUD C | 12 |
| 2011-14 | ITESOFT - RECONNAISSANCE DE MOTS CURSIFS | BILATERAL | LIKFORMAN L | 180 |
| 2011-12 | SAMSUMG HIGH EFFICIENCY VIDEO | BILATERAL | LE FEUVRE J | 105 |
| 2011-13 | B2M (Broadcast mobile multimedia) | AUTRE | DUFAUX F | 20 |
| 2012-15 | EMMA (Embedded software for mass market connected applications) | AUTRE | PELACHAUD C | 239 |
| 2012-13 | IDF EMOTIONS | AUTRE SEMI PUBLIQUE | PELACHAUD C | 18 |
| 2013-13 | CANON DASH (Advanced streaming over HTTP) | BILATERAL | CONCOLATO C | 85 |

### 13.4.3 Public Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2009-11 | SEMAINE (Sustained Emotionally coloured Machine-human Interaction using Nonverbal Expression) | CEE | C. Pelachaud | 223 |
| 2009-14 | SSPNET (Social Signal Processing Network of Excellence) | NoE-CEE | C. Pelachaud | 373 |
| 2009-13 | PERSEE (Perceptual scheme for 2D and 3D video coding) | ANR Blanc | M. Cagnazzo | 194 |
| 2011-14 | HILAIRE (Incorporating Laughter into Human-Avatar Interactions: Research and Evaluation ) | CEE | C. Pelachaud | 282 |
| 2011-14 | VERVE (Vanquishing fear and apathy through E-inclusion: Personalised and populated Realistic Virtual Environments for clinical, home and mobile platforms) | CEE | C. Pelachaud | 487 |
| 2012-16 | MOCA (Mon petit monde de compagnons artificiels) | ANR | C. Pelachaud | 157 |
| 2010-13 | SWAN (Source aWAre Network coding-Codage réseaux pour le multimédia) | DIGITEO | M. Cagnazzo | 0 |
| 2008-10 | KIVAOU | ANR | CHOLLET G | 80 |
| 2008-11 | PINGO | DGE | CONCOLATO C | 448 |
| 2008-10 | SEBASTIAN2 | DGE | PESQUET B | 253 |
| 2008-10 | RADIO+ | ANR | CONCOLATO C | 307 |
| 2008-12 | CECIL | ANR | PELACHAUD C | 127 |
| 2008-12 | GV-LEX | ANR | PELACHAUD C | 133 |
| 2009-10 | CALLAS | EU | PELACHAUD C | 221 |
| 2009-12 | COMPANIONABLE | EU | CHOLLET G | 151 |
| 2009-12 | CALDER | ANR | LE FEUVRE J | 191 |
| 2009-12 | IMMEMO | ANR | PELACHAUD C | 182 |
| 2009-13 | SURFONHERTZ | ANR | CHOLLET G | 148 |
| 2010-12 | ACDC (Adaptive Content Delivery Cluster) | DGE | PESQUET B | 789 |
| 2010-11 | EndT2End | DGE | LE FEUVRE J | 92 |
| 2010-13 | ANIPEV | DGE | PELACHAUD C | 106 |
| 2010-11 | VUE | DGE | MOISSINAC JC | 46 |
| 2010-12 | OPENWIDGET | DGE | DUFOURD JC | 511 |
| 2010-12 | ROME MOBILE | DGE | LIKFORMAN L | 196 |
| 2010-13 | HYB RADIO | ANR | CONCOLATO C | 222 |
| 2011-13 | ARHOME (Majordome électronique pour un bouquet d'échanges et de services à destination des acteurs des services et de l'hospitalisation à domicile, de l'action sociale et de leurs clients) | DGE | CHOLLET G | 246 |
| 2011-14 | NEVEX (The next video experience) | DGE | DUFAUX F | 201 |
| 2011-14 | TARDIS (Training young adult's regulation of emotions and development of social interaction skills) | EU | PELACHAUD C | 272 |
| 2011-14 | VASSIST (Voice controlled assistive care and communication services for the home) | DGE | CHOLLET G | 137 |

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2012-14 | PLAYSERIOUS | DGE | PELACHAUD C | 249 |
| 2012-14 | ILOT (Innovative Learning Objects for Teaching) | AUTRE | MOISSINAC JC | 256 |
| 2012-15 | COLTRAM | AUTRE | DUFOURD JC | 299 |
| 2012-15 | HACHETTE / CIFRE GROS | CIFRE | MOISSINAC JC | 36 |
| 2012-15 | 4EVER (Développement de l'économie numérique) | FUI (13) | LEFEUVRE J | 207 |
| 2012-15 | AUSTRAL (Architecture universelle over the top sécurisée de télévision de rattrapage, à la demande et live) | FUI (13) | B PESQUET | 405 |
| 2012-13 | M44G (Multimedia for 4G) | PROGRAMME D' INVESTISSEMENT D'AVENIR (PIA) | LEE FEUVRE J | 129 |
| 2012-14 | OPTISAT | FUI (14) | LEFEUVRE J | 107 |
| 2012-14 | MEDIA FACTORY | PROGRAMME D' INVESTISSEMENT D'AVENIR (PIA) | DUFOURD JC | 140 |
| 2012-15 | AVATAR A1&1 (Interactions avatars taille humaine) | PROGRAMME D' INVESTISSEMENT D'AVENIR (PIA) | PELACHAUD C | 315 |

### 13.4.4 Patents and Software

| Period | Title | Funding | Authors | Status |
|---|---|---|---|---|
| 2009 | Schéma d'adaptation sur critère de minimisation d'erreur quadratique pour l'optimisation d'un codage H.264 | CIFRE SFR | N. Tizon and B. Pesquet-Popescu | Accepted patent |
| 2010 | Scheduling Method For Data Streaming in a Telecommunication Network Infrastructure | Alcatel-Lucent | N. Changuel, B.Sayadi and M. Kieffer | Accepted pantent |
| 2013 | Codage et décodage par héritage progressif | CIFRE Orange Labs. | E. Mora, J. Jung | Accepted patent |
| 2013 | Prédiction d'un bloc par héritage d'un champ de mouvement dense estimé par la technique du flux optique | CIFRE Orange Labs. | E. Mora, J. Jung, M. Cagnazzo, B. Pesquet | Submitted patent |

# 13.5 PhDs (Appendix 7)

## 13.5.1 Defended PhDs

[3808] A. b. Abou-Elailah. *Techniques for improving the performance of distributed video coding*. PhD thesis, TELECOM ParisTech, Dec. 2012.

[3809] M. Bendris. *Indexation audio-visuelle des personnes dans un contexte de télévision*. PhD thesis, Télécom-ParisTech, July 2011.

[3810] I. Daribo. *Codage et rendu de séquence vidéo 3D, et applications à la télévision tridimensionnelle (TV3D) et à la télévision à base de rendu de vidéos (FTV)*. PhD thesis, Télécom ParisTech – Site Barrault – Amphi B310, Nov. 2009.

[3811] C. Greco. *Diffusion robuste de la vidéo en temps réel sur réseau sans fil*. PhD thesis, TELECOM-ParisTech, July 2012.

[3812] T. Hueber. *Reconstitution de la parole par imagerie ultrasonore et vidéo de l'appareil vocal : vers une communication parlée silencieuse*. PhD thesis, UPMC, Dec. 2009.

[3813] W. Karam. *Imposture audio-visuelle et robustesse de la vérification de l'identité*. PhD thesis, Télécom-ParisTech, Feb. 2010.

[3814] G. Laroche. *Modules de codage par compétition et suppression de l'information de compétition pour le codage de séquences vidéo.* PhD thesis, Télécom ParisTech – Site Barrault – Amphi B312, May 2009.

[3815] T. Maugey. *Codage vidéo distribué de séquences multi-vues*. PhD thesis, TELECOM-ParisTech, Oct. 2010.

[3816] B. Pellan. *Multimedia scenes scalability*. PhD thesis, Telecom ParisTech, Oct. 2010.

[3817] P. Perrot. *L'imposture vocale en sciences forensiques*. PhD thesis, Télécom-ParisTech, Nov. 2010.

[3818] G. Petrazzuoli. *Interpolation temporelle et inter-vues pour l'amélioration de l'information adjacente dans le codage vidéo distribué*. PhD thesis, TELECOM-ParisTech, Jan. 2013.

[3819] T. Petrisor. *Décomposition en ondelettes redondantes pour le codage par descriptions multiples des images fixes et des séquences vidéo.* PhD thesis, Télécom ParisTech – Site Barrault – Amphi Grenat, Sept. 2009.

[3820] B. H. Rodriguez. *Un modele SOA, multimodal et sémantique et son support pour la découverte et l'enregistrement de services d'assistance*. PhD thesis, Télécom ParisTech, Feb. 2013.

[3821] N. Tizon. *Codage vidéo scalable pour le transport dans un réseau sans fil Scalable video coding for wireless transmission*. PhD thesis, Télécom ParisTech – Site Barrault – Amphi B312, Dec. 2009.

## 13.5.2 Ongoing PhDs

- R. Bouazizi (11/12 –). *Création de services Transmédia pour la maison*.
- N. Bouzakaria (12/12 –). *Contributions au streaming adpatatif avancé*.
- M. Calemme (12/12 –). *Codage de cartes de profondeur par representation des contours comme courbes élastiques*.
- G. Chierchia (10/11 –). *Solutions de codage et transmission de la vidéo multi-vue pur des applications d'interactivité*.
- M. Chollet (11/11 –). *Modèles de comportements non-verbaux dans un contexte socio-émotionnel*.
- M. Decombas (10/10 –). *Codage vidéo bas débit pour des applications de reconnaissance*.
- Y. Ding (01/11 –). *Modèle d'apprentissage appliqué à l'animation d'agent virtuel*.
- A. Fiengo (12/12 –). *Optimisation debit-distorsion par allocation des ressources de codage dans le cadre d'un codeur video de nouvelle generation (HEVC)*.
- N. Fourati (11/11 –). *Modèles des mouvements émotionnels*.
- N. Glas (01/13 – ). *Modèle d'engagement dans une interaction avec des avatars à taille humaine*.
- V. Gros (03/12 –). *de l'enrichissement sémantique des contenus pour fabriquer les e-Book de demain*.
- H. Khemiri (09/10 –). *Unified Data-Driven Approach for Audio Indexing, Retrieval and Recognition*.

- P. Lauga (11/11 –). *Etude des représentations HDR pour la vidéo numérique et mettre en œuvre de nouveaux algorithmes de conversion vidéo de LDR vers HDR*.
- M. Meddeb (02/13 –). *Compression et transmission vidéo pour un système de visioconférence innovant*.
- H. Medina (11/10 – ). *Codage réseau de la théorie à la pratique*.
- P. Milhorat (04/12 –). *Conception d'un assistant personnel a interface vocale en langage naturel*.
- E. G. Mora (11/10 –). *Codage vidéo multi-view pour des nouveaux services multimédias*.
- O. Morillot (10/11–). *Reconnaissance de documents multilingues par réseaux Bayesiens dynamiques et Réseaux de neurones récurents*.
- I. Nemoianu. (10/09 – 06/13) *Codage réseau pour la diffusion de contenus vidéo de haute qualité*.
- C. Oprean (10/11 –). *Reconnaissance de textes manuscrits grand vocabulaire par adaptation de modèles de langage*.
- F. Pecune (12/12 –). *Modèle computationnel de l'influence de la personnalité d'un agent virtuel sur son comportement*.
- G. Petrazzuoli (11/09 – 01/13). *Signaux à taux d'innovation fini et applications à la vidéo distribué et multivue*.
- B. Ravenet (03/12 –). *Modélisation des relations sociales entre agents dans un environnement virtuel*.
- B. H. Rodriguez. *Définition de capacités multimédia abstraites de haut niveau et des moyens de leur composition automatique en réseau*.
- M. Sarkis (04/13 –). *Plateforme de services transmédia pour la maison*.
- Y. Tabet. *Représentation paramétrique du signal de la parole*.
- Y. Xing (01/12 – ). *Codage vidéo pourl'holographie numérique 3D*.

# Chapter 14

# Statistics and Applications (STA)

## 14.1 Executive Summary (Appendix 1)

**Team Leader** S. Clémençon (FP) (F. Roueff (FP), –02/13)

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**Initial Staff** 6 Professors; 6 Research Scientists; 0 Postdocs; 12 PhD Students.

**Staff who Left** 8 Permanent Staff (430 months) ; 23 PhD Students (550 months) ; 9 Postdocs (140 months).

**Staff who Were Hired** 1 Associate Professor (Post-doc at CNES), recruited on Nov. 2008; 1 Associate Professor (AP at Supélec), recruited on Dec. 2008; 1 Associate Professor (Post-doc at Duke University), recruited on Dec. 2012; 1 Research Scientist (Research Scientist in the AAO team of LTCI), recruited on Jan. 2010.

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**Scientific Highlights**

- Developpement of the component separation algorithm [3854] used to process the data collected by the Planck satellite (officialy released in March 2013).
- Design of an on-line version of the celebrated Expectation-Maximization algorithm [3850].
- Organization at IHP of a reference seminar in the Paris area on Monte-Carlo methods (following the AdapMC and BigMC ANR projects).
- Design of TreeRank, a benchmark ranking algorithm [3860].
- Response to the Big Data trend through the industrial chair project "Machine-Learning", the scientific responsibility of the 7-th "Entretiens Telecom ParisTech" dedicated to Big Data and the lauch of the "Big Data: management and analysis (master spécialisé)" program.

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**Scientific Production** 161 in Journals; 5 Book chapters; 181 in Proceedings; 47 Invited talks.

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**Major Publications**

- Kullback-Leibler upper confidence bounds for optimal sequential allocation. Annals of Statistics, 2013 (to appear). O. Cappé, A. Garivier, O.-A. Maillard, R. Munos and G. Stoltz. [3853]
- Convergence of adaptive and interacting Markov chain Monte Carlo algorithms. Annals of Statistics, 39(6):3262–3289, 2012. G. Fort, E. Moulines and P. Priouret. [3897]
- Performance of statistical tests for single-source detection using random matrix theory. IEEE Transactions on Information Theory, 57(4):2400–2419, 2011. P. Bianchi, M. Debbah, M. Maïda, Mylène and J. Najim. [3845]
- Locally stationary long memory estimation. Stochastic processes and their applications, 121(4):813–844, 2011. F. Roueff and R. von Sachs. [3944]
- Adaptive partitioning schemes for bipartite ranking. Machine Learning, 83(11):31–69, 2010. S. Clémençon, M. Depecker and N. Vayatis. Machine Learning. [3864]

**Major Documents**

- TopRank software, registered at the APA (2008, F. Roueff and C. Lévy-Leduc).
- TreeRank software, registered at the APA, and patent (2012, S. Clémençon).
- Patent for an estimation method applied to fluorescence measurements (2010, F. Roueff).
- Patent for automatic source separation via joint use of segmental information and spatial diversity (2011, C. Févotte).
- CosmoPMC code to implement Monte-Carlo sampling method to explore the likelihood of various cosmological probes. (with contributions from O. Cappé, J-F. Cardoso and G. Fort).

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**Impact and Attractivity**

- CNRS Silver medal (2010) and France Telecom Grand Prix of the French Academy of Sciences (2011) awarded to E. Moulines.
- Paul Doistau–Émile Blutet prize awarded to Jean-François Cardoso by the French Academy of Sciences (2013) for his contribution to the Planck mission.
- Participation to the steering committees of the GdR Isis (O. cappé, C. Févotte), the Gretsi society (O. Cappé) and the Institut Mines-Télécom's scientific network "Mathématiques Appliquées et Informatique Fondamentale" (G. Fort).
- Organization of two international workshops on large random matrices (J. Najim) and an international workshop on Performance Analysis of Monte Carlo methods (G. Fort); co-organization of reference seminars in the Paris area on statistics, machine-learning and Monte-Carlo methods (SemStat, Smile, BigMC).
- Editorial responsabilities: P. Bianchi (Signal Processing), O. Cappé (IEEE SPTM commitee, JRSSB), C. Févotte (IEEE MLSP commitee), G. Fort (Bernoulli), E. Moulines (SPA, JSPI, ESAIM P&S, Ed. in Chief of Bernoulli since 2012).

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**Interaction with Economic and Social Spheres**

- Orange has been the team's main industrial partner (4 funded PhD theses).
- Other partners include CEA, DGA, Thales, Renault, Natixis and Exane.
- Support to the spin-off Score4Biz (S. Clémençon).

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**Contributions to Higher Education**

- Co-responsability of the master programs "Applied mathematics and finance" and "Statistical learning and data mining" at Telecom ParisTech.
- Co-responsability of the domain "mathematics for engineers" at Telecom ParisTech.
- Master courses: O. Cappé (Dauphine), G. Fort (ENS Cachan), C. Levy-Leduc (Dauphine), E. Moulines (Paris 6, Paris 7, Dauphine, ENS Cachan), F. Roueff (Paris 6).
- Courses within ParisTech engineering schools: O. Cappé (Polytechnique), S. Clémençon (ENSAE, ENPC), F. Roueff (Polytechnique).
- Launch (in 2013) of a new specialized master program, dedicated to Big Data.

## 14.2 People

**Team leader** S. Clémençon (FP) (F. Roueff (FP), –02/13).

**Faculty** K. Abed Meraïm (AP, –08/12), G. Blanchet (FP, 06/13, Emeritus 07/13–), P. Bianchi (AP, 09/08–), O. Cappé (SRS), J-F. Cardoso (SRS), M. Charbit (FP, –06/13; Emeritus 07/13–), S. Clémençon (AP, –12/10; FP, 01/11–), C. Févotte (JRS, 01/10–12/12), G. Fort (JRS, –09/12; SRS, 10/12–), A. Garivier (JRS, –08/12), J. Jakubowicz (AP, 11/08–10/11), C. Lévy-Leduc (JRS, –08/12), E. Moulines (FP), J. Najim (JRS, –09/12), F. Roueff (FP), J. Salmon (AP, 12/12–).

**PhD students** A. Attaya (11/10–), S. Audière (10/08–12/11), S. Barembruch (–09/10), A. Bader (12/10–), A. Bellacheab (also with Telecom Sud Paris,10/12–) A. Ben Hadj Alaya (–10/08), H. Braham (12/12–), B. Jabbeur (–09/09), H. Benoudnine (–07/08, phd started at USTO, Algeria), N. Castaneda, (–07/08), E. Chautru (10/09–), J. Cornebise (–06/09, also at Univ. Paris 6), A. Dematteo (10/11–), M. Depecker (10/07–12/10), J.F. Germain (–10/08), F. Guilloux (–12/08, also at Univ. Paris 7), Z. Harchaoui (–11/08), O. Iacoboaiea (10/12–), M. Jala (11/10–, also with Orange Labs Issy-Les-Moulineaux), Y. Khan (04/11–), E. Kaufmann (09/11–), M. Kharouf (–06/10), O. Kouamo (–01/11, also at Univ. Yaoundé 1, Cameroon), N. Ksairi (10/08–03/10, also with Supélec), S. Le Corff (10/09–10/12), A. Lefèvre (10/10–10/12, also with INRIA/Sierra) A. Lung-Yut-Fong (10/08-12/11), N. Mahler (02/08-12/11, also at ENS Cachan), G. Morral Adell (10/11–), A. Nouvellet (03/13–, also with CEA List), S. Filipi (10/07–11/10), S. Robbiano (10/09–), A. Sanchez-Perez (09/12–), N. Seichepine (09/12–) P. Sendorek (04/11–), A. Schreck (09/11–), T. Rebafka (–11/09), E. Siboni (09/12–), T. Sim (03/13–, also with Telecom Sud Paris), N. Sokolovska (–02/10), M. Thameri (10/10–), J. Villard (11/08–12/11, also with Supélec), T. Wohlfarth (02/10–), J. Yao (09/10–), R. Zhang (10/10–), B. Zheng (02/10–).

**Post-docs, engineers and sabbaticals** T. Rebafka (12/09–09/10), T. Courtat (04/13–), O. Dikmen (02/10–01/12), C. Dhanjal (11/09–10/11, 12/12-), B. Miasojedow (10/11–08/12), R. Gaudel (09/10–08/11), L.-V. Lozada (02/10–08/10, 02/11–08/11, N. Mahler (08/11–04/12), D. Rohde (07/10–06/11), A. Roodaki (03/11–02/12), A. Saumard (11/10–11/11); M.S. Taqqu (Prof. at Boston Univ., 5 months), V. Reisen (MC, Vitória Univ., Brazil, 4 months).

## 14.3 Overview

During the last twenty years, scientific discovery has become increasingly dependent on the collection and interpretation of data and, more generally, quantitative information. There's a general consensus that the core academic disciplines that are most relevant to the information society encompass computer science, mathematics and statistics. The Statistics and Applications (STA) group at LTCI plays an important role in this context by focussing on statistical methods and their application in domains relevant to the information society at large.

The members of the STA group are actively participating to teaching, typically at the master level and in the fields of probability, statistics, signal processing, machine learning and applied mathematics, at Télécom ParisTech but also in several other Grandes Ecoles affiliated to ParisTech (Ecole Polytechnique, ENSAE, ENPC) and universities (M2 *Modélisation aléatoire* at Paris 7 Denis Diderot, M2 *Modélisation Vision Apprentissage* at ENS Cachan, M2 *Probabilités et Modèles Aléatoires* at Paris 6 Pierre et Marie Curie, M1 *Mathématiques de la Modélisation et de la Décision* at University Paris-Dauphine).

The STA group has developed long term research collaborations with several academic Parisian partners such as Univ. Paris 7 Denis Diderot (LPMA and ADAMIS), Univ. Paris 10 Nanterre (MODAL'X), Univ. Paris-Est (IGM), Institut d'Astrophysique de Paris, Univ. Paris-Dauphine (Cérémade), research groups in other ParisTech schools (CMBIO, Mines and CERMICS, Ponts) and with the Ecoles Normales Supérieures Ulm (INRIA projects TREC, WILLOW and SIERRA) and Cachan (CMLA). Such collaborations are essential to the group for achieving long term research

programs, and, more generally, for exchanging ideas and views within a stimulating academic environment.

These academic relationships parallel industrial partnerships. The latter have been developed in the framework of national research projects (ANR), bilateral contracts, or the funding of PhD theses (mainly through CIFRE conventions, but also with bilateral contracts). Beside favoring our financial autonomy, such partnerships bring practical applications which are helpful for our opening and to remaining active on new research prospects. In the last years, regular industrial partners include the Commissariat à l'Energie Atomique (CEA), Thales Avionics, Orange, Direction Générale de l'Armement (DGA), Natixis, Liligo.com.

The group enjoys a high national and international recognition with editorial board members in top ranked international journals such as Bernoulli (E. Moulines, Editor in Chief, G. Fort, associate Editor), ESAIM P&S, Stoch. Proc. and their Appl. Journal of Statistical Planning and Inference (E. Moulines, Associate Editor), the Journal of the Royal Statistical Society, Series B (O. Cappé), Signal processing (P. Bianchi) as well as regular participation as program committee members in the major international conferences (IEEE ICASSP, IEEE statistical Signal Processing workshop, International Conference on Machine Learning, Neural Information Processing Systems, Artificial Intelligence and Statistics). The group regularly organizes or co-organizes scientific events such as summer schools (E. Moulines, 13th Brazilian school of probability, 2009, 22nd Jyvaskyla Summer School, C. Févotte, *Ecole d'Eté en traitement du signal et des images* in Peyresq (2010)), special sessions in international conferences (G. Fort, AMSDA 06/11); national workshops (G. Fort, GDR ISIS 11/11, P. Bianchi, GDR ISIS 02/12), as well as recurrent scientific seminars in Paris (*séminaire parisien de statistiques*, ParisTech Machine Learning reading group *Smile*, BigMC seminar on Monte Carlo methods at IHP).

Members of the group are regularly invited to give talks or lectures. E. Moulines was a keynote speaker at the Journées MAS 2010, GRETSI 2011 and EUSIPCO 2012 and was invited speaker in numerous workshops and conferences including Stochastic approximation: methodology, theory and applications in statistics (Bristol, 2012), Structure and uncertainty: modelling, inference and computation in complex stochastic systems (Bristol, 2012). C. Lévy-Leduc and F. Roueff were invited to give talks at the 58th World Statistics Congress of the International Statistical Institute (2011). O. Cappé was a keynote speaker at the StatLearn'13 workshop in Bordeaux, invited speaker at the Allerton Conference on Communication, Control, and Computing in 2013 and gave a tutorial at the 2009 IEEE Workshop on Statistical Signal Processing.

Two members of the group have been distinguished by prestigious scientific prizes during the period. E. Moulines received the Silver Medal of CNRS in October 2010, for his work on Probabilities applied to Signal Processing and Machine Learning. He also received the 2011 France Telecom Grand Prix of the French Academy of Siences. Jean-François Cardoso received the Paul Doistau–Émile Blutet prize of the French Academy of Sciences in 2013 for his contributions in the field of astronomy.

In recent years, the group has seen a significant turnover with the departures of J. Jakubowicz (now associate professor in Télécom Sud Paris) in 2011, and of A. Garivier (now full professor at Univ. Toulouse), C. Lévy-Leduc (full professor at Agro Paristech), J. Najim (senior research scientist at LIGM - Univ. Paris Est) and C. Févotte (junior research scientist at Laboratoire Lagrange, Nice) in 2012 and the recruitment of J. Salmon in 2012. In 2013, two other members of the group (G. Blanchet and M. Charbit) will retire and a recruitment from Télécom parisTech (at the associate professor level) is scheduled for the second semester of 2013.

## 14.4 Research Themes

### 14.4.1 Statistical Learning

**Faculty** O. Cappé, A. Garivier, S. Clémençon, E. Moulines, F. Roueff, J. Salmon.

**Highlights: Scientific Production** [3853, 3850, 3953, 3869, 3908, 3869]

**Highlights: Impact** projects MGA (Graphical Models and Applications, ANR, 2008–2011), BEMOL (Prediction of internet users' behavior, simulation and collaborative filtering, 2008–2011), ERASM (recommending systems, Eurostars project, 2012–)

**Highlights: Interactions with Society** Contracts with Orange (two PhD theses), Renault (one PhD thesis), Liligo.com (one phd thesis) and with BNP Exane (one PhD thesis). Patent for the TreeRank algorithms.

The group has a long standing interest in **(dynamic) graphical models** and, more generally **Bayesian methods**. In the context of the MGA project, we contributed both to general methodological questions (in particular concerning the online learning of parameters [3983, 4149]) and to the advance of methods for statistical natural language processing. On the latter topic, as a follow up to our work on the use of Lasso (or L1) type regularization for training of large scale conditional random field (CRF) models [3950], we developed an highly efficient software called `Wapiti` [4122]. `Wapiti` is faster than existing alternatives and is highly competitive for sequence tagging tasks as demonstrated, in particular, by the independent evaluations posted on MLcomp `http://mlcomp.org/`, a community website for objective comparison of machine learning programs. Another important contribution of the period has been the development of an **online** version of the EM algorithm [3850], together with several extensions [3849]. More generally, the ubiquity of very large data sets has generated in recent years a renewed interest in online learning algorithms, for instance based on the stochastic approximation principle, that are both fast and scalable [3997].

Since 2007, the group has a raising interest in **reinforcement learning** and its applications to telecommunications. The PhD of Sarah Filippi (2007-2010), funded by Orange, was motivated by cognitive radio problems [3852] and targeted internet advertisement [4090]. In these applications, the environment is typically non-stationary; these applications brought us into investigating adapted bandit algorithms [4094]. We also promote the use of Kullback-Leibler divergence in optimistic algorithms: we proved in [4093, 3853] the optimality of a resulting upper-confidence bound algorithm for bandit problems, and we proposed in [4035] an improved algorithm for reinforcement learning in discrete Markov Decision Processes. The PhD of E. Kaufmann on the same topic has already produced an important result on the optimality of methods inspired by the Bayesian paradigm [4114, 4113] that are used, for instance, in the Google Analytics engine. The PhD thesis of Marjorie Jala, funded by Orange in the context of the Whist joint lab, is devoted to active learning methods for the estimation of upper quantiles of the exposition to electromagnetic fields which are also strongly inspired by bandits algorithms.

In the context of supervised learning, significant advances in the **ranking** problem have been made in [3860], [3861], [3864] and [3866] both from practical and theoretical perspectives. Strong empirical evidence supporting the efficiency of the Treerank technique thus are presented in the PhD thesis defended by Marine Depecker (2007/10, in collaboration with Renault Technocentre). This work has been extended in the PhD thesis of S. Robbiano by considering "multi-class" extensions and plug-in approaches, see [4049].

Unsupervised ranking, sometimes also described as *rank aggregation*, is also a crucial issue in e-commerce, in database middleware or in information retrieval. In the context of the Digiteo project Bemol (in collaboration with ENS Cachan and the company "Mille-Mercis"), novel techniques for rank aggregation have been developed in [4047], [4065] and [4095], offering promising alternatives to the classical "median approach". The pairwise clustering approach has also been studied from a theoretical perspective in [4044].

Non-parametric estimation and model selection is another important research theme in the group. Non-parametric prediction of time-series has been studied in the PhD theses of N. Mahler (2008/10, in collaboration with ENS Cachan and Strategic Risk Management) and R. Zhang (2010/13, in collaboration with ENS Cachan and BNP Exane) considering multivariate financial time-series, while the PhD thesis of Till Wohlfarth focused on travel price forecasting [4166, 4165]. Other related works focused on structured data such as functional curves in [4045] and graphs in [4046, 4061, 4062, 3986] or [4064] (projects ANR Viroscopy, Digiteo Bemol). Finally, the design of model selection techniques based on data-dependent complexity penalization has been

considered in the projects "Meta-Rank" (Institut Mines-Télécom Futur & Ruptures program) and "Crank-Up" (Digiteo funding, in collaboration with Lip6) [4060].

### 14.4.2 Blind Source Separation

**Faculty** J-F. Cardoso, C. Févotte.

**Highlights: Scientific Production** [3854, 3936]

**Highlights: Impact** Adoption of the SMICA algorithm [3854] in the Planck CMB processing pipeline (distinguished by the Paul Doistau–Émile Blutet prize awarded to Jean-François Cardoso), ANR project TANGERINE (Theory and applications of nonnegative matrix factorization, 2009–).

**Highlights: Interactions with Society** Patent in automatic source separation (2011, C. Févotte).

Data is often nonnegative by nature, consider for example pixel intensities, amplitude spectra, occurrence counts, food consumption, user scores or stock market values. **Nonnegative matrix factorization** (NMF) is a linear regression technique with growing popularity in the fields of machine learning and signal/image processing. NMF, and its extension to nonnegative tensor factorization (NTF), are young research topics that call for answers to many open problems. The background for most of the research on NMF in the Stats group is the ANR project TANGERINE. The following topics have been addressed: model selection and learning algorithms [3893],factorization with structural constraints [4127, 4085], online and stochastic algorithms [4128, 4088]. Several applications have been considered such as music transcription [3933, 3934], audio source separation [3936, 3985] and identification of dietary behaviors [3867].

The **Planck space mission** of the European Space Agency has delivered on March 2013 a large set of papers and scientfic products after a 20-year preparation since the intial design (see [3978] and the following references). The highlight of the mission is the production of a full-sky, high-resolution, high SNR map of the Cosmic Microwave Background, litterally a snapshot of our Universe in its infancy, the oldest image in the Universe. J.-F. Cardoso has been working within the Planck collaboration with increasing commitment for more than 10 years, bringing in his theoretical expertise in the field of Independent Component Analysis and Blind Source separation. Planck produces nine maps of the full sky seen in nine frequency channels (from 30 GHz to 857 GHz), containing all sorts of Galactic and extragalactic emissions. As it turned out, the blind statistical approach to component separation –as developped specifically for Planck data [3854]– provided the Planck mission with the best way to combine its nine channels into a single clean map of the Cosmic Background of unprecented quality.

### 14.4.3 Sensor Networks

**Faculty** K. Abed-Meraim, P. Bianchi, M. Charbit, G. Fort, J. Jakubowicz, E. Moulines, J. Najim, F. Roueff.

**Highlights: Scientific Production** [3843, 3845, 3916]

**Highlights: Impact** ANR project SESAME (consistent estimation and large random matrices). Two international workshops (subject: "Random Matrices and Their Applications") were organized at Télécom Paristech in 2010 and 2012, and partially funded by the ANR project SESAME.

ANR project SVELTE (Système d'évaluation de la dépense énergétique et de la condition physique pour la prévention et le traitement de l'obésité)

**Highlights: Interactions with Society** Research contracts with Thales and with CEA DAM.

Since 2008 (with the recruitement of P. Bianchi and J. Jakubowicz), the group has been gradually more involved in the development of mathematical and statistical tools for performance evaluation and optimization of sensing and communication networks. The term *sensor* should be understood in a wide sense, including physical sensors (accelerometers, microphones, etc.),

distributed processors, smart phones or mobile robots. We distinguish between centralized and distributed network architectures.

In the framework of **centralized systems**, a special attention has been devoted to applications to **source detection and localization**. In the context of a joint work with the CEA and CNRH-hospitals (ANR project SVELTE), signal processing and classification methods have been applied to accelerometric data collected by body sensors [3935, 4144]. Two industrial contracts with CEA leaded to original algorithms for the detection of infrasound sources and the estimation of their angles of arrival [4043, 4041]. A Phd thesis started in 2013 to investigate some theoretical aspects of this problem, in particular, how to build meaningful data sets to evaluate various detection algorithms in realist situations.

Motivated by application to *cognitive radio* (ANR project SESAME), we analyzed the performance of different hypothesis tests in terms of error exponents [3845, 3846]. The design of quantization methods maximizing the error exponents is addressed in [3980]. We used **random matrix theory** as a central tool for the analysis of detection problems in large sensor networks. For instance, the study of the fluctuations and the large deviations of the extreme eigenvalues of sampled covariance matrices are crucial to characterize error exponents [3845]. In parallel, random matrix theory has also been extensively used for solving wireless communication problems. We analyzed *Ricean* Multiple Input Multiple Output (MIMO) channels in [884, 3906]. The analysis is made difficult because of the presence of a line-of-sight component. The last part of ANR project SESAME has been devoted to two related issues. First, the detection and estimation issues in Large Antenna Networks [893, 894], in a context where the number of antennas scales with the dimension of the received signal. Second, the estimation of large covariance matrices and/or functionals of large covariance matrices.

In the framework of **distributed systems**, we investigated the issue of distributed optimization in a network of autonomous agents seeking to reach an agreement on some global parameter. In a first part of our work, we analyzed the asymptotic behavior of gossip-based distributed stochastic approximation methods [3843, 4142]. An extension of our method to distributed online expectation-maximization is proposed in [4028]. Applications to distributed power control, resource allocation, sensor localization, motion coordination and smart grids have are addressed respectively in [3843, 3916, 4027, 4039, 4069]. A theoretical analysis of the effect of misbehaving agents on the convergence is provided in [4013**?** ] where a robust distributed optimization method is also proposed. More recently, we proposed an asynchronous version of a proximal-point algorithm for finding the zeros of a sum of two monotone operators, and derived an asynchronous distributed optimization algorithm based on the alternating direction method of multipliers.

### 14.4.4 Monte Carlo Methods

**Faculty** O. Cappé, S. Clémençon, G. Fort, E. Moulines.

**Highlights: Scientific Production** [3897, 3899, 3919, 3885, 3981]

**Highlights: Impact** ANR Projects BigMC (Issues in large scale Monte Carlo, 2009–2012). C-FLAM (Coordination Flotilla Localization and Mapping, 2008–2011). Siminole (Large-scale simulation-based probabilistic inference, optimization, and discriminative learning with applications in experimental physics, 2011–2014). Viroscopy (Stochastic modeling and statistical inference for propagating infectious diseases: from micro to macroscopic behavior, 2008–2011). Digiteo project Bemol (2009–2011). G. Fort was a member of the organization committee of the international workshop on *Performance Analysis of Monte Carlo methods* held in November 2012, in Brown University. G. Fort also organized a monthly seminar on Monte Carlo methods (held at the Institut Henri Poincare) where many searchers from Paris and its region working or using Monte Carlo methods meet.

The group is internationally recognized for its contributions on Markov chain Monte Carlo (MCMC), Sequential Monte Carlo (also called Particle Filtering), and novel Monte Carlo approaches at large. The group contributes actively to the theory and the methods of Monte Carlo

simulation; it also considers applications to the so-called *Bayesian inverse problems*, most often in the context of collaborative projects.

New challenges in MCMC methods deal with **adaptive methods** (in which the simulation parameters are adapted to improve the mixing efficiency) and interacting Monte Carlo techniques (in which several Monte Carlo are run in parallel and interacts). The group has a strong expertise in convergence analysis of classical MCMC algorithms; in the past years, the group has responded to some of these new challenges by developing new tools for the theoretical study of these new MCMC samplers [3982, 3897, 3898, 3899]. We have developed and analyzed novel interacting algorithms, extending the so-called *equi-energy sampler*; see [3948]. These works have been developed in collaboration with researchers from Univ. Pierre et Marie Curie, Univ. Paris Est (in the context of the BigMC project), the Univ. of Michigan [3824, 3825] (USA), the Univ. of Jyvaskyla (Finland) [3929].

We have also contributed to the theory and methods of **sequential Monte Carlo**. In [3885], an efficient particle smoothing algorithm (called the Forward Filtering Backward Simulation, or FFBSi algorithm), with a complexity growing linearly with the number of particles, has been described. The consistency, asymptotic normality, and stability of the forward filtering backward smoothing algorithm has also been discussed in this work, which has later been extended to the approximation of smoothing functionals in [4081, 3887]. The long-term stability of sequential Monte Carlo techniques has only been established under rather stringent ergodicity conditions (uniform mixing for the Markov kernel). We have started to study the stability under much weaker conditions. A first step in this direction has been done in [3883] and [3884].

In the ANR project C-FLAM, lead by the LIRMM in Montpellier, the group has developed novel landmark-based Simultaneous Localization and Mapping algorithms. Our approach consists in solving the *marginal SLAM* problem by using Sequential Monte Carlo methods, and the Mapping problem by adapting online Expectation-Maximization algorithms (previously proposed by our group in [3849, 3983]) [4123, 4125, 3919, 3920].

Interacting and branching particle system techniques and sequential Monte-Carlo methods have been developed and used for *rare event simulation/probability estimation* in the contexts of food risk analysis and of mathematical epidemiology (ANR project `Viroscopy` - 2008/11), see [3859] and [3839]. In [4095] (Digiteo project `Bemol` - 2009/11), dedicated MCMC techniques have been developed for rank aggregation.

Following our past experience in the context of the ANR project `ECOSSTAT`, where the group contributed to the development of an original **adaptive importance sampling** scheme [3981, 3913, 4188] (with associated distributed software implementation [3913]) for Bayesian analysis of multi survey cosmological data, we launched a new project in this field in 2011. This project called Siminole and also funded by the ANR is lead by the LAL in Orsay and our contribution is focused on the exploitation of cosmic ray data gathered in the context of the Auger experiment. A first algorithm for solving switching label problems has been proposed in [3999]

### 14.4.5 Time Series

**Contributors** K. Abed-Meraïm, O. Cappé, M. Charbit, S. Clémençon, C. Lévy-Leduc, E. Moulines, F. Roueff.

**Highlights: Scientific Production** [3858, 3886, 3907, 3856, 3945]

**Highlights: Impact** CNRS-FRS-WBI mobility program, Project DGA REI (Recherche Exploratoire et Innovation) ISREPTMu (Interception de signaux radar en présence de trajets multiples), ANR project Mataim (Anisotropic models for textures with applications to medical imaging),

**Highlights: Interactions with Society** Research contract with Natixis (1 PhD thesis), Research contract with Echosens (1 PhD thesis)

Following the thorough analysis of semi-parametric Wavelet methods for estimating the **long memory parameter** that we conducted in the past years, we have explored new directions in this topic: robust estimation of the memory parameter ([3914]), non stationary (change-point and

locally stationary) long memory modelling ([4116, 3915, 3944]), non-Gaussian and non-linear long memory processes ([3856, 3945]). We have studied the asymptotic properties of a new robust estimator of the autocovariance of Gaussian processes having either short or long-range dependence in [3926]. These results have been established thanks to the asymptotic properties of general $U$-processes in the long-range dependence context of [3924, 3925]. A large part of these works were conducted in a long standing collaboration with M.S. Taqqu (Boston Univ.).

We also pursued our work on the topic of **change point** detection. The method proposed in a previous research project for centralized anomaly detection in the Internet traffic has been extended to deal with a decentralized anomaly detection approach in [3928] and [4133] in which a robust change-point detection method based on multivariate rank statistics is proposed. Finally, we proposed a multiple change-point estimation with LASSO in [3907].

The Markov assumption being among the weakest assumptions involved in time series modelling, renewal theory for **Markov processes** has been used for analyzing the (asymptotic and non asymptotic) behavior of sample mean, U-statistics and extreme-value statistics based on general Markovian data, in [3837, 3858, 3898] and [3840]. We have also pursued our long-lasting work on the theory of Hidden Markov Model; in [3886] and [3881] we have obtained the convergence of the relative entropy in the HMM for both well- and mis-specified models, under the weakest known conditions. A preliminary discussion of a regenerative bootstrap approach for HMM has been considered in [4058].

Ongoing applications in statistical signal processing based on time series or random fields modelling include radar processing and medical diagnosis [4148, 3996]. A related field of interest for non-cooperative communications is **blind identification**: In the context of AINTERCOM project, we developed blind demodulation approaches using approximate Maximum Likelihood methods [3830], [3829].

# 14.5 Achievements (Appendix 6)

## 14.5.1 Scientific Productions

### Articles in Journals


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### Book Chapters

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[4151] F. Roueff. Nonstationary models with long memory. In *International Statistical Institute (58th congress)*, Dublin, Irelande, Aug. 2011.
[4152] N. Seichepine, S. Essid, C. Févotte, and O. Cappé. Soft nonnegative matrix co-factorization with application to multimodal speaker diarization. In *ICASSP*, Vancouver, May 2013.
[4153] P. Sendorek, M. Charbit, K. Abed-Meraim, and S. Legoll. Weighted sum of least squares estimators for accurate positionning in presence of outliers. In *DASC*, Williamsburg, VA, USA, Oct. 2012.
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[4155] V. Y. F. Tan and C. Févotte. Automatic relevance determination in nonnegative matrix factorization with the beta-divergence. In *NIPS workshop on Sparse Representation and Low-rank Approximation*, Sierra Nevada, Spain, 2011.
[4156] M. Thameri, K. Abed-Meraim, and A. Belouchrani. Algorithmes adaptatifs rapides pour l'estimation des vecteurs propres mineurs. In *Coloque GRETSI*, Sept. 2011.
[4157] M. Thameri, A. Kammoun, K. Abed-Meraim, and A. Belouchrani. Fast principal component analysis and data whitening algorithms. In *7th International Workshop on Systems, Signal Processing and their Applications*, Tipaza, Algerie, May 2011.
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[4159] M. Thameri, K. Abed-Meraim, and A. Belouchrani. New algorithms for adaptive bss. In *11th International Conference on Information Science, Signal Processing and their Applications (ISSPA)*, Montreal, Canada, July 2012.
[4160] M. Thameri, R. Boyer, and K. Abed-Meraim. Derivation of an analytical expression of the gaussian model statistical resolution limit. In *ICASSP*, Vancouver, Canada, May 2013.
[4161] L. Thiagarajan, S. Attallah, L. Ying-Chang, and K. Abed-Meraim. Channel identifiability for blind subspace-based channel estimator in uplink mc-cdma systems. In *Proc. ICC*, May 2008.
[4162] J. Villard and P. Bianchi. High-rate vector quantization for the neyman-pearson detection of some mixing processes. In *ISIT*, Oct. 2010.
[4163] J. Villard and P. Bianchi. Quantification vectorielle haute résolution pour la détection de processus stationnaires. In *GRETSI*, Bordeaux, Sept. 2011.
[4164] J. Villard, P. Bianchi, E. Moulines, and P. Piantanida. High-rate quantization for the neyman-pearson

detection of hidden Markov processes. In *ITW*, Oct. 2010.

[4165] T. Wohlfarth, S. Clémençon, F. Roueff, and X. Casellato. Prédiction de l'occurence d'une baisse de prix pour le conseil à l'achat d'un billet en ligne. In *GRETSI*, Bordeaux France, Sept. 2011.

[4166] T. Wohlfarth, S. Clémençon, F. Roueff, and X. Casellato. A data-mining approach to travel price forecasting. In *ICMLA*, Honolulu (Hawaï), USA, Dec. 2011.

### Invited Talks

[4167] P. Bianchi. Analyse en grandes dimensions de tests d'hypothèses pour la détection d'émetteur. In *Jounées MAAS 2009*, Bordeaux, Nov. 2009.

[4168] O. Cappé. An introduction to sequential Monte Carlo for filtering and smoothing. In *Workshop on statistical modeling of extremes in data assimilation and filtering approaches*, Strasbourg, France, June 2008.

[4169] O. Cappé. Inside sequential Monte Carlo methods (tutorial). In *2009 IEEE Workshop on Statistical Signal Processing*, Cardiff Wales, UK, Aug. 2009.

[4170] O. Cappé. Online EM algorithms for mixtures, HMMs and beyond. In *Mixture estimation and applications Workshop, International Centre for Mathematical Sciences*, Edinburgh, UK, Mar. 2010.

[4171] O. Cappé. Méthodes bayésiennes pour les modèles à variables latentes. In *5ème école d'été de Peyresq en traitement du signal et des images*, Peyresq, France, June 2010.

[4172] O. Cappé. From importance sampling to sequential Monte Carlo methods (tutorial). In *Second Training School of the EU MC Impulse Network*, Windermere, Cumbria, UK, Sept. 2011.

[4173] O. Cappé. Learning with the online EM algorithm. In *StatLearn'13 workshop*, Bordeaux, France, Apr. 2013.

[4174] S. Clémençon. Large population limits and inference for a stochastic sir model with contact-tracing. In *R0 and Related Concepts*, Paris, France, Oct. 2008.

[4175] S. Clémençon. Regeneration-based statistics for Markov chains. In *Journées MAS*, Rennes, Aug. 2008.

[4176] S. Clémençon. Ranking the best instances. In *Journées d'Apprentissage Statistique*, Orléans, France, Mar. 2008.

[4177] S. Clémençon. A stochastic epidemic model with contact-tracing. In *XII-th Congress in Operations Research*, La Havane, Cuba, Feb. 2008.

[4178] S. Clémençon. Extreme value statistics for Markov chains. In *Statistics for Dependent Data*, Malakoff, France, May 2008.

[4179] S. Clémençon. Exposition aux risques alimentaires et processus stochastiques. In *Congrès de la SMAI*, La Colle sur Loup, France, May 2009.

[4180] S. Clémençon. Recent advances in ranking. In *Learning Theory - State of the Art (SMF)*, Paris, France, May 2011.

[4181] J. Cornebise, E. Moulines, and J. Olsson. Adaptive methods for sequential importance sampling. In *Opening workshop of SAMSI 2008-09 Program on Sequential Monte Carlo methods*, Durham, Etats-Unis, Sept. 2008.

[4182] J. Cornebise, E. Moulines, and J. Olsson. Adaptive methods for sequential importance sampling. In *Journées MAS de la SMAI*, Rennes, France, Aug. 2008.

[4183] G. Fort. Fluid limit-based tuning of some hybrid MCMC samplers. In *Adap'SKI*, Bormio, Italie, July 2008.

[4184] G. Fort. Stability of Markov chains based on fluid limit techniques. applications to MCMC. In *Congrès SSC-SFDS*, Ottawa, Canada, July 2008.

[4185] G. Fort. On adaptive stratification. In *2009 INFORMS Applied Probability Society*, July 2009.

[4186] G. Fort. Limit theorems for adaptive MCMC algorithms. In *41eme journées de Statistiques de la SFDS*, Bordeaux, France, July 2009.

[4187] G. Fort. Adaptive MCMC : theory and methods. In *Optimization in MCMC*, Warwick, GB, July 2009.

[4188] G. Fort. Estimation of cosmological parameters using adaptive importance sampling. In *Workshop "Astro-Statistique"*, Grenoble, France, Dec. 2011.

[4189] G. Fort. New online-EM algorithms for general hidden Markov models. application to the slam problem. In *International Conference "Latent Variable Analysis - Independent Component Analysis"*, Tel-Aviv, Israël, Feb. 2012.

[4190] G. Fort. Adaptive equi-energy samplers. In *ISBA*, Kyoto, Japon, June 2012.

[4191] G. Fort. Stochastic approximation-based adaptation for interacting MCMC. In *Workshop "Advances in Markov chain Monte Carlo"*, Edimburgh, Royaume-Uni, Apr. 2012.

[4192] G. Fort. Adaptive and interacting Monte Carlo methods for Bayesian analysis. In *Workshop "Big Bang, Big Data, Big Computers"*, Paris, France, Sept. 2012.
[4193] G. Fort. Convergence and efficiency of the wang-landau algorithm. In *Winter School "New directions in Monte Carlo methods"*, Gainesville, USA, Jan. 2013.
[4194] G. Fort and E. Moulines. Parallel tempering and interacting algorithms. In *Workshop "Challenges and Advances in High Dimensional and High Complexity Monte Carlo Computation and Theory"*, Calgary, Canada, Mar. 2012.
[4195] S. Le Corff. The block online expectation maximization algorithm. In *14th Conference of the ASMDA International Society*, Rome, Italie, June 2011.
[4196] S. Le Corff. Nonparametric estimation in hidden Markov models. In *8th world congress in Probability and Statistics*, Istanbul, Turquie, July 2012.
[4197] S. Le Corff. Convergence of a particle based online estimation procedure in hidden Markov models. In *SMC 2012*, Warwick, UK, Sept. 2012.
[4198] T. Rebafka and F. Roueff. Minimax estimation of the mixing density of a mixture of exponential distributions. In *European Meeting of Statisticians*, Toulouse, France, Aug. 2009.
[4199] T. Rebafka, F. Roueff, and A. Souloumiac. Information bounds and MCMC parameter estimation for the pile-up model with application to fluorescence measurements. In *7th World Congress in Probability and Statistics*, Singapore, July 2008.
[4200] F. Roueff. Asymptotic statistics for the scalogram of time series. In *Fourier meets wavelets - in statistics*, Karlsruhe, Allemagne, Sept. 2010.
[4201] F. Roueff. Time-varying long memory estimation. In *Self-similarity and related fields*, Le Touquet, France, Sept. 2011.
[4202] F. Roueff. Wavelet analysis of long range dependent processes. In *Long-Range Dependence, Self-Similarity and Heavy Tails*, Research Triangle Park, North Carolina, USA., Apr. 2012.
[4203] F. Roueff. Nonstationary models with long memory. In *Multifractal, Non Stationarity, Risks*, Paris, France, July 2012.
[4204] F. Roueff. Some recent results fornon-linear processes with long range dependence. In *IWAP 2012 (workshop)*, Jerusalem (Israel), Aug. 2012.
[4205] A. Schreck. Adaptive equi-energy sampler: convergence and illustration. In *8th World Congress in Probability and Statistics*, istanbul, turquie, July 2012.
[4206] A. Schreck. An adaptive version of the equi-energy sampler. In *15th Annual Winter Workshop: New Directions in Monte Carlo Methods*, Gainesville, Etats-Unis, Jan. 2013.
[4207] B. Zheng. Price jump prediction in limit order book. In *Quantitative Methods in Finance*, Sydney, Australia, Dec. 2011.
[4208] B. Zheng. Price jump detection in limit order book. In *Interdisciplinary workshop on "Econometric and statistical modelling of multivariate time series"*, Louvain-La-Neuve, Belgique, May 2011.
[4209] B. Zheng, E. Moulines, and F. Abergel. Price jump prediction in limit order book. In *Market Microstructure Conference Confronting Many Viewpoints*, Paris, France, Dec. 2010.
[4210] B. Zheng, F. Roueff, and F. Abergel. Application of spread constrained limit order book hawkes process to financial high frequency data modelling. In *Market Microstructure: confronting many viewpoints*, Paris, France, Dec. 2012.

### 14.5.2 Public Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008-2012 | SESAME - Consistent estimation and large random matrices | ANR MDCO | J. Najim | 138 |
| 2008-2012 | CFLAM | ANR PSIRob | E. Moulines | 46 |
| 2008-2011 | MGA - Modèles graphiques et apprentissage | ANR Blanc | O. Cappé | 50 |
| 2008-2010 | ULISS/AGEXPO | DGE poles | M. Charbit | 65 |
| 2009-2011 | VIROSCOPY | ANR | S. Clémençon | 176 |
| 2009-2013 | TANGERINE - Theory and application of nonnegative matrix factorization | ANR JC | C. Févotte | 140 |
| 2009-2012 | BIG MC - Méthodes de Monte Carlo en grande dimension | ANR Blanc | G. Fort | 75 |
| 2009-2011 | BEMOL | Digiteo | S. Clémençon | 55 |
| 2009-2013 | SVELTE | ANR | P. Bianchi | 71 |
| 2010 | Modèles à mémoire longue variant dans le temps | CNRS-FRS-WBI | F. Roueff | 5 |
| 2010-2014 | ORIGAMI 2 | ANR | M. Charbit | 107 |
| 2010-2014 | SIMINOLE - Méthodes de simulations pour la physique expérimentale | ANR Cosinus | O. Cappé | 185 |
| 2012-2015 | Allocation doctorale Sanchez Perez | Région IdF | F. Roueff | 97 |
| 2012-2016 | Projets Maths-Ingénierie | Labex LMH | F. Roueff, S. Clémençon | 10 |
| 2012-2014 | ERASM | Eurostars | S. Clémençon | 180 |

### 14.5.3 Private Fundings

| Period | Project details | Funding | Principal investigator | Annual total (k€) |
|---|---|---|---|---|
| 2008-2011 | CIFRE PhD S. Audière | Echosens | M. Charbit | 40 |
| 2009-2010 | Spécifications de capteurs | ONERA | E. Moulines | 26 |
| 2009 | Etude évaluation colmatage | EDF | E. Moulines | 3 |
| 2009-2011 | CIFRE PhD S. Grimoud | Orange | E. Moulines | 17 |
| 2009-2011 | Projet REI Irespt Mu | DGA | M. Charbit | 67 |
| 2009-2010 | Hybridation multiple IMU/GNSS | Thales | M. Charbit | 16 |
| 2010-2013 | CIFRE PhD T. Wohlfarth | Findworks | S Clémençon | 45 |
| 2010-2013 | CIFRE PhD B. Zheng | Natixis | E. Moulines | 45 |
| 2010 | Etude | Withings | K. Abed-Meraim | 5 |
| 2010-2011 | Infrasonore | CEA | M. Charbit | 81 |
| 2010-2013 | CIFRE Fox | Parrot | M. Charbit | 36 |
| 2010-2013 | CIFRE PhD M. Jala | Orange | C. Lévy Leduc | 30 |
| 2010-2013 | CIFRE PhD R. Zhang | Exane | S. Clémençon | 30 |
| 2011-2014 | CIFRE PhD P. Sendorek | Thales | K. Abed-Meraim | 45 |
| 2011-2014 | Allocation doctorale G. Morral Adell | DGA | P. Bianchi | 55 |
| 2011-2014 | CIFRE PhD A. Dematteo | GTT | S. Clémençon | 27 |
| 2012-2015 | CIFRE PhD Y. Khan | Orange | E. Moulines | 30 |
| 2012-2015 | CIFRE PhD H. Braham | Orange | E. Moulines | |
| 2012-2013 | Infrasonore2 | CEA | M. Charbit | 39 |
| 2012-2015 | CIFRE PhD O. Iacoboaiea | Orange | P. Bianchi | 30 |
| 2012-2015 | Approches Séquentielles pour l'estimation des quantiles | Orange | E. Moulines | 60 |

## 14.6 PhDs (Appendix 7)

### 14.6.1 Defended PhDs

[4211] A. B. H. Alaya. *Métrologie dans les réseaux d'accès radio pour la gestion de ressources pour le développement du concept "Always Best Connected"*. PhD thesis, Télécom ParisTech, Dec. 2008.

[4212] S. Barembruch. *Méthodes de filtrage particulaire par la détection et l'estimation autodidacte*. PhD thesis, Télécom ParisTech, Sept. 2010.

[4213] N. Castaneda. *Géo-localisation adaptative par modèles bayésiens hiérarchiques*. PhD thesis, Télécom ParisTech, July 2008.

[4214] J. Cornebise. *Processus Empirique et approximation particulaire*. PhD thesis, Télécom ParisTech, June 2009.

[4215] M. Depecker. *Modélisation de la performance perçue à partir de données explicatives fonctionnelles issues de mesures physiques*. PhD thesis, Télécom ParisTech, Dec. 2010.

[4216] S. Filippi. *Apprentissage des processus de décision markoviens partiellement observés*. PhD thesis, Télécom ParisTech, Nov. 2010.

[4217] J.-F. Germain. *Contributions des méthodes statistiques et des techniques d'optimisation à la quantification de données multi-dimensionnelles d'agrément de conduite.* PhD thesis, Télécom ParisTech, Oct. 2008.

[4218] Z. Harchaoui. *Apport de l'analyse COR pour le classement semi-supervisé*. PhD thesis, Télécom ParisTech, Nov. 2008.

[4219] T. B. Jabeur. *Technique d'égalisation partielle du canal dans un système de transmissions numériques pultiparteuses OFDM*. PhD thesis, Télécom ParisTech, Sept. 2009.

[4220] A. Kammoun. *Contributions à l'égalisation et l'identification semi-aveugle et analyse de performances*. PhD thesis, Télécom ParisTech, Apr. 2010.

[4221] M. Kharouf. *Application de la théorie des matrices aléatoires à l'évaluation de performances en communications numériques*. PhD thesis, Télécom ParisTech, June 2010.

[4222] O. Kouamo. *Estimation du coefficient de memoire par analyse du scalogramme*. PhD thesis, Télécom ParisTech, Jan. 2011.
[4223] N. Ksairi. *Stratégie de coopération dans les réseaux mobiles de type DFDMA*. PhD thesis, Télécom ParisTech, Mar. 2010.
[4224] S. Le Corff. *Estimations pour les modèles de Markov cachés et approximations particulaires. Applications à la localisation et cartographie simultanées*. PhD thesis, Télécom ParisTech, Sept. 2012.
[4225] A. Lefevre. *Méthodes d'apprentissage de dictionnaire appliquées à la séparation des sources*. PhD thesis, Télécom ParisTech, Oct. 2012.
[4226] A. Lung-Yut-Fong. *Détection robuste de ruptures pour les signaux multidimensionnels. Application à la détection d'anomalies dans les réseaux*. PhD thesis, Télécom ParisTech, Dec. 2011.
[4227] N. Mahler. *Méthodes d'apprentissage pour des flok discrets multi-échelles et applications à la finance*. PhD thesis, Télécom ParisTech, Jan. 2012.
[4228] T. Rebafka. *Estimation d'une distribution de temps de réponse très rapide en fluorescence mollécullaire*. PhD thesis, Télécom ParisTech, Oct. 2009.
[4229] N. Sokolovska. *Contributions to the estimation of probabilistic discriminative models: semi-supervised learning and feature selection*. PhD thesis, Télécom ParisTech, Feb. 2010.
[4230] J. Villard. *Stratégies de coopération ciblées pour réseaux de capteurs sans fil*. PhD thesis, Télécom ParisTech, Dec. 2011.
[4231] J. A. Ybanez. *Poursuite multimodales de personnes*. PhD thesis, Télécom ParisTech, June 2008.

### 14.6.2 Ongoing PhDs

- G. M. Adell *Optimisation stochastique distribuée dans les réseaux de capteurs*.
- A. Ataya *Algorithmes d'apprentissage pour les modèles de Markov cachés via une approche bayésienne*.
- A. Bader *Etude et optimisation de la partie couche physique des réseaux de relais multi-sauts évolutifs*.
- A. Bellachehab *Optimisation distribuée dans les variétés. Application aux réseaux de capteurs.*
- H. Braham (12/12–) *Environment aware radio resource optimization in next generation radio access networks*
- E. Chautru *Apprentissage statistique des ensembles de niveau et application à l'analyse risque-bénéfice en nutrition*.
- A. Dematteo *Etude statistique de la spatialisation du phénomène de sloshing et mesures du risque*.
- C. Fox *Réduction de bruit dans la prise de son, mono/multi microphones*.
- B. Guedj *Agrégation d'estimations et de classifications : théorie et méthodes*.
- M. Jala *Analyse statistique de l'exposition du fœtus aux emissions des equipements de communication sans fils*.
- E. Kaufmann (09/11–) *Approche bayésienne et sélection de modèle pour l'apprentissage par renforcement*.
- Y. Khan *L'optimisation automatique de la gestion des ressources radio dans les réseaux cellulaire de la 4ème génération*.
- N. Ksairi *Stratégie de coopération dans les réseaux mobiles de type DFDMA*.
- A. Nouvellet (03/13–) *Traitement statistique du signal pour les sources infrasonores*.
- S. Robbiano *Méthodes d'apprentissage pour le Ranking Multi-classe*.
- A. Sanchez-Perez (09/12–) *Estimation adaptative pour des séries temporelles localement stationnaires*.
- A. Schreck (09/11–) *Méthodes de Monté Carlo robustes pour la simulation dans des espaces de grandes dimensions*.
- N. Seichepine (09/12–) *Factorisations Multimodales pour la structuration non supervisée des documents audiovisuels*.

- P. Sendorek *Etude d'un système d'autolocalisation comportant plusieurs récepteurs GNSS-RVs utilisant un système de géolocalisation tel que le GPS et plusieurs centrales inertielles K-IMU*.
- E. Sibony *Approches nouvelles pour l'agrégation d'ordonnancements : Transport Optimal et analyse harmanique*.
- M. Thameri *Techniques de poursuite et d'estimation robuste avec analyse de performance*.
- T. Wohlfarth *Méthodes d'apprentissage statistique pour la prédiction de séries temporelles et application à la prévision du prix des voyages*.
- J. Yao *Estimation en grande dimension*.
- R. Zhang *Méthodes d'apprentissage statistique en gestion de portefeuille pour la sélection de titres, la gestion du risque et l'optimisation de portefeuille*.
- B. Zheng *Détection d'évènements rares dans les données hautes fréquences et applications au trading algorithmique*.

# Cinquième partie

# Stratégie et perspectives scientifiques

# Chapitre C

# Stratégie du LTCI

Ce chapitre est consacré à la stratégie et aux perspectives scientifiques du LTCI. Il s'appuie notamment sur les réflexions stratégiques des équipes de recherche de l'unité qui seront détaillées dans le chapitre D.

Comme dans la partie bilan, nous nous plaçons ici dans la perspective proposée pour la période quinquennale 2015–2019 d'évolutions distinctes de deux composantes de l'unité ; d'une part, la composante de l'unité relevant des sciences et technologies de l'information et de la communications (STIC) qui porte le projet de renouvellement du LTCI ; et, d'autre part, la composante de l'unité relevant des sciences humaines et sociales (SHS) dont la perspective est celle de la création d'une unité multi tutelles (CNRS, Télécom ParisTech, Mines ParisTech, Ecole Polytechnique) relevant disciplinairement des SHS et centrée autour du thème de l'innovation (projet *I3 : Institut interdisciplinaire de l'innovation*). Dans la suite de ce chapitre, le terme LTCI est donc utilisé pour désigner la composante STIC de l'unité actuelle structurée en quatorze équipes réparties dans les trois départements, Communications et électronique (COMELEC), Informatique et réseaux (INFRES) et Traitement du signal et des images (TSI) dont le bilan pour la période 2008–2013 est détaillé dans les parties I à IV du document (voir la table B.1 pour une vision synthétique des équipes et départements).

## C.1 Analyse stratégique

Le LTCI est une unité mixte de recherche rattachée à l'Institut des sciences de l'information du CNRS et à Télécom ParisTech (Institut Mines-Télécom). **Ses missions sont de contribuer à l'avancement des connaissances dans le champ des sciences de l'information ainsi qu'au développement du potentiel d'innovation français dans le domaine du numérique**. Pleinement intégré au projet de l'Université Paris-Saclay, le LTCI a également pour ambition de contribuer à certains de ses objectifs majeurs que sont, **le renforcement de la formation par la recherche**, **l'émergence de recherches interdisciplinaires**, **le développement du potentiel d'innovation et de transfert** ainsi que **le rayonnement international**.

Pour analyser les perspectives du LTCI, nous utilisons dans cette partie le canevas conventionnel d'une analyse «SWOT» résumée par la table C.1.

En balayant les facteurs mentionnés dans la table C.1 de haut en bas, et en commençant donc par les facteurs internes, on trouve tout d'abord des aspects liés au **positionnement du LTCI** par rapport notamment aux laboratoires avec lesquels il est comparé, en France comme à l'international. L'unité a été évaluée collectivement au niveau A+ par l'AERES en 2010, avec toutes ses équipes au niveau A ou A+. L'unité a par ailleurs sur la période écoulée montré une forte attractivité, avec des recrutements de très bon niveau tant via le CNRS que Télécom ParisTech. A l'inverse, l'unité est moins bien placée en ce qui concerne la mise en valeur du potentiel individuel de ses chercheurs (absence de lauréat ERC, des récompenses et distinctions prestigieuses — cf. tableau B.6 — mais obtenues plutôt par des chercheurs confirmés ou des doctorants du

| | POSITIF | NEGATIF |
|---|---|---|
| **INTERNE** | • Unité de 130 permanents de niveau A+<br>• Forte attractivité pour le recrutement de jeunes chercheurs (CNRS et Télécom ParisTech)<br>• 220 Doctorants & 75 CDD<br>• Couverture thématique large des STIC<br>• Grande capacité de recherche partenariale<br>• Intégré à une grande école du *top ten* centrée sur les STIC | • Peu de A++<br>• Difficulté à faire émerger des thèmes portés par les jeunes chercheurs<br>• Hétérogénéité des non permanents<br>• Peu de travaux interdisciplinaires<br>• Faible production de propriété intellectuelle<br>• Faible capacité à briguer des financements très compétitifs<br>• Inhomogénéité de la charge d'enseignement<br>• Faible capacité d'attraction des diplômés Télécom ParisTech en doctorat |
| **EXTERNE** | • IMT : Réseau national, politique internationale<br>• UPSay : Visibilité, attractivité<br>• UPSay : Dynamique pluridisciplinaire et pluri-établissements<br>• UPSay : Emulation scientifique<br>• UPSay : Doctorat «diplôme phare» de l'UPSay<br>• Le Numérique-STIC est la thématique centrale du LTCI | • Complexité multi-référentiels (Télécom ParisTech, IMT, UPSay)<br>• UPSay : Départ de chercheurs de valeur, perte de relations structurantes<br>• UPSay : Perte d'efficacité par complexité organisationnelle<br>• UPSay : Manque de capacité d'adaptation de l'organisation interne (du LTCI et de Télécom ParisTech)<br>• Déplacement du barycentre des activités du numérique en dehors de l'Europe<br>• Conjoncture économique difficile qui risque de réduire nos ressources |

TABLE C.1 – Analyse SWOT du LTCI (abbréviations : IMT – Institut Mines-Télécom, UPSay – Université Paris Saclay).

LTCI). Il nous semble indispensable de mieux accompagner les chercheurs sur ces aspects, en particulier en début ou milieu de carrière. Cette question prendra d'autant plus d'importance au sein de l'Université Paris-Saclay, environnement stimulant où la concurrence pour attirer les meilleurs talents se fera au plus haut niveau.

En ce qui concerne les **personnels non permanents** ceux-ci sont nombreux au LTCI (environ 220 doctorants et 75 chercheurs sous contrat ou postdoctorants). Ils constituent une force de recherche considérable portée par un taux de ressources propres très significatif (environ 215 personnels non permanents sont directement financés sur des ressources propres). Néanmoins, au sein de cet ensemble, on note une certaine inhomogénéité tant dans les missions que sur les niveaux de recrutement ; aspects sur lesquels il nous faudra travailler, en lien notamment avec l'ambition du site Paris-Saclay de faire du doctorat le diplôme phare de la future Université Paris-Saclay.

Sur l'**interdiscplinarité**, le LTCI a un potentiel important de par sa couverture très large du domaine des STIC ainsi que, sur un autre plan, de par sa proximité avec les équipes du département Sciences humaines et sociales (SES) de Télécom ParisTech. Néanmoins sur la période écoulée, les points saillants en matière d'interdisciplinarité restent peu nombreux et le cloisonnement au sein des ensembles disciplinaires que constituent les équipes et les départements reste assez déterminant. Il s'agit sans aucun doute d'un aspect sur lequel le potentiel de l'unité n'est pas suffisamment exploité.

La grande capacité de **recherche partenariale** est un des atouts de l'unité qui bénéficie pleinement de l'action volontariste de Télécom ParisTech et de l'Institut Mines-Télécom sur cet aspect, notamment, à travers le montage de projets d'envergure de type chaires ou laboratoires

communs. Le bilan de la période 2008–2013 fait apparaître une croissance significative des ressources propres de l'unité (voir tableau B.9) en lien avec le soutien fort des pouvoirs publics au niveau national sur cette période [1]. Cette croissance des ressources ne s'est pas systématiquement traduite par un accroissement de la production que se soit en termes de publications scientifiques ou en terme de propriété intellectuelle (brevets, transferts). Par ailleurs, tant l'abondance de ces ressources propres que le temps de permanents qu'elles mobilisent constituent probablement un des facteurs à l'origine de notre présence, comparativement faible, sur des financements d'excellence. Compte tenu de ces éléments, une réflexion est nécessaire pour privilégier les instruments qui, tout en préservant un niveau de ressources propres indispensable au fonctionnement de l'unité, nous permettent d'atteindre au mieux nos deux objectifs essentiels que sont une recherche scientifique de haut niveau et une contribution significative à l'innovation et au transfert.

La contribution de l'unité à **l'enseignement et la formation** s'effectue, de façon majoritaire, dans le cadre privilégié qui est celui d'une grande école de référence, au niveau national, dans le domaine du numérique. Cette grande adéquation entre l'identité de l'école Télécom ParisTech et les recherche menées au LTCI constitue un atout. Néanmoins, l'implication des personnels de l'unité en enseignement se répartit de façon assez inhomogène entre les équipes, la capacité de recherche de certains enseignants-chercheurs de l'unité s'en trouvant impactée. Par ailleurs, le taux de poursuite en doctorat des élèves ingénieurs de Télécom ParisTech est faible (moins de 5%) ce qui nous conduit également à nous interroger sur la capacité d'attraction du LTCI envers les diplômés de Télécom ParisTech.

Si on passe aux facteurs externes (partie inférieure de la table C.1), l'unité bénéficie tout d'abord fortement de son rattachement à deux établissements nationaux, **le CNRS et l'Institut Mines-Télécom**, qui confèrent une grande visibilité à son action, lui assurent une bonne légitimité, vis à vis notamment des acteurs publics, et disposent de leviers d'actions — on pense notamment à l'international ou aux aspects liés aux partenariats et à la valorisation — précieux pour l'unité. Depuis 2012, Télécom ParisTech et le LTCI s'inscrivent également dans le cadre particulièrement ambitieux d'un projet national de création d'une université de classe mondiale construite par fédération des différents acteurs (au moins une douzaine d'établissements supérieurs et une demi douzaine d'organismes nationaux) qui gardent leurs identités propres. Ce projet d'**Université Paris-Saclay** est porteur pour l'unité d'enjeux particulièrement importants en termes de collaborations, d'émulation scientifique, de visibilité et d'attractivité.

Cet environnement particulièrement privilégié ne va pas néanmoins sans poser des questions importantes pour l'avenir de l'unité. Tout d'abord, le fait d'appartenir à des référentiels multiples génère une complexité organisationnelle et structurelle difficile à gérer, peu motivante pour les personnels et très consommatrice de temps. Un exemple parlant est celui de la recherche de financements doctoraux qui est devenu depuis quelques années un véritable jeu de pistes avec une dizaine de guichets différents où potentiellement déposer une même demande [2]. Au delà d'un certain degré de complexité on constate malheureusement que la balance entre l'augmentation du nombre d'opportunités de financement et le temps de personnels chercheurs ou enseignants-chercheurs investi dans le montage de projet (tant pour la soumission en elle-même que pour l'évaluation) n'est plus suffisamment équilibrée. Cette situation est d'autant plus préoccupante pour la période transitoire qui nous sépare de 2017 dans laquelle les forces du laboratoire sont mobilisées à la fois pour construire les nouveaux instruments du site Paris-Saclay (grands projets structurants, écoles doctorales, formations de masters) mais également pour faire fonctionner les instruments existants : école doctorale EDITE, formations de masters (avec l'Université Pierre et Marie Curie), laboratoires (par exemple le LINCS) et projets communs (GIS avec

1. Sur la base des chiffres 2011–2012, les ressources propres de l'unité se répartissent en 17% de financements européens, 57% de financements publics nationaux et 26% de financements impliquant des partenaires industriels ; ces derniers correspondent environ pour moitié à des encadrements de thèses CIFRE ou à des chaires, qui bénéficient également de mesures incitatives sur financements publics (subvention ANRT pour les thèses CIFRE, et Crédit Impôt Recherche pour les chaires).

2. Appel DGA «Club des partenaires ParisTech», financements du RTRA Digiteo et des Labex Digicosme, LMH et SMART, campagne interne à l'Institut Mines-Télécom «Futurs et ruptures», appels à projets interdisciplinaires de l'Idex Paris-Saclay, allocations de l'école doctorale EDITE, ...

le LIP6, Labex SMART) avec des partenaires parisiens. Enfin, il est clair que l'intégration à l'Université Paris-Saclay nécessitera une grande capacité d'adaptation de nos personnels et de nos structures internes — même si l'aspect recherche est probablement celui qui sera le moins impacté dans la période 2015–2019 — qui seront soumis à rude épreuve. La section C.2 ci-dessous présente quelques pistes de réflexion autour de ces thèmes qui seront bien sûr à approfondir, notamment durant la phase qui nous sépare de la reconduction, proposée, de l'unité en 2015.

Le dernier aspect concerne le **positionnement thématique** du LTCI sur un domaine, celui de **la société de l'information et du numérique**, identifié comme stratégique au niveau national [3]. Ce fort soutien, assis sur une analyse des attente économiques et sociétales fortes autour des STIC, constitue manifestement un atout majeur pour le LTCI. Néanmoins la conjoncture est difficile et il est peu vraisemblable d'imaginer un soutien plus significatif qu'il ne l'a été au cours de la dernière décennie de la part des pouvoirs publiques et on peut au contraire légitimement tabler sur une érosion lente des moyens disponibles au niveau des tutelles de l'unité pour la période 2015–2019. De même, sur certains domaines au cœur de l'activité du LTCI comme les télécommunications, l'industrie nationale, ou même européenne, montre des signes de faiblesses préoccupants. La section «Objectifs» ci-dessous comporte plusieurs proposition d'actions (renforcer l'interdisciplinarité, nouer des partenariats stratégiques) qui tiennent compte de ces incertitudes pesant sur l'avenir du domaine phare du LTCI.

## C.2 Objectifs stratégiques

Cette section présente les objectifs majeurs de l'unité pour la période 2015–2019 ainsi que certaines pistes pour s'en rapprocher. Il ne s'agit en l'état que de possibilités qui vont demander un nouveau travail de consultation et de construction au sein de l'unité d'ici à son renouvellement en 2015.

L'identification de ces objectifs stratégiques résulte à la fois de l'analyse de la situation actuelle du LTCI et de ses perspectives présentée ci-dessus, des points saillants apparus lors du du processus de réflexion stratégique engagé au niveau des quatorze équipes de l'unité ainsi que de la prise en compte des grandes orientations de l'établissement Télécom ParisTech.

### C.2.1 Réussir l'intégration à l'université Paris-Saclay

Plus qu'un simple projet immobilier de déménagement, le déplacement de Télécom ParisTech dans sa future implantation de Palaiseau (livraison second semestre 2017) doit être envisagé comme un véritable projet d'intégration dans une construction plus ambitieuse (l'Université Paris-Saclay) qui se propose d'avancer vers la fédération et la mutualisation des forces des différents partenaires dans le respect de leurs identités propres.

Ce projet implique notamment une refonte totale des engagements de l'unité dans les formations de master ainsi que la sortie progressive, à partir de 2015 (avec un biseau jusqu'en 2017 pour les thèses débutées en 2014), de l'Ecole doctorale EDITE Informatique, télécommunications, électronique (ED130) que Télécom ParisTech co-animait avec l'Université Pierre et Marie Curie [4]. Comme souligné dans le paragraphe précédent, ce mouvement, inédit à l'échelle de Télécom ParisTech, comporte des risques, puisqu'il implique de mettre fin à des relations fructueuses établies de longue date, et sa réussite, en particulier pendant la phase de transition

3. «Information, communications et nanotechnologies» était un des trois axes mis en avant dans la Stratégie nationale de recherche et d'innovation en 2009 ; «Société de l'information et de la communication» est un des neufs Défis sociétaux identifiés dans l'Agenda stratégique France Europe 2020 en 2013.

4. Au moment de rédiger ce document, il ne nous est pas encore possible d'avoir une vision entièrement stabilisée des projets d'écoles doctorales et de masters Paris-Saclay pour la période 2015–2019 qui seront finalisés pour la fin de l'année 2013 uniquement. Il est d'ores et déjà acquis néanmoins que le LTCI sera associé très majoritairement à la future école doctorale STIC (dont l'Institut Mines-Télécom sera co-opérateur) et, plus marginalement, aux écoles doctorales Mathématiques et *Electrical, Optical & Bio Engineering*.

entre 2015 et 2017, est un des objectifs majeurs de la période tant pour l'établissement Télécom ParisTech que pour l'unité.

De la même façon, il importera de développer des collaborations renforcées et efficaces avec les autres unités du domaine STIC (et au delà) du site Paris-Saclay. Deux phases distinctes sont envisagées à cet égard. D'ici à 2017, Télécom ParisTech n'aura pas encore déménagé et la modalité principale d'interaction scientifique avec les partenaires du site de Saclay se fera sous la forme de projets transversaux inter-établissements. Le LTCI est en particulier fortement impliqué dans le RTRA Digiteo, le Labex Digicosme (Mondes numériques Données, programmes et architectures distribués) et de façon plus modeste dans le Labex LMH (Labex Mathématique Hadamard). Télécom ParisTech a par ailleurs joué un rôle moteur dans le montage de plusieurs projets soutenus dans le cadre de l'appel à projets structurants de l'Idex Paris-Saclay en 2013 (Institut de la société numérique, Plateforme Nanodesign) et est impliqué dans plusieurs projets qui pourraient être soutenus en 2014. Dans une seconde phase, à partir de 2017, il s'agira de préparer le mandat suivant de l'unité en envisageant les évolutions possibles pour le LTCI dans son nouveau contexte saclaysien.

Enfin, tout au long de la période qui vient il sera important de porter une attention particulière aux questions liées aux personnels. On sait en effet que tant le bouleversement des habitudes de travail que le manque de perspective d'amélioration rapide de la desserte en transports du site de Palaiseau (la ligne 18 de métro de surface depuis Massy est annoncée pour 2023) sont des facteurs qui peuvent fragiliser l'adhésion des personnels au projet. Au niveau de l'unité, nous veillerons en particulier à renforcer tous les aspects qui peuvent concourir au renforcement de la cohésion (meilleure diffusion de l'information, partage plus large des responsabilités, notamment avec les responsables des équipes) en utilisant également le potentiel des nouveaux locaux de Télécom ParisTech à partir de 2017, notamment pour favoriser l'organisation d'événements fédérateurs au niveau du laboratoire (workshops, séminaires, colloques).

### C.2.2 Soutenir les jeunes chercheurs

Le développement, l'épanouissement puis la consolidation de la carrière des jeunes chercheurs contribuent évidemment à la visibilité scientifique du laboratoire mais demandent des attentions et aménagements particuliers qui ne sont pas nécessairement ancrés dans le mode de fonctionnement du LTCI et de Télécom ParisTech

Un effort spécifique va être entrepris dans l'accompagnement de jeunes chercheurs pour la constitution de dossiers de bourses et/ou de mécénats d'excellence comme les projets ERC, à l'échelle européenne, les chaires Idex du site Paris-Saclay, ou pour des financement privés comme les Google Awards.

De manière plus modeste, nous souhaitons revoir la communication interne à l'unité de façon à mieux partager l'information concernant, notamment, les modes de financement de thèses qui se sont multipliés ces dernières années et ont fini par devenir illisibles pour les nouveaux arrivants.

Il nous semble également indispensable de mieux faire connaître l'activité des chercheurs du LTCI, notamment des nouveaux arrivants, au sein de la population étudiante de Télécom ParisTech. Il est clair que la configuration actuelle des locaux ne nous aide pas et que des opérations comme la Fête de la science ne rencontrent, à Télécom ParisTech, qu'un écho assez faible. A partir de 2017, nous envisageons d'utiliser le potentiel des nouveaux locaux pour organiser des événements autour du LTCI impliquant plus fortement la population des étudiants de Télécom ParisTech. Cette meilleure visibilité de la recherche du LTCI peut, entre autres facteurs, contribuer à augmenter la proportion d'étudiants de Télécom ParisTech qui poursuivent leurs études en doctorat (pas nécessairement au LTCI), ce qui constitue un des objectifs stratégiques de Télécom ParisTech pour la période à venir.

### C.2.3 Renforcer l'interdisciplinarité

Par rapport à d'autres d'unités STIC de taille comparable, le LTCI se caractérise par une grande continuité thématique qui couvre un spectre large au sein du domaine des STIC, avec des aspects qui vont de la modélisation de la propagation dans des média physiques (antennes ou fibres optiques) jusqu'à des aspects qui relèvent en partie des mathématiques (méthodes algébriques pour la cryptographie par exemple). Cet atout n'est pas encore suffisamment exploité et les travaux les plus emblématiques de l'unité ne sont que rarement associés à des recherches impliquant les expertises de plusieurs équipes du LTCI.

Pour favoriser l'émergence de tels travaux, une première étape d'importance a constitué à identifier, dans le cadre de notre réflexion stratégique pour la période 2015–2019, des *Axes stratégiques d'établissement* susceptibles de fédérer largement nos forces de recherche, au delà des frontières d'équipes ou de départements, voire au delà de l'unité en prenant en compte les orientations stratégiques du département Sciences économiques et sociales (SES) de Télécom ParisTech (qui devrait, à partir de 2015, développer une dynamique propre en dehors du LTCI). Ces axes stratégiques sont décrits dans la section C.4 tandis que leur articulation avec les thématiques prioritaires des départements et des équipes est analysée et illustrée dans la section C.3.2.

Une question qui reste à approfondir est de savoir si certains de ces axes stratégiques peuvent également donner lieu à revisiter l'organisation interne de l'unité, par exemple en faisant apparaître des actions ou projets transversaux, réunissant plusieurs équipes de recherche autour d'un axe de travail. Cette option n'est néanmoins pas jugée prioritaire car peu réaliste compte tenu des difficultés actuelles liées au locaux (éparpillement des équipes sur trois sites distants) mais sera évaluée d'ici à l'emménagement dans les nouveaux locaux de Télécom ParisTech (en 2017).

Une action à plus court terme consiste à rechercher, parmi les unités et établissements du site Paris-Saclay, des partenaires susceptibles de s'impliquer sur des projets de grande envergure autour de ces axes stratégiques. Plusieurs contacts en ce sens sont en cours concernant, notamment, les axes «Big data» et «Très grands réseaux». L'Université Paris-Saclay fournit en effet un cadre très favorable au développement de projets interdisciplinaires. Ce soutien peut prendre la forme de grands projets structurants comme l'*Institut de la Société Numérique* (un des projets lauréats de l'appel Idex en 2013) dans lequel nous avons prévu de développer des recherches pluridisciplinaires impliquant des chercheurs du LTCI ainsi que des membres du département de SES de Télécom ParisTech. Une autre modalité d'action de l'Université Paris-Saclay consiste à soutenir l'interdisciplinarité par des actions plus ciblées (projets de recherche, allocations doctorales, soutien à des groupes de travail) qui sont bien adaptées à la mise en valeur de certaines expertises spécifiques d'excellence du LTCI comme l'imagerie médicale (en lien avec l'*Electrical engineering* et les Sciences du vivant) ou l'information quantique (en lien avec la Physique).

Ces pistes représentent un enjeu particulièrement significatif pour l'unité dans la mesure où, s'il est incontestable que son champ d'action prioritaire se situe dans le domaine des STIC, l'unité développe également des recherches, de niveau reconnu, aux frontières des STIC sur des thèmes qui recoupent de grand défis sociétaux comme l'énergie (amélioration de l'efficacité énergétique des réseaux de communication), la mobilité (réseaux véhiculaires), la santé (imagerie médicale) ou le domaine spatial (communications et imagerie satellitaires).

### C.2.4 Constituer des alliances stratégiques

La très grande majorité des partenariats tant académiques qu'industriels du laboratoire repose pour l'instant sur des relations directes de chercheurs de l'unité. Il en résulte, notamment en ce qui concerne les partenariats internationaux, un manque de lisibilité et une difficulté à soutenir ces partenariats au delà des invitations régulières de chercheurs étrangers au LTCI (selon une politique, gérée au niveau de Télécom ParisTech, qui nous amène à soutenir une quinzaine de séjours sabbatiques de courte durée par an ainsi que quelques séjours à l'étranger de personnels de l'unité).

Pour la période à venir, nous souhaitons tout d'abord, donner un cadre plus pérenne à des relations structurantes qui existent déjà avec certains partenaires industriels du laboratoire, en particulier à travers les outils que sont les chaires et laboratoires communs ; cet aspect sera développé dans le paragraphe suivant.

En ce qui concerne les collaborations académique nationales, en particulier au sein de l'Université Paris-Saclay, nous souhaitons là encore, lorsque c'est possible et pertinent, donner un cadre à des relations plus structurantes notamment à travers des outils comme les fédérations de recherche CNRS — des contacts sont en cours notamment sur les thèmes des réseaux et de l'information quantique — mais également en tirant parti des outils proposés, soit directement par l'Idex Paris-Saclay soit par les projets associés (Labex Digicsome et LMH, Equipex Digiscope, IRT SystemX, projets ISN et NanoDesign).

Le même objectif se décline à l'international en s'appuyant sur des relais qui peuvent être des structures existantes — unités de recherche mixtes internationales (Laboratoire Poncelet à Moscou, CMM au Chili notamment) ou hôtels à projets internationaux (des contacts sont par exemple en cours avec le LIAMA en Chine sur le thème des réseaux) — mais également sur les ressources de l'Institut Mines-Télécom, d'une part, et de l'Université Paris-Saclay, d'autre part, qui ont pour objectif de développer des politiques internationales volontaristes. L'institut Mines-Télécom a par exemple inauguré en juillet dernier un laboratoire de recherche commun avec quatre partenaires académiques sud-coréens (dont la KAIST) autour du thème de l'Internet des objets, projet qui pourrait à terme impliquer des chercheurs du LTCI. De même, Télécom ParisTech a pour ambition de contribuer à la politique internationale de l'Université Paris Saclay, ce qui derait nous permettre de développer des liens privilégiés avec certains des principaux partenaires académiques de l'unité en Chine (Jiao Tong à Shanghai, Tsinghua à Pékin), en Inde (Indian Institute of Science, Bangalore), aux Etats-Unis (Stanford, Carnegie Mellon), en Amérique du Sud (Universidad de la República, Uruguay) et en Europe (Politechnico de Turin et de Milan, UPC à Barcelone, Université d'Edimbourg…)

### C.2.5 Augmenter l'impact socio-économique de nos recherches

Le LTCI inscrit ses recherches dans un axe identifié comme prioritaire par les pouvoirs publics, notamment du fait de son fort impact attendu sur le développement économique national. Eu égard à cette ambition, il apparaît essentiel d'amplifier l'efficacité de l'unité dans les domaines du transfert et de l'innovation à travers des dispositifs adaptés. Cette orientation est cohérente avec la stratégie de l'école Télécom ParisTech qui a pour ambition d'être reconnue, au sein de l'Université Paris Saclay, pour son action en faveur de l'entrepreunariat et de l'innovation dans le domaine du numérique.

Une première direction envisagée consiste à **développer les chaires et laboratoires communs**. Les chaires et laboratoires communs consacrent tous les deux des relations pérennes entre des industriels et des chercheurs de confiance et de compétence éprouvées sur un périmètre scientifique donné. Les deux instruments procurent une grande souplesse dans l'utilisation des moyens qu'ils apportent, laissant une forme d'autonomie et d'initiative aux chercheurs, et garantissent surtout la visibilité (d'une durée minimale de trois ans) nécessaire à des travaux de recherche ambitieux. Les chaires n'ont en général pas d'implication directe en terme de valorisation ou de transfert puisqu'elles relèvent du mécénat mais permettent de rendre visibles les activités de l'unité en lien avec de grands défis sociétaux du domaine du numérique. A l'inverses, les laboratoires communs manifestent le caractère stratégique de certaines recherches et conduisent en général à une valorisation à court ou moyen terme des travaux par le partenaire industriel du laboratoire commun. Le montage de chaires bénéficie à Télécom ParisTech du fort soutien de la Fondation Télécom. Le LTCI compte proportionnellement peu de chaires (celles-ci sont plus nombreuses dans la partie de Télécom ParisTech qui relève des SHS) et six laboratoires communs actifs. Parmi les pistes envisagées figurent le lancement d'une seconde chaire sur le Big data, consacrée plus spécifiquement aux problématiques du commerce en ligne. En ce qui concerne les laboratoires communs, sont actuellement en discussion la concrétisation d'une col-

laboration de longue date avec Thales sur les réseaux mobiles ad-hoc ainsi que la pérennisation de nos relations avec Samsung autour du multimedia.

L'autre direction privilégiée consiste à **développer les actifs de propriété intellectuelle — brevets et logiciels –** pour lesquels l'action de l'unité peut être amplifiée[5]. Un premier pas important à été franchi début 2013 par Télécom ParisTech qui a introduit, en se basant sur les retours d'expérience des chercheurs qui avaient précédemment déposé des brevets au LTCI, une procédure simplifié dite *démarche conjointe publications brevets*. Le principe est de synchroniser les calendriers de publication académique et de dépôt de brevet en réduisant significativement le délai inhérent à la protection. Par ailleurs cette démarche vise également à susciter le réflexe d'intégrer au fil de la production scientifique un questionnement sur l'opportunité d'une protection de la propriété intellectuelle. Plus qu'une course systématique au nombre de brevets, il est souhaitable de mieux anticiper et faire fructifier le potentiel de valorisation. En ce qui concerne la valorisation, le LTCI devrait bénéficier, d'une part, d'un accord signé en 2013 entre l'Institut Mines-Télécom et France Brevets qui permet de déléguer la valorisation (à France Brevets) et, d'autre part, de la mise en place progressive du système d'innovation de l'Université Paris-Saclay et notamment d'une Société d'accélération de transfert de technologie propre au site Paris-Saclay. Par ailleurs, une voie possible de valorisation est le lancement de spin-offs, aspect sur lequel le LTCI a d'ores et déjà acquis une expérience positive (voir la table B.8 dans la partie I du bilan) sur laquelle nous souhaitons mieux communiquer, notamment en direction des doctorants qui sont des porteurs naturels de ce type de projets.

## C.3 Perspectives scientifiques

### C.3.1 Contenu et méthode

Trois visions stratégiques emboîtées, de granularité, de portée et de nature différentes sont présentées dans ce chapitre. Elles résultent toutes d'une consultation *bottom-up*, des équipes vers les départements, qui s'est déroulée sur une période de trois mois entre avril et juin 2013. Ce travail d'élaboration stratégique par équipe a également été mené à bien au niveau du département Sciences économiques et sociales (SES) de Télécom ParisTech. Enfin, l'ensemble des équipes et des départements — y compris le département SES — ont partagé leurs réflexions (notamment lors d'un séminaire commun qui a eu lieu début juillet 2013) en s'appuyant également sur les grandes orientations stratégiques de l'établissement Télécom ParisTech et de sa tutelle, l'Institut Mines-Télécom.

A l'issue de ce processus, il a été choisi de retenir trois types d'éléments. Tout d'abord, les **stratégies des équipes** sont présentées en détail dans le chapitre D. Ces réflexions stratégiques d'équipe s'articulent autour d'un canevas commun qui met en évidence des *expertises* qui décrivent l'activité actuelle de l'équipe, des *objectifs* qui correspondent aux orientations principales de la recherche de l'équipe pour la période 2015–2019 et enfin les *leviers* prioritaires d'action envisagés au niveau de l'équipe. Le deuxième élément constitutif de la stratégie scientifique se situe au niveau de chaque département pour lesquels on été définis des **axes stratégiques de département** qui fédèrent les expertises stratégiques des équipes du département. Les axes stratégiques des département sont présentés dans la section C.5. Enfin, ont également été définis des **axes stratégiques de l'établissement Télécom ParisTech** (abrégés en AXSE pour « axe stratégiques d'établissement » de façon à les différencier de ceux qui précèdent). Il est important de préciser que ces quatre axes stratégiques d'établissement ne partitionnent en rien toutes les activités de recherche du LTCI. Par ailleurs, il prennent également en compte la stratégie scientifique des équipes du département SES ainsi que les orientations stratégiques de Télécom ParisTech, raison pour laquelle ils sont qualifiés « d'établissement ». Ces axes stratégiques ont été identifiés comme présentant un fort potentiel de fédération de nos forces de

5. Une étude réalisée par l'Institut INS2I du CNRS en 2013 sur les laboratoires communs, brevets et spin-offs a permis de nous benchmarker avec les autres unités rattachées à l'INS2I nous situant plutôt dans la moyenne des laboratoires sur ces critères.

recherche — de façon transversale aux frontières d'équipes ou de département — autour de grands défis de la société numérique. Ces axes stratégiques (décrits ci dessous dans la section C.4) fournissent par ailleurs une grille de lecture accessible de nos orientations thématiques majeures partageable, notamment, avec nos partenaires industriels ou avec les acteurs publics.

Au niveau de la stratégie des équipes et des départements, un soin particulier a été apporté à fournir, pour chaque orientation thématique, des **éléments de dimensionnement** : nombre de chercheurs concernées, principales actions en cours, contrats ou projets liés à cette thématique, etc. Bien entendu, ces données ne fournissent qu'un ordre de grandeur, en général basé sur les chiffres observé en 2012, et n'ont pas une vocation prédictive pour la période 2015–2019.

## C.3.2 Vision synthétique

Dans le même objectif de dimensionner, d'étayer et de mettre en relation les différents éléments de la réflexion stratégique, sont présentés dans cette section les liens qui existent entre d'une part les axes stratégiques d'établissement et ceux des département et, d'autre part, entre ces derniers et les expertises des équipes.

### Axes stratégiques d'établissement

| | **Axes stratégiques d'établissement (AXSE)** | | | |
|---|---|---|---|---|
| **Axes stratégiques des départements** | ***AXSE 1. Big data : dynamique des données et des connaissances*** | ***AXSE 2. Très grands réseaux et systèmes*** | ***AXSE 3. Confiance numérique : sécurité, sûreté et risques*** | ***AXSE 4. Interactions réel-virtuel*** |
| **COMELEC** | | | | |
| Axe 1. Confiance numérique : sécurité physique et sûreté matérielle | | | X | |
| Axe 2. Débit à la demande, de la physique jusqu'au système | X | X | | |
| Axe 3. Flexibilité numérique : couche physique et intelligence intégrée | | X | | X |
| **INFRES** | | | | |
| Axes 1. Modélisation pour l'évaluation, la vérification, l'optimisation (réseaux, systèmes embarqués, systèmes distribués) | X | X | | |
| Axe 2. Systèmes large échelle, autonomie, systèmes dynamiques, systèmes non déterministes, nouveaux paradigmes architecturaux et protocoles | X | X | | |
| Axe 3. Sécurité et sûreté de fonctionnement :identité, protection des ressources, tolérance aux fautes, définition et vérification de mécanismes de sécurité | | | X | |
| Axe 4. Données, interactions, raisonnement | X | | | X |
| **TSI** | | | | |
| Axe 1. Modélisation : méthodes et applications (images, 3D, video, audio, signaux physiologiques) | X | | | X |
| Axe 2. Apprentissage statistique et intelligence artificielle | X | | | |
| Axe 3. Interactions entre les activités humaines et le virtuel | | | | X |

TABLE C.2 – Positionnement des axes stratégiques d'établissement vis-à-vis des axes stratégiques des départements.

La tableau C.2 présente la façon dont les axes stratégiques d'établissement reposent sur les axes stratégiques identifiés au niveau de chacun des trois départements du LTCI. Ce tableau met notamment en évidence le caractère interdisciplinaire des AXSE qui impliquent assez largement les différents départements en s'appuyant sur leurs expertises qui sont d'essence beaucoup plus disciplinaires (voir les sections C.4 et C.5 pour le détail des axes identifiés). L'axe «Big data» est celui qui s'appuie sur le plus grand nombre d'axes département (6 sur 10), sans surprise, compte tenu de l'omniprésence des défis liés au « passage à l'échelle » dans la société numérique. Par ailleurs, cet axe recouvre également de manière forte des aspects liés aux disciplines du département SES de Télécom ParisTech (en particulier, l'économie et la sociologie) autour de problématiques liées, notamment, à l'utilisation de données personnelles (thème de la chaire «Valeurs et politiques des informations personnelles» lancée en 2013 avec Télécom SudParis et Télécom Ecole de management).

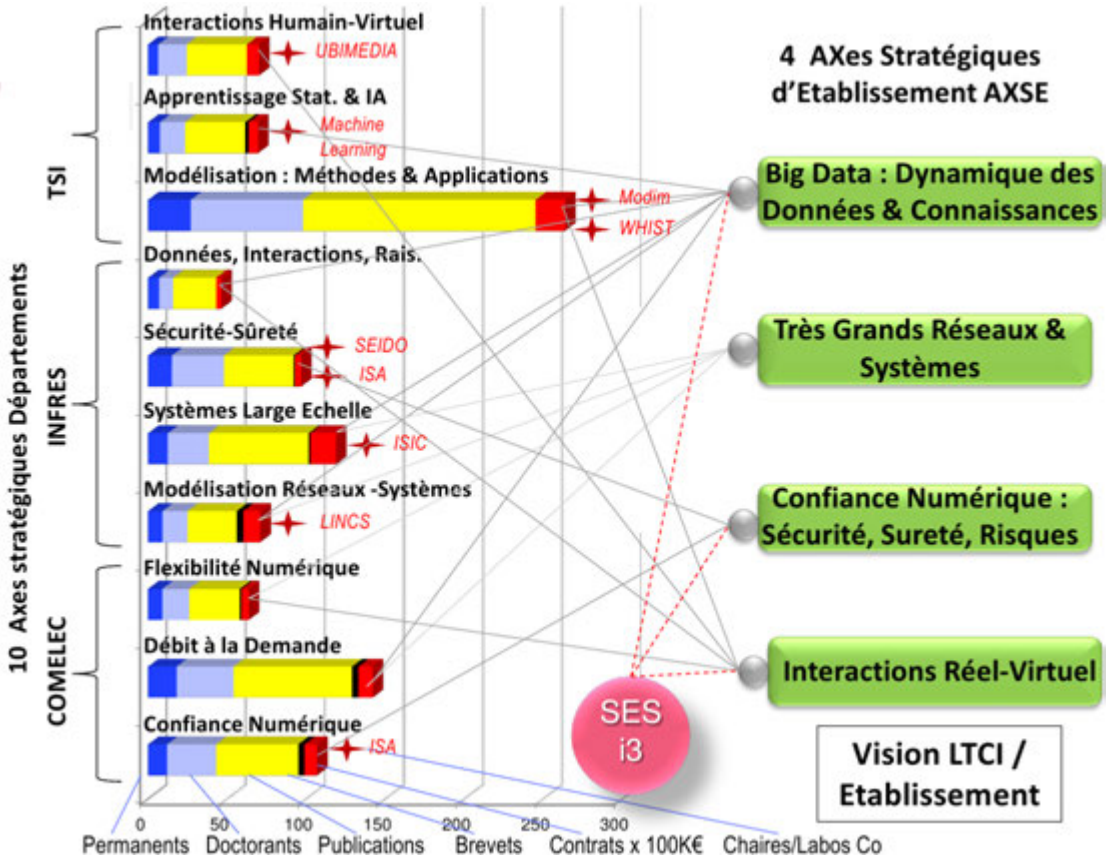


FIGURE C.1 – Fondations des axes stratégiques d'envergure : Les Axes stratégiques des départements étayés par leurs forces de recherche et leurs productions scientifiques.

La figure C.1 complète le tableau C.2 sur deux aspects. Elle permet tout d'abord de visualiser le nombre et l'étendue des fondations scientifiques des AXSE en matérialisant les connexions entre les AXSE et les axes stratégiques des départements. On note par exemple que « Big data » est le plus connecté, « Confiance numérique » le moins. Ont été rajoutées sur la figure C.1 les interactions pluridisciplinaires, au-delà des départements STIC du LTCI avec le département SES de Télécom ParisTech (I3 faisant référence au projet d'UMR porté par ce département).

Le figure C.1 comporte également une synthèse graphique des données de dimensionnement des axes de départements qui figurent dans la section C.5. Chaque graphique en bâton illustre les données de dimensionnement de l'axe stratégique de département correspondant en figurant les différents éléments : forces de recherche (permanents, doctorants), productions

scientifiques en 2012 (publications, brevets-licences, contrats, chaires et laboratoires communs). Les chaires et laboratoires communs existants se rapportant à un axe stratégique sont représentés individuellement par des étoiles. Un facteur d'échelle de 100 k€ rend compatible les ordres de grandeur des montants de contrats de recherche avec les autres données. Cette représentation permet une comparaison rapide des différents axes stratégiques de département sur l'ensemble des critères retenus pour le dimensionnement.

On note sur la figure C.1 que les données de dimensionnement des axes stratégiques de départements sont à peu près comparables, sauf pour ce qui concerne l'axe du département TSI intitulé *Modélisation : méthodes et applications*. Cette singularité correspond à des caractéristiques propres au domaine du traitement du signal et des images que sont, d'une part, l'importance donnée à la modélisation et, d 'autre part, le spectre large des signaux envisagés : audio, vidéo, 3D, imagerie médicale, ...(voir également la figure C.4) Cette singularité mérite d'être considérée plus en détail — Provient elle d'une granularité trop importante au niveau des axes du département TSI ? Nécessite t'elle la mise ne place d'un cinquième axe d'établissement plus disciplinaire sur ce thème ? — lors de la phase de mise en place opérationnelle de la stratégie à la fois au niveau de l'unité et au sein de Télécom ParisTech.

#### Axes stratégiques du département Communications et électronique

Le tableau C.3 et la figure C.2 présentent un travail analogue portant cette fois sur les axes spécifiques au département Communications et réseaux (COMELEC). Les fondations scientifiques des trois axes stratégiques du département COMELEC reposent sur des combinaisons des *expertises stratégiques* des cinq équipes de COMELEC, C2S, ComNum, GTO, RFM et SEN-LabSOC (ces expertises étant décrites plus précisément dans le chapitre D).

A l'instar de la figure C.1, la figure C.2 présente le dimensionnement des fondations scientifiques des axes stratégiques du département COMELEC sous forme de barres verticales dont la taille reflète directement les forces de recherche (permanents, doctorants) et les productions scientifiques (publications, brevets, contrats).

Les degrés de connexion des trois axes stratégiques du département aux dix expertises des équipes sont très semblables. Sept des dix expertises stratégiques présentent des données de dimensionnement relativement homogènes. L'expertise « Design methodologies for AMS nanoscale systems », de l'équipe C2S souffre d'un effectif très réduit de 1.1 permanent. Une réflexion devra être entreprise pendant la période 2015–2019 sur les manières de traiter au mieux cette situation. Les expertises de l'équipe SEN-LabSOC, dont les données de dimensionnement traduisent l'importance désormais acquise par cette équipe, lui confèrent un rôle central dans l'axe « Confiance numérique » du département COMELEC et, par la suite, un rôle important dans l'axe stratégique d'établissement du même nom (cf. figure C.1).

#### Axes stratégiques du département Informatique et réseaux

Le tableau C.4 détaille les fondations scientifiques des quatre axes stratégiques du département INFRES, en lien avec les expertises stratégiques des équipes du département (RMS, S3, IC2, SR, MIC2).

L'axe « Systèmes large échelle » s'appuie sur le plus grand nombre d'expertises stratégiques (5 sur 11). A l'inverse, l'axe « Données interactions raisonnement » est celui qui repose intégralement sur les deux expertises stratégiques de l'équipe IC2.

La figure C.3 représente, comme précédemment, les liens entre les axes stratégiques du département INFRES et les expertises stratégiques de ses équipes, ainsi que les éléments de dimensionnement associés. L'expertise stratégique « Modèles stochastiques et géométrie aléatoire » de l'équipe MIC2 appelle une attention particulière, eu égard à sa taille très faible (sur tous les critères) par rapport aux 10 autres expertises.

| | **Axes stratégiques du département COMELEC** | | |
|---|---|---|---|
| **Expertises stratégiques des équipes** | ***Confiance Numérique : sécurité physique et sûreté matérielle-logicielle*** | ***Débits à la demande : de la physique jusqu'au système*** | ***Flexibilité numérique : couche physique et intelligence intégrée*** |
| **RFM Radio-fréquences et micro-ondes** | | | |
| 1. Conception et modélisation conjointes de sous-systèmes RF, antenne et canal | X | X | |
| 2. Large bande sans fil, antenne, circuits, métamatériaux | | X | X |
| **GTO Télécommunications optiques** | | | |
| 1. Traitements numériques et matériels du signal adaptés aux propriétés spécifiques et à l'architecture des systèmes optiques | | X | X |
| ES2. Propriétés fonctionnelles des dispositifs photoniques | | X | |
| **C2S Circuits et systèmes de communication** | | | |
| 1. Smart analog et mixed signals (AMS) design for wireless systems | | X | X |
| 2. Design methodologies for AMS nanoscale systems | X | X | |
| **SEN-LabSOC Electronique des systèmes numériques complexes** | | | |
| 1. Architecture et méthodes de conception de systèmes intégrés et embarqués | X | X | |
| 2. Analyse de la sécurité et de la sûreté des architectures des circuits et systèmes embarqués | X | | |
| **ComNum Communications numériques** | | | |
| 1. Codage algébrique et théorie des réseaux de points : codage de réseau, sécurité par la couche physique, MIMO, stockage distribué | X | X | X |
| 2. Théorie de l'information : gestion de l'interférence, communications interactives, grandes matrices aléatoires | | X | X |
| Nombre de permanents | 12 | 18 | 9 |
| Nombre de doctorants | 31 | 36 | 17 |
| Publications en 2012 | 52 | 75 | 32 |
| Brevets licences en 2012 | 4 | 4 | 1 |
| Contrats commencés en 2012 x 100 k€ | 7,8 | 9 | 4,66 |
| Chaires | 0 | 0 | 0 |
| Labos communs | 1 (Morpho) | 0 | 0 |

TABLE C.3 – Positionnement des axes stratégiques du département COMELEC vis-à-vis des expertises stratégiques de ses cinq équipes : RFM, GTO, C2S, SEN-LabSOC et ComNum.

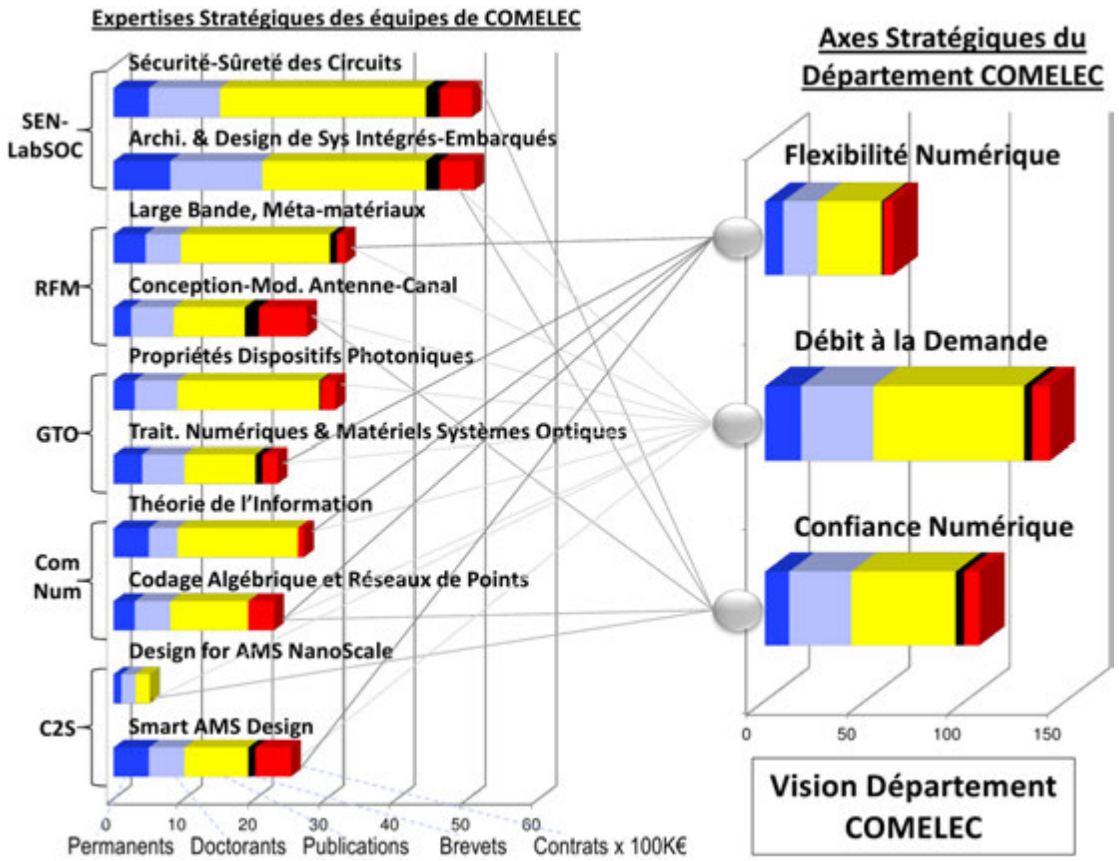


FIGURE C.2 – Fondations des Axes stratégiques du département COMELEC : les expertises stratégiques (ES) de ses cinq équipes, avec leurs forces de recherche et leurs productions scientifiques.

| | **Axes stratégiques du département INFRES** | | | |
|---|---|---|---|---|
| **Expertises stratégiques des équipes** | **Modélisation pour l'évaluation, la vérification et l'optimisation (réseaux, systèmes embarqués, systèmes distribués)** | **Systèmes large échelle, autonomie, systèmes dynamiques, systèmes non déterministes, nouveaux paradigmes architecturaux et protocoles** | **Sécurité et sûreté de fonctionnement : identité, protection des ressources, tolérance aux fautes, cryptographie et cryptographie quantique, définition et vérification de mécanismes de sécurité** | **Données, interactions et raisonnement** |
| **RMS Réseaux, mobilité et services** | | | | |
| 1. Pervasive access (wireless and optical networks) | | X | | |
| 2. Very large networks (future internet, cloud, internet of things, smart grid). | | X | | |
| 3. Modeling and performance evaluation (traffic engineering, optimization, metrology and testbed) | X | | | |
| **S3 Systèmes, logiciels et services** | | | | |
| 1. Systèmes répartis (informatique autonomique, intergiciels, algorithmique répartie, génie logiciel, sûreté, langages, vérification) | | X | | |
| 2. Systèmes embarqués critiques (ingénierie des modèles, systèmes de systèmes, sûreté, vérification, temps réel) | X | | X | |
| **IC2 interaction, cognition et complexité** | | | | |
| 1. Web (big) data management and mining | | X | | X |
| 2. Human-computer interaction and visualization | | | | X |
| **SR Sécurité et réseaux** | | | | |
| 1. Information quantique | | | X | |
| 2. Sécurité des réseaux | | | X | |
| **MIC2 Mathematiques de l'information, des communications et du calcul** | | | | |
| 1. Mathématiques discrètes | | | X | |
| 2. Modèles stochastiques et géométrie aléatoire | X | X | | |
| Nombre de permanents | 9,1 | 12,5 | 15 | 7 |
| Nombre de doctorants | 16 | 26 | 33 | 9 |
| Publications en 2012 | 31 | 63 | 44 | 27 |
| Brevets licences en 2012 | 4 | 1 | 1 | 0 |
| Contrats commencés en 2012 x 100 k€ | 10,9 | 16,3 | 3,75 | 3,3 |
| Chaires | 0 | 1 (ISIC) | 0 | 1 (Modim) |
| Labos communs | 2 (LINCS & SEIDO) | 0 | 2 (ISA & SEIDO) | 1 (Ubimedia) |

TABLE C.4 – Positionnement des axes stratégiques du département INFRES vis-à-vis des expertises stratégiques de ses cinq équipes : RMS, S3, IC2, SR, MIC2.)

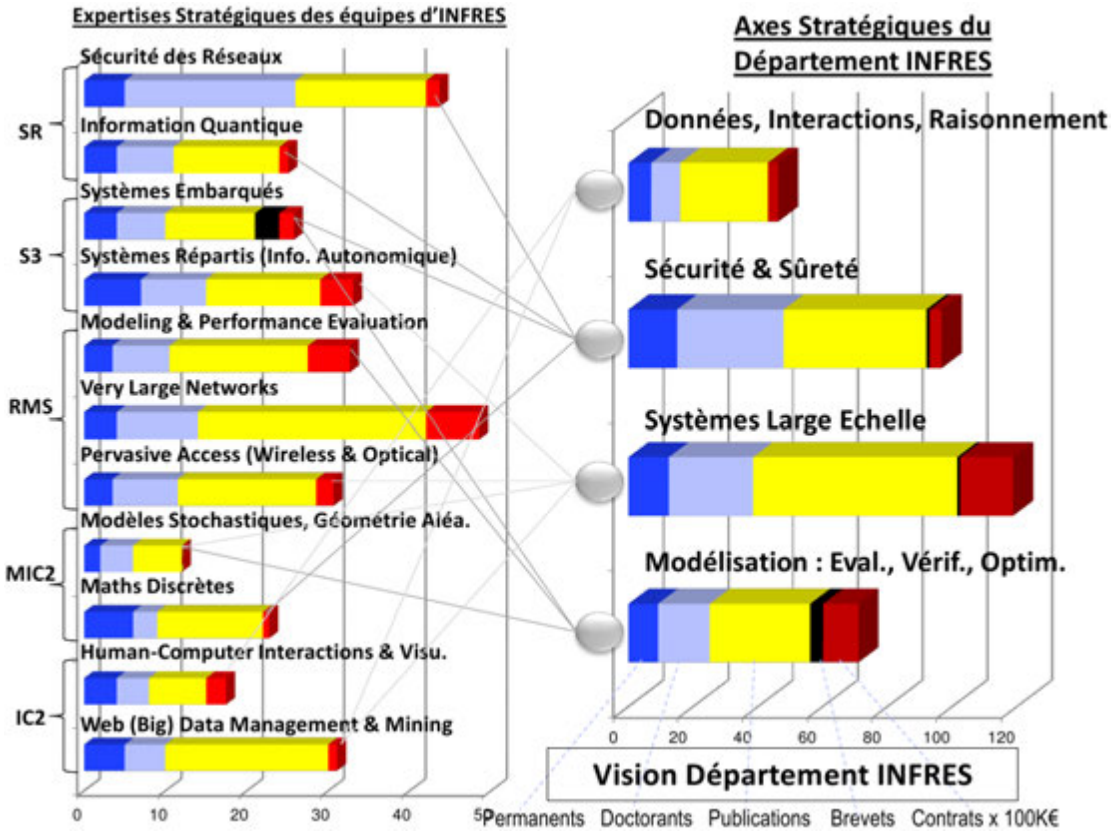


FIGURE C.3 – Fondations des Axes stratégiques du département INFRES : Les expertises stratégiques de ses cinq équipes, avec leurs forces de recherche et leurs productions scientifiques.

**Axes stratégiques du département Traitement du signal et des images**

| | Axes stratégiques du département TSI | | |
|---|---|---|---|
| **Expertises stratégiques des équipes** | **Modélisation : méthodes et applications (images, 3d, vidéo, audio, signaux physiologiques)** | **Machine learning : apprentissage statistique et intelligence artificielle** | **Interaction entre les activités humaines et le virtuel** |
| **AAO Audio, acoustiques, ondes** | | | |
| 1. Analyse, modèles et représentations pour le traitement des signaux audio | X | | |
| 2. Méthodes et modèles pour le traitement des signaux multimodaux et physiologiques | X | | |
| **TII Traitement et interprétation des images** | | | |
| 1 & 2. Modèles pour les Images et le 3D et Applications | X | | |
| 2. Indexation et apprentissage : pour les images et volumes numériques. | | X | |
| **MM Multimedia** | | | |
| 1. Nouveaux modes de compression, représentation et diffusion multimédia immersif | X | | |
| 2. Interactions et communications multimodales | | | X |
| **STA Statistiques et applications** | | | |
| 1. Statistique pour l'ingénierie en STIC | | X | |
| 2. Machine Learning | | X | |
| 3. Modélisation et simulation | X | | |
| Nombre de permanents | 27 | 7,5 | 6,5 |
| Nombre de doctorants | 71 | 16 | 18 |
| Publications en 2012 | 174 | 38 | 38 |
| Brevets licences en 2012 | 0 | 2 | 0 |
| Contrats commencés en 2012 x 100 k€ | 18,55 | 5,97 | 7,69 |
| Chaires | 1 (MODIM) | 1 (ML) | 1 (MODIM) |
| Labos communs | 2 (WHIST, UBIMEDIA) | 0 | 0 |

TABLE C.5 – Positionnement des axes stratégiques du département TSI par rapport aux expertises stratégiques de ses quatre équipes : AAO, TII, MM et STA.

Le tableau C.5 détaille les fondations scientifiques des trois axes stratégiques du département TSI, en référence aux expertises stratégiques des quatre équipes du département (AAO, TII, MM et STA). L'axe « Modélisation : méthodes et applications » s'appuie sur le plus grand nombre d'expertise stratégiques (5 sur 9) et est partagé par toutes les équipes du département. L'axe stratégique « Interactions entre les activités humaines et virtuelles » correspond uniquement à l'expertise stratégique de la partie de l'équipe MM qui travaille sur ce type de sujets.

La figure C.4, analogue dans son principe à celles déjà commentées des départements COMELEC et INFRES, fournit des éléments quantitatifs sur les axes stratégiques du département ainsi que leurs liens avec les expertises des équipes. La figure C.4 suggère qu'un accompagnement particulier devra être apporté sur la période 2015–2019 à la croissance de l'expertise de l'équipe AAO « Méthodes et modèles pour le traitement des signaux multimodaux et physiologiques » qui repose sur des forces comparativement faibles. L'expertise « Indexation et apprentissage » de l'équipe TII correspond à des compétences historiques qui ont plutôt vocation à s'intégrer ou s'associer à d'autres expertises («Modélisation» et «Machine learning», notamment). La figure C.4 montre également que la taille importante de l'axe « Modélisation : méthodes et applications » déjà signalée ci-dessus à propos des axes stratégiques d'établissement correspond, en grande partie, aux expertises principales de l'équipe TII.

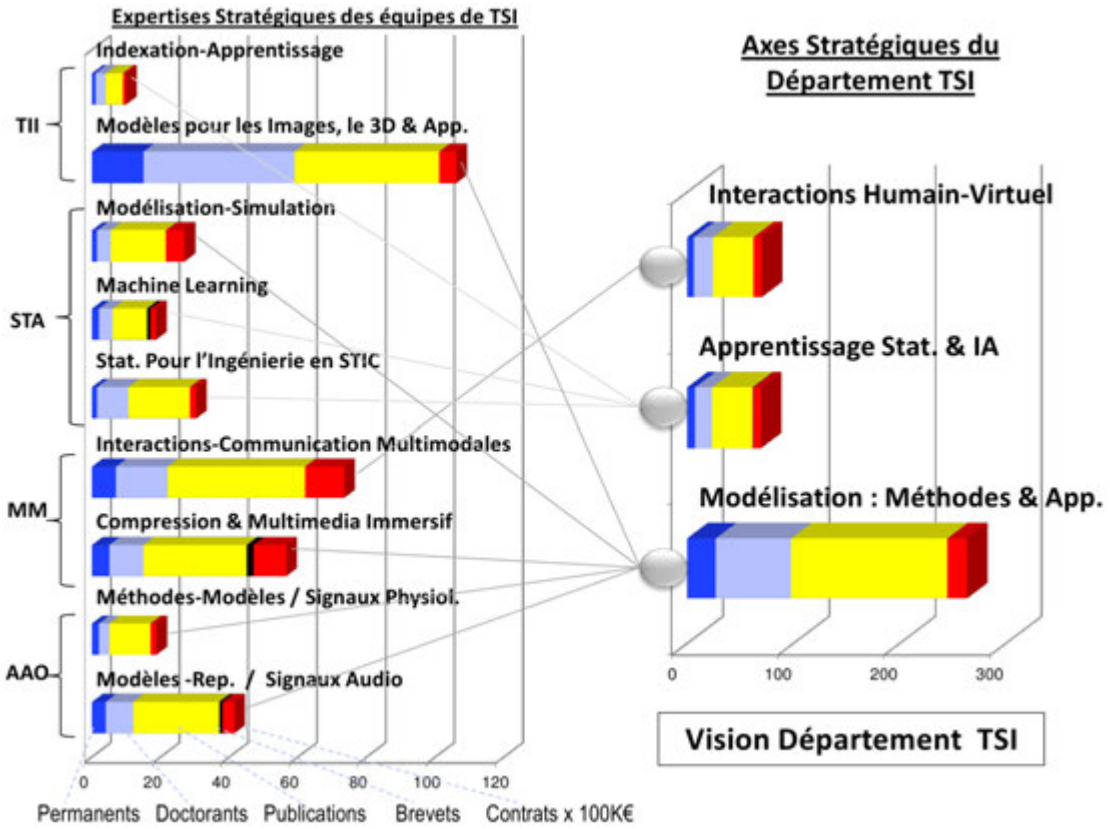


FIGURE C.4 – Fondations des Axes stratégiques du département TSI : Les expertises stratégiques de ses quatre équipes, avec leurs forces de recherche et leurs productions scientifiques.

## C.4 Axes stratégiques d'établissement

### C.4.1 Big data : dynamique des données et des connaissances

Le terme de *Big data* est dorénavant utilisé couramment pour désigner un ensemble de défis liés à l'omniprésence des données dans la sphère socio-économique. On peut citer, notamment, les réseaux sociaux, les nouveaux systèmes d'information de l'entreprise, la gestion «intelligente» des villes, des réseaux de transport, des réseaux énergétiques ou des systèmes de santé. La façon dont s'effectue la science est elle même est influencée par cet espoir d'exploiter les données, désormais largement disponibles, pour effectuer de nouvelles découvertes.

Pour ne développer qu'un seul des ces exemples, il est incontestable qu'une véritable révolution des systèmes d'information de l'entreprise est d'ores et déjà en cours. Les bases de données utilisées, provenant de sources diverses y compris d'activités enregistrées sur le Web ou les réseaux sociaux, comportent désormais des informations personnelles très détaillées sur les clients et leurs activités qui s'ajoutent à des données plus classiques sur les fournisseurs ou l'entreprise elle même. L'entreprise dispose de masses de données qui transforment le degré de précision du marketing amont, permettent d'optimiser prix et campagnes de ventes et d'accélérer les cycles de ventes tout en diminuant la prise de risques dans les décisions stratégiques. Cet exemple montre d'ailleurs que ces progrès technologiques s'accompagnent de questions d'une importance considérable dont la résolution ne relève pas uniquement de questions technologique — Quelle est la part de confidentialité qui doit rester attachée au données ? — Est-il possible et souhaitable de maintenir une certaine forme d'anonymat, par exemple, dans les échanges sur le Web ou les réseaux sociaux ?

Le Big data porte l'espoir d'extraire des informations toujours plus pertinentes à partir de masses de données toujours croissantes et de moins en moins structurées. Au paradigme plus traditionnel de la base de données centralisée et au contenu soigneusement validé se substituent des sources multiples d'information, le plus souvent stockées à distance dans le réseau, et de qualité plus difficilement contrôlable (logs d'activité sur le Web, messages échangés sur les réseaux sociaux, images ou vidéos partagées ou capturées par des dispositifs de surveillance, etc.)

La question majeure posée par le Big data est celle du **passage à l'échelle**. D'une part, avec des questions qui relèvent plus du domaine de l'**analyse de données** et d'autre part avec des défis soulevés par la gestion même du **volume de données**. Sur ce second aspect, les problématiques sont en fait multiples avec des données remarquables non seulement par leur taille, plusieurs ordres de grandeur supérieurs à ce qu'un serveur et son système de gestion de base de données traditionnel peut gérer, mais également par leur vélocité c'est-à-dire la rapidité à laquelle elles sont produites et, dans certains cas, la rapidité à laquelle le flux de données doit être traité. La diversité des données elle-même constitue un défi et leur mode de stockage décentralisé introduit des contraintes d'accès qui impactent fortement les traitements qu'il est possible d'effectuer. Comment, **optimiser et paralléliser le traitement de l'information** dans ces conditions ? Quelles sont les **limites fondamentales en termes de stockage**, d'accès, ou de préservation de la confidentialité associées aux différents modes de stockage en réseau ?

Enfin, un autre grand défi est celui de la compréhension des données : indépendamment des performances qu'il est possible d'obtenir avec des techniques de traitement totalement automatisées, de nombreuses applications requièrent que le résultat du traitement puisse être compris, illustré ou questionné par des opérateurs humains (on pense à la médecine par exemple). Peut on **représenter des données** peu structurées et de natures diverses (textes, textes structurés, images, vidéos) ? Comment extraire leur signification ou leur sémantique ? Comment **visualiser** des milliers de résultats sur un écran et comment les exploiter ? Peut on amener plusieurs analystes à interagir de concert à travers des interfaces innovantes de façon à partager les interprétations ou la compréhension des données ?

Comme on le constate, les thématiques liées au Big data couvrent un spectre particulièrement large dont il serait vain de prétendre les traiter entièrement au sein du LTCI. Néanmoins, le tableau C.2 et la figure C.1 montrent que l'unité agrège des forces de recherche éprouvées sur

différents aspects du Big data, tant sur des thèmes plus liés à l'analyse de données (machine learning, indexation d'images, extraction de connaissances, visualisation de données) que sur des thèmes liés à l'accès au données (recherche d'information, stockage distribué, réseaux de capteurs). Par ailleurs, plusieurs équipes ont choisi de faire figurer dans leurs objectifs stratégiques les questions liées au passage à l'échelle, direction qui s'est concrétisée notamment avec le démarrage de la chaire *Machine Learning for Big Data* qui regroupe notamment des expertises issues des équipes STA (département TSI) et IC2 (INFRES). Par ailleurs, comme indiqué précédemment le Big data soulève également des questions légales ou économiques liées en particulier à la régulation inhérentes à l'explosion de l'utilisation de données personnelles. Sur ces questions, le LTCI bénéficie de l'environnement favorable du département SES de Télécom ParisTech (et plus généralement à terme du projet d'UMR I3 qu'il porte) avec, notamment, une chaire, créée en 2013, au niveau de l'Institut Mines-Télécom, centrée sur la problématiques des informations personnelles (soutenue par l'Imprimerie nationale, BNP Paribas, Dassault Systèmes et la CNIL).

### C.4.2 Très grands réseaux et systèmes

Les réseaux de demain [6] doivent connecter un vaste ensemble hétérogène qui va des objets (mobiles) communicants (comprenant senseurs, actuateurs, smartphone ou voiture connectée) au cloud (on parle de plus en plus souvent d'internet des objets) et se donnent les objectifs suivants :

- Une forte **densité d'objets intelligents et communicants intégrés** dans les environnements de la vie quotidienne, à la maison, au travail, dans la ville, dans les transports, drainant des informations hétérogènes et en grande quantité, qu'il s'agit d'échanger, de traiter et d'exploiter au mieux pour en tirer connaissances et services ;
- Une **interopérabilité entre des objets, des terminaux et des systèmes de technologies** et de marchés disparates, permettant un partage des infrastructures et la mise au point de services composites trans-domaines à haute valeur ajoutée ;
- Une **production et un traitement** des contenus et des données largement **distribués** sur des infrastructures virtualisées (réseau et cloud) ;
- Des services **pertinents et personnalisés** pour les utilisateurs et les communautés virtuelles, utilisateurs et communautés étant eux-mêmes producteurs de contenus et de services ; des services adaptés aux contextes de l'environnement et de l'utilisateur ;
- Des services **fiables et de confiance, résilients**, avec une qualité d'expérience améliorée et déterministe, y compris la capacité de délivrer des services à haut niveau de criticité (santé, sécurité ...) ;
- La **qualité d'usage** en situation de mobilité placée au cœur des solutions.

Ces objectifs requièrent de lever des défis scientifiques et technologiques qui suivent en **matière d'architecture, de capacité et de consommation des réseau, mais aussi de lien entre réseau et applications** :

- Des **réseaux d'accès omniprésents**, avec les performances requises pour chaque application, tirant partie de technologies hétérogènes. Cet **accès universel** doit à la fois faire appel à des réseaux spontanés entre objets y compris mobiles, aux réseaux cellulaires, aux WLAN et proposer de manière automatisée, dynamique et optimisée la solution d'accès la plus adéquate, et **garantir une réelle transparence à l'utilisateur** aux moyens mobilisés, avec une **continuité de service préservée** quand ces moyens évoluent dynamiquement ou lorsque la connectivité est sporadiquement inexistante.

6. Ce texte s'inspire d'une vision des « Très grands réseaux » co-écrite par Olivier Audouin (Alcatel-Lucent) et Gérard Mémmi, responsable du département Informatique et réseaux, utilisée notamment lors du lancement de SystemX dont Télécom ParisTech est l'un des co-fondateurs.

- Repenser **l'organisation de l'architecture réseau**, la **distribution** et l'implémentation des fonctions et hiérarchies, entre réseau domestique ou privé, réseau d'accès/métropolitain et réseau cœur, pour l'adapter au contexte de l'explosion des objets communiquants en périphérie, à l'intégration avec les ressources de calcul et de stockage du cloud, tout en prenant en compte les questions de **consommation énergétique globale**.
- La **gestion de la complexité des réseaux** inhérente à la quantité d'objets à gérer, à la multiplicité des technologies mises en œuvre, à la multiplicité des services et de leurs exigences. Cette gestion exige de faire appel à des **approches « autonomiques»** visant à automatiser les opérations des réseaux, approches qui ont la difficile tâche de concilier optimisation et fiabilité en présence d'un grand nombre de degrés de liberté et d'aléas possibles (tels que ceux liés au trafic, aux pannes des objets, etc). Les questions **algorithmiques, de modélisation, et de stratégie d'exploitation et de partage d'informations distribuées** et parcellaires sont parmi les enjeux scientifiques sous-jacents.
- Les réseaux « centrés-contenus », dont les approches de codage, de routage, de différenciation du trafic, de stockage intermédiaire, basées sur une **capacité de reconnaissance des différents types de contenus** doivent répondre aux changements de mode de production, de distribution et de consommation de contenus, et à l'emprise hégémonique des contenus vidéos sur le trafic.
- La **virtualisation des infrastructures réseau** et l'intégration de la gestion des ressources réseau et des services associés avec les ressources et les services informatiques.
- Les **intergiciels permettant l'abstraction des services rendus par les objets**, l'autodécouverte de ces services et de leurs sémantiques, leur composition, leurs interopérations au travers d'interfaces ouvertes et leur combinaisons automatisées avec des services de communication et du Web. Des approches cognitives permettant plusieurs niveaux d'abstraction des services, qui devront trouver leur correspondance avec l'interprétation des besoins de l'utilisateur devront être conduites. Une **mobilité des services sur différents terminaux, objets et infrastructures** sous-jacents doivent être assurées pas ces couches d'abstraction.
- Des **interfaces enrichies et ouvertes entre réseau et application** permettant, d'une part, d'assurer des performances réseaux individualisées telles que requises par l'application et, d'autre part, de conférer au réseau, grâce à l'information qu'il détient sur le contexte, l'environnement, le profil de l'utilisateur, d'avoir un rôle déterminant dans les propositions de services pertinents et configurés de manière appropriée.
- Un **débit accru des réseaux** par plusieurs ordres de grandeur, ce qui demande des approches spécifique des questions de **consommation énergétique** et de gestion des **interférences**, notamment pour les réseaux sans fil. Ces demandes simultanées nécessitent une **optimisation jointe globale** associée à une gestion **inter-couches**.

L'étendue des défis inhérents aux très grands réseaux requiert donc un éventail large de compétences au sein du domaine des STIC. Le LTCI est bien positionné sur ces thèmes à travers ses départements COMELEC et INFRES (voir table C.2 et figure C.1). Une des spécificités de l'unité est de pouvoir contribuer à la fois sur des aspects liés de la couche physique, avec par exemple des travaux novateurs sur les transmissions optiques menés en collaboration entre les équipes GTO et ComNum du département COMELEC, mais également sur les aspects caractéristiques des couches les plus élevées du modèle OSI (on pense par exemple aux travaux sur la caractérisation aveugle du trafic généré par des applications Web menés dans l'équipe RMS). Les deux départements partagent d'ailleurs une vision commune sur le fait que les nouvelles modalités de communications envisagées pour les futurs réseaux de télécommunications (cf. l'exemple de la radio «cognitive») nécessitent de plus en plus une recherche largement interdisciplinaire qui remplace l'approche plus traditionnelle d'un système de communications construit en couches étanches par des experts qui travaillent séparément, chacun dans son domaine.

### C.4.3 Confiance numérique : sécurité, sûreté et risques

Au cœur de la **société numérique**, la **confiance** des utilisateurs dans les technologies de l'information conditionne de manière critique le lien entre **société et technologie** et constitue de ce fait un lieu d'enjeu économique et politique d'importance.

Ce lien se traduit de façon réglementaire : peut-on autoriser tous les usages nés des nouvelles technologies ? Comment contrôler l'utilisation qui peut être faite des données confidentielles et protéger les libertés individuelles ? Ces questions de régulation et d'usage constituent d'ailleurs un axe de réflexion majeur au sein du département SES de Télécom ParisTech.

Le maintien du lien de confiance se traduit également en termes techniques, et fait ressortir deux exigences fondamentales : la **sûreté** — Les commandes sont-elles exécutées conformément aux attentes techniques ? — et la **confidentialité** — Les données échangées sont-elles protégées structurellement de toute forme d'intrusion, surtout malveillante ?

Le premier point concerne en premier lieu les fonctions critiques qui touchent à la sécurité des personnes, dans le transport ou la santé notamment. Comment garantir techniquement qu'un système numérique fonctionnera sans défaillance et exécutera les actions attendues sans erreur, dans des contextes de plus en plus complexes où la meilleure décision est parfois ambiguë ? **Analyse de propriétés, vérification, tolérance aux fautes, certification, auto-guérison, preuves de fonctionnement** touchent l'ensemble de la chaîne numérique, depuis l'écriture et l'exécution des programmes jusqu'à l'implémentation matérielle et la fiabilité des systèmes. L'ensemble de ces éléments font l'objet de recherches au LTCI, à la fois, dans les équipes SR et S3 du département INFRES (dans des contextes qui vont des applications réseaux aux systèmes embarqués), mais également au sein d'une équipe comme SEN-LabSoc (COMELEC) qui étudie la résilience vis à vis des défauts matériels des composants.

Le lien de confiance repose également sur la protection inconditionnelle des données, dans un contexte où les échanges numériques se font à l'intérieur de réseaux de plus en plus ouverts. Assurer l'intégrité des données sur l'ensemble de la chaîne de communication nécessite de couvrir techniquement les **étapes protocolaires, la certification, le cryptage, le contrôle des flux à l'intérieur du réseau** ainsi que le traitement intègre des données dans les systèmes de traitement numérique. Au LTCI ces thèmes sont abordés à la fois sous l'angle du cryptage, notamment pour les applications biométriques (avec des recherches menées au sein de l'équipe MIC2 dans le cadre du laboratoire commun avec Morpho *Identity & Security Alliances*) mais également du point de vue de la robustesse vis à vis des attaques matérielles (par exemple par analyse de consommation) au sein de l'équipe SEN-LabSoC du département COMELEC.

### C.4.4 Interactions réel-virtuel

Cet axe stratégique couvre toute la palette des **interactions entre l'humain et le monde numérique**, allant de la **synthèse** de ce monde numérique, qu'il soit photo-réaliste où qu'il s'abstraie des références au monde réel, jusqu'aux techniques permettant l'interaction entre l'humain et le numérique, en passant également par l'analyse de ces interactions, et en englobant les interactions entre humains via une médiation numérique. Les problématiques s'étendent jusqu'aux réseaux de capteurs interagissant avec le corps.

Ce thème des interactions réel-virtuel est probablement celui sur lequel la distance qui sépare les travaux de recherche et les applications dans le domaine du numérique est la plus faible, tant sont grandes les attentes en la matière. Que l'on pense aux interfaces tactiles, à l'utilisation de la synthèse d'images 3D dans l'industrie du spectacle et des jeux, à la robotique domestique, voire aux avatars animés, il s'agit d'autant de situations rencontrées dans la vie courante qui mettent en jeu des techniques ou des dispositifs technologiques très avancés. Dans ce contexte, le place d'un laboratoire de recherche comme le LTCI est avant tout de contribuer aux connaissances de base qui permettent d'envisager de nouvelles ruptures dans le domaine (modélisation mathématiques des volumes et des objets, modélisation de la dynamique gestuelle ou des comportements émotionnels, etc.) Le LTCI est également impliqué dans des projets pilotes qui visent à démontrer la pertinence de nouveaux usages inédits de ces recherches comme le projet d'Equipex

Digiscope (Idex Paris-Saclay).

Ce thème des interactions entre le réel et le virtuel fédère plusieurs expertises disciplinaires des équipes et départements du LTCI (cf. table C.2 et figure C.1) concernant notamment :

- la **synthèse d'images et la réalité virtuelle**, afin de permettre la manipulation interactive de mondes virtuels par le biais de méthodes mathématiques de représentation et de modélisation des objets 3D, des volumes (maillages) ou des textures,
- le développement de nouveaux **principes et modes d'interaction** (en particulier surfaces sensitives),
- l'adaptation des techniques de **visualisation de l'information** et des méthodes interactives de fouille de données,
- la réalisation **d'avatars ou agents conversationnels** susceptible d'exprimer eux mêmes des intentions et émotions, ainsi que de reconnaître l'état émotionnel de l'utilisateur
- le développement d'une **intelligence de l'interaction** par des formes d'adaptation de l'environnement aux besoins de l'utilisateur selon son rôle, son comportement, ses actions, son humeur, ses émotions, etc.
- **« l'incarnation » des interfaces** entre l'homme et la machine à partir de capteurs physiologiques (travaux sur les interfaces cerveaux-machines notamment),
- Les **interactions numériquement médiées** entre humains, par exemple en travail collaboratif, en vidéoconférence ou en télé-présence,
- **l'interaction ambiante**, avec l'environnement immédiat de la personne, l'interaction gestuelle, 3D « en l'air » (Kinect, etc.) ou 2D sur la surface d'objets aussi divers que les murs, le mobilier, les objets domestiques, les vêtements, le corps...

## C.5 Axes stratégiques des départements

Dans cette section sont présentés les axes stratégiques des départements qui fédèrent et organisent avec une granularité moins fine, à l'échelle d'un département — soit cinq équipes pour les départements COMELEC et INFRES et quatre pour TSI —, les orientations thématiques majeures des équipes qui le compose. L'articulation entre ces axes stratégiques de département et les thématiques des équipes sur lesquels ils reposent a déjà été abordée de façon globale dans la section C.3.2 ci-dessus.

Les axes stratégiques de département sont donc décrits ci-dessous de façon synthétique dans la mesure où les thématiques sur lesquelles ils s'appuient seront développées en détail, au niveau de chaque équipe, dans le chapitre suivant. Sont également rappelées pour mémoire (sous forme de tableaux) les éléments de dimensionnent des axes stratégiques de département qui ont été résumés de façon illustrée dans la section C.3.2.

A la différence des axes stratégiques d'établissement présentés dans la section C.4, les axes de département peuvent être considérés comme réalisant une partition des thématiques du département avec deux nuances d'importance. Tout d'abord, certains thèmes de recherche peu représentés peuvent ne pas transparaître dans les axes de département, du fait de leur granularité, sans que cela n'enlève rien à la qualité des travaux menés sur ces thèmes (ces cas spécifiques sont discutés dans les documents stratégiques des équipes concernées). Par ailleurs, si les axes de département partitionnent les thématiques, ils ne constituent pas pour autant des regroupements d'équipes dans la mesure où il est fréquent qu'une même équipe, voire un même chercheur, contribue significativement à au moins deux axes de département.

### C.5.1 Communications et électronique (COMELEC)

**Responsable** Bruno Thédrez

**Taille** 39 enseignants/chercheurs et chercheurs, 4 ingénieurs de recherches, 5 permanents en soutien

| **1. Confiance numérique : sécurité physique et sûreté matérielle-logicielle** |
|---|
| **Forces de recherche** |
| *12 permanents, 31 thèses en cours en 2012 ; équipes impliquées : RFM, C2S, SEN-LabSoc, ComNum* |
| **Expertises stratégiques impliquées** |
| *RFM 1. Conception et modélisation conjointes de sous-systèmes RF, antenne et canal*<br>*C2S 2. Design methodologies for AMS nanoscale systems*<br>*SEN-LabSoc 1. Architecture et méthodes de conception de systèmes intégrés et embarqués*<br>*SEN-LabSoc 2. Analyse de la sécurité et de la sûreté des architectures des circuits et systèmes embarqués*<br>*ComNum 1. Codage algébrique et théorie des réseaux de points : codage de réseau, sécurité par la couche physique, MIMO, stockage distribué* |
| **Descripteurs** |
| **Nombre de publications (revues et conférences) en 2012** *52*<br>**Montant des contrats de recherche en 2012** *780 k€*<br>**Brevets et licences en 2012** *4*<br>**Alliances stratégiques** *Labo commun avec Morpho* |
| **2. Débits à la demande : de la physique jusqu'au système** |
| **Forces de recherche** |
| *18 permanents, 36 thèses en cours en 2012 ; équipes impliquées : RFM, GTO, C2S, SEN-LabSoc, ComNum* |
| **Expertises stratégiques impliquées** |
| *RFM 1. Conception et modélisation conjointes de sous-systèmes RF, antenne et canal*<br>*RFM 2. Large bande sans fil, antenne, circuits, métamatériaux*<br>*GTO 1. Traitements numériques et matériels du signal adaptés aux propriétés spécifiques et à l'architecture des systèmes optiques*<br>*GTO 2. Propriétés fonctionnelles des dispositifs photoniques*<br>*C2S 1. Smart analog et mixed signals (AMS) design for wireless systems*<br>*C2S 2. Design methodologies for AMS nanoscale systems*<br>*SEN-LabSoc 1. Architecture et méthodes de conception de systèmes intégrés et embarqués*<br>*ComNum 1. Codage algébrique et théorie des réseaux de points : codage de réseau, sécurité par la couche physique, MIMO, stockage distribué*<br>*ComNum 2. Théorie de l'information : gestion de l'interférence, communications interactives, grandes matrices aléatoires* |
| **Descripteurs** |
| **Nombre de publications (revues et conférences) en 2012** *75*<br>**Montant des contrats de recherche en 2012** *906 k€*<br>**Brevets etlicences en 2012** *4* |
| **3. Flexibilité numérique : couche physique et intelligence intégrée** |
| **Forces de recherche** |
| *9 permanents, 17 thèses en cours en 2012 ; équipes impliquées : RFM, GTO, C2S, ComNum* |
| **Expertises stratégiques impliquées** |
| *RFM 2. Large bande sans Fil, Antenne, Circuits, Métamatériaux*<br>*GTO 1. Traitements numériques et matériels du signal adaptés aux propriétés spécifiques et à l'architecture des systèmes optiques*<br>*C2S 1. Smart analog et mixed signals (AMS) design for wireless systems*<br>*ComNum 1. Codage algébrique et théorie des réseaux de points : codage de réseau, sécurité par la couche physique, MIMO, stockage distribué*<br>*ComNum 2. Théorie de l'information : gestion de l'interférence, communications interactives, grandes matrices aléatoires* |
| **Descripteurs** |
| **Nombre de publications (revues et conférences) en 2012** *32*<br>**Montant des contrats de recherche en 2012** *466 k€*<br>**Brevets et licences en 2012** *1* |

TABLE C.6 – Axes stratégiques du département Communications et électronique (COMELEC).

Le département **Communications et électronique** concentre ses activités sur les couches matérielles des technologies de l'information. A la façon des entreprises «sans usine» (fabless), le département conçoit des architectures et des algorithmes de communication point à point où à relais, ainsi que des architectures de circuits électroniques qu'il teste ensuite dans le cadre de réalisations expérimentales en laboratoire. Ses activités se partageront dans la période à venir sur trois grands axes stratégiques.

**Axe Stratégique 1. Confiance Numérique : sécurité physique et sûreté matérielle-logicielle**

Toutes les activités sociétales et économiques du domaine du numérique reposent sur des prérequis de sécurité particulièrement exigeants : des failles dans les systèmes d'authentification ou de protection des données pourront conduire au rejet des technologies numériques dans de nombreux secteurs d'activités. Du fait de son impact, le thème de la confiance numérique regroupe plusieurs sujets de recherche au sein du département COMELEC :

- Développement de contre-mesures protégeant les circuits contre les attaques par canaux cachés (consommation, rayonnement) sur la base d'analyses mathématiques et expérimentales.
- Protection des communications sans fil exploitant les fluctuations et l'aspect statistique du canal radio
- Utilisation de données distribuées, tant pour les communications radio que pour le stockage à l'intérieur d'un nuage d'ordinateurs. La confidentialité dans ce cas est obtenue en réduisant l'information mutuelle entre l'émetteur et l'attaquant en dessous des limites fondamentales permettant la reconstitution des données communiquées ou stockées.

La confiance repose également sur la fiabilité et la certification. Le développement de méthodes formelles combinées à des simulations avancées doit conduire à la conception rapide d'architectures électroniques sans faille pour les Systems-on-Chip. En parallèle, des méthodes et des outils pour la conception d'architectures de circuit sont développés de façon à concevoir des circuits fiables à partir de composants présentant de façon probabiliste des défaillances arbitraires.

**Axe Stratégique 2. Débits à la Demande : de la physique jusqu'au système**

La formidable accélération des communications fixes et mobiles depuis l'avènement du téléphone portable s'est durablement installée dans les usages et façonne **un monde de plus en plus consommateur de technologies de l'information et des télécommunications**.

L'augmentation des vitesses de communications et des quantités d'information, l'intégration dans des univers de plus en plus miniaturisés et mobiles d'une quantité croissante de technologies du multimédia réclament un effort technologique à de nombreux niveaux :

- L'interface analogique/numérique des systèmes embarqués est une des clés d'entrée dans le monde des communications numériques sans fil. Le département COMELEC traite le signal depuis sa forme radio (antenne, mélangeurs microondes, ...) jusqu'à sa conversion analogique pour atteindre des performances de vitesse et de précision aux limites des technologies.
- Le département prépare en parallèle de nouvelles architectures de systèmes embarqués reconfigurables compatibles avec les normes à venir — LTE-A, 5G — dotées de capacités de calcul supérieures à 100 GOPS, sous forte contrainte de puissance consommée.
- En télécommunication fixe, l'intérêt du département porte sur les systèmes de transport optiques passifs (PON) chez l'abonné, fonctionnant sous contrainte de coût à des débits proches du Gigabit/s, et sur les réseaux dorsaux où les nouveaux défis se décrivent en terabit/s par longueur d'onde.
- Après le succès des codes spatiaux-temporaux, la croissance des débits en communications sans fil sera portée par une utilisation optimisée du média de propagation, avec une focalisation de la recherche sur les canaux à interférence.

**Axe Stratégique 3. Flexibilité numérique : couche physique et intelligence intégrée**

La performance actuelle des circuits numériques leur permet d'embarquer des algorithmes de plus en plus sophistiqués qui facilitent leur pénétration dans des domaines très variés. En particulier, leur capacité de réponse en temps réel offre de nouvelles voies d'exploration pour les futurs systèmes d'information et de communications.

- Au niveau des circuits, la réduction de la jigue temporelle où la synchronisation fine des horloges sera atteinte par contrôle algorithmique. Associées à des architectures reconfigurables, les optimisations seront décidées par calcul en temps réel de façon à réduire la consommation, ou prendre en compte les résultats de mesure de capteurs intégrés. Ces évolutions seront particulièrement exploitées en radio-logicielle et en radio opportuniste.
- Au niveau des composants, les algorithmes de décision temps réels agiront sur des antennes reconfigurables pour modifier leur lobe de diffraction ou leur profil spectral, ou compenser des défauts rédhibitoires par de la pré- ou de la post- distorsion.
- En communication fixe, le département développe des traitements algorithmiques post-réception de plus en plus sophistiqués pour éliminer les problèmes de dispersion ou de polarisation et bientôt de non-linéarité en fibre qui limitent les débits.
- En communication mobile, l'allocation de ressource, le codage seront de nouveaux lieux d'application des algorithmes temps réel qui seront exploités notamment pour le traitement des canaux à interférence.
- L'agilité apportée par l'algorithmie temps-réel ouvre des perspectives exploitables pour des architectures de réseau inter-couches. Cette approche sera utilisée pour la gestion des bits et des paquets dans des liens optiques reconfigurables.

## C.5.2 Informatique et réseaux (INFRES)

**Responsable** Gérard Memmi

**Taille** 50 enseignants/chercheurs et chercheurs, 3 ingénieurs de recherches, 4 permanents en soutien

Le tableau C.7 résume les principales caractéristiques des axes stratégiques du département INFRES qui sont au nombres de quatre. Ces axes stratégiques correspondent souvent au respect de contraintes de haut niveau parmi lesquelles il faut compter bien entendu performance, disponibilité ou intégrité des données (axe 4), mais aussi sécurité, sûreté de fonctionnement (axe 3), mobilité (qui implique non déterminisme), et plus récemment maîtrise de la consommation énergétique.

Les systèmes étudiés, conçus (axe 2) ou analysés et évalués (axe 1) sont souvent critiques (pouvant même mettre la vie de l'homme en danger — par exemple, dans les applications liées au transport ou à l'énergie), et bien sûr, comprennent toutes sortes d'architectures de réseaux ou de logiciels. Ces systèmes sont toujours de nature distribuée et de plus en plus souvent de grande taille, posant des problèmes aigus de passage à l'échelle qui imposent de nouveaux traits architecturaux (tels l'autonomie ou l'internet des objets) ou de nouveaux algorithmes et protocoles (axe2). Cette «grande taille» de système s'exprime au moins sur trois dimensions : son nombre de composants (axe 2), la quantité de données manipulées, acquises ou visualisées (axe 4), le nombre d'utilisateurs en attente de performances à un moment donné (axe 1) et d'un niveau de sécurité adéquat (axe 3).

**Axe Stratégique 1. Modélisation pour l'évaluation, la vérification et l'optimisation (réseaux, systèmes embarqués, systèmes distribués)**

La modélisation et l'évaluation de performance pour les réseaux constitue une composante historiquement forte des recherches menées au département. Plus récemment, ce domaine de

| **1. Modélisation pour l'évaluation, la vérification et l'optimisation (réseaux, systèmes embarqués, systèmes distribués)** |
|---|
| **Forces de recherche** |
| *9.5 EC, 16 doctorants, équipes impliquées : RMS, S3, MIC2* |
| **Expertises stratégiques impliquées** |
| *RMS 3. Modeling and performance evaluation*<br>*S3 2. Systèmes Embarqués critiques*<br>*MIC2 2. Modèles stochastiques et géométrie aléatoire* |
| **Descripteurs** |
| **Nombre de publications (revues et conférences) en 2012** *31*<br>**Chaires et laboratoires communs** *LINCS, SEIDO*<br>**Montant des contrats de recherche en 2012** *1087 k€*<br>**Brevets et licences en 2012** *Un brevet et trois logiciels licences APP*<br>**Alliances stratégiques** *LIP6, INRIA, IRT SystemX, Alcatel, EDF* |
| **2. Systèmes large échelle, autonomie, systèmes dynamiques, systèmes non déterministes, nouveaux paradigmes architecturaux et protocoles** |
| **Forces de recherche** |
| *12.5 EC, 26 doctorants, 1 émérite, 1 associé ; équipes impliquées : RMS, S3, IC2, MIC2* |
| **Expertises stratégiques impliquées** |
| *RMS 1 & 2. Pervasive access, Very large networks*<br>*S3 1. Systèmes répartis*<br>*IC2 1. Web (big) data management and mining*<br>*MIC2 2.Modèles stochastiques et géométrie aléatoire.* |
| **Descripteurs** |
| **Nombre de publications (revues et conférences) en 2012** *63*<br>**Chaires et laboratoires communs** *Chaire Ingénierie des systèmes complexes*<br>**Montant des contrats de recherche en 2012** *1627.8 k€*<br>**Brevets et licences en 2012** *Un brevet*<br>**Action de normalisation** *LISP à l'IETF*<br>**Alliances stratégiques** *Ecole Polytechnique, IRT SystemX* |
| **3. Sécurité et sûreté de fonctionnement : identité, protection des ressources, tolérance aux fautes, cryptographie et cryptographie quantique, définition et vérification de mécanismes de sécurité** |
| **Forces de recherche** |
| *12 EC, 2Cs, 33 doctorants, 1 émérite, 1 associé ; equipes impliquées : S3, MIC2, SR* |
| **Expertises stratégiques impliquées** |
| *S3 2. Systèmes embarqués critiques*<br>*SR 1 & 2. Information quantique, Sécurité des réseaux*<br>*MIC2 1. Mathématiques discrètes* |
| **Descripteurs** |
| **Nombre de publications (revues et conférences) en 2012** *44*<br>**Chaires et laboratoires communs** *ISA, SEIDO*<br>**Montant des contrats de recherche en 2012** *375.6 k€*<br>**Brevets et licences en 2012** *Un logiciel libre : Virmanel (mai 2012)*<br>**Alliances stratégiques** *LIAFA, EDF, Morpho, Cassidian*<br>**Spin-offs** *Ethertrust (secured smart card) et SeQureNet (sécurité quantique)* |
| **4. Données, interactions et raisonnement** |
| **Forces de recherche** |
| *6 EC, 1 C, 9 doctorants ; equipe impliquée : IC2* |
| **Expertises stratégiques impliquées** |
| *IC2 1 & 2. Web (big) data management and mining, Human computer interactions and vizualization.* |
| **Descripteurs** |
| **Nombre de publications (revues et conférences) en 2012** *27*<br>**Chaires et laboratoires communs** *Ubimedia, projet de chaire bigdata for E-commerce, participation aux chaires Modélisation des Imaginaires et Machine Learning*<br>**Montant des contrats de recherche en 2012** *327.8 k€* |

TABLE C.7 – Axes stratégiques du département Informatique et réseaux (INFRES).

recherche c'est étendu à des aspects liés à l'évaluation de la qualité de service et la modélisation non plus seulement de réseaux mais également de systèmes (en particulier de systèmes embarqués ou distribués) afin d'évaluer et de vérifier leurs propriétés fonctionnelles. Des outils innovants de simulation, de vérification ou de transformation ont été conçus à cet effet permettant de considérer des objets (réseaux, systèmes, logiciels) plus complexes ou de plus grande envergure. L'analyse débouche souvent sur des avancées en terme d'optimisation des objets considérés, ce qui constitue une valeur ajoutée importante à ce type de travaux plus amont de modélisation.

**Axe Stratégique 2. Systèmes large échelle, autonomie, systèmes dynamiques, systèmes non déterministes, nouveaux paradigmes architecturaux et protocoles**

La grande tailel des système est devenue un objet d'attention majeur dans le domaine de l'informatique et des réseaux. La croissance rapide du nombre de composants des systèmes a induit des enjeux forts en terme de durabilité, d'hétérogénéité et de latence. La croissance parallèle du nombre d'utilisateurs pose des questions ardues en terme de confidentialité et de sécurité. Dans beaucoup de cas, le passage à l'échelle ne peut plus continuer à s'effectuer via de simples ajustements et implique de repenser compléter les architectures de réseaux ou de systèmes existantes à travers la mise au point de nouveaux protocoles et algorithmes.

**Axe Stratégique 3. Sécurité et sûreté de fonctionnement : identité, protection des ressources, tolérance aux fautes, cryptographie et cryptographie quantique, définition et vérification de mécanismes de sécurité**

Les découvertes de failles dans les systmèmes informatiques et réseaux de communication sont devenues fréquentes et sont souvent reportées dans les journaux grand public. Les fraudes, la cybercriminalité ou le dévoilement d'informations personnelles constituent une des barrières les plus sérieuses au déploiement et à l'acceptation d'un vaste ensemble d'applications du domaine du numériques qui vont du e-commerce, à la voiture intelligente ne passant par la e-santé. L'analyse de vulnérabilité, la vérification de systèmes ainsi que de la résilience aux pannes constitue des enjeux majeurs de ce troisième axe stratégique du département.

**Axe Stratégique 4. Données, interactions et raisonnement**

Cette axe, malgré sa taille plus réduite, est intentionnellement séparé des trois autres axes afin de souligner l'attention particulière que nous souhaitons apporter à la visualisation, la structuration, la recherche et l'analyse des masses données qui sont désormais stockées de façon décentralisée et distribuée, souvent sur le Web, mises à jour en permanence par l'activité de millions d'utilisateurs voire de réseaux de capteurs de grande échelle. Les principaux challenges que nous nous sommes fixés au sein du département concernent l'extraction et la visualisation d'informations sémantiques à partir de masses de données faiblement structurées ainsi que l'interaction avec des équipements de plus en plus miniaturisés.

### C.5.3 Traitement du signal et des images (TSI)

**Responsables** Yves Grenier

**Taille** 41 enseignants/chercheurs et chercheurs, 2 ingénieurs de recherche, 6 permanents en soutien

Pour le département Traitement du signal et des images, les orientations thématiques des équipes se regroupent assez naturellement autour des trois axes principaux présentés de façon synthétique dans le tableau C.8.

Le premier de ces axes est d'une dimension très importante par rapport aux deux autres dans la mesure où il représente l'activité autour de laquelle s'est organisée le département TSI depuis

| **1. Modélisation : Méthodes et applications (images, 3D, vidéo, audio, signaux physiologiques)** |
|---|
| **Forces de recherche** |
| *27 EC, 71 thèses en cours en 2012* |
| **Expertises stratégiques impliquées** |
| *AAO 1. Analyse, modèles et représentations pour le traitement des signaux audio*<br>*AAO 2. Méthodes et modèles pour le traitement des signaux multimodaux et physiologiques*<br>*TII 1. Modèles pour les images et le 3D*<br>*TII 2. Large Spectre d'applications : biomédical, télédétection, photographie numérique, infographie*<br>*MM 1. Nouveaux modes de compression, représentation et diffusion multimédia immersif*<br>*STA 3. Modélisation et simulation* |
| **Descripteurs** |
| **Nombre de publications (revues et conférences) en 2012** *174*<br>**Chaires et labos communs** *Laboratoire Whist avec Orange ; Labo commun en compression sécurisée en cours de montage ; Participation aux labos communs UBIMEDIA, avec Alcatel-Lucent Bell Labs, et ISA, avec Morpho ; Participation à la chaire Modélisation des imaginaires*<br>**Montant des contrats de recherche en 2012** *1855 k€*<br>**Contributions à la normalisation** *Activités de standardisation collaborations avec Samsung (MPEG-U) et avec Canon (MPEG-DASH, MPEG HEVC)* |
| **2. Machine Learning : apprentissage statistique et intelligence artificielle** |
| **Forces de recherche** |
| *7,5 EC, 16 thèses en cours en 2012* |
| **Expertises stratégiques impliquées** |
| *TII 3. Indexation et apprentissage*<br>*STA 1. Statistique pour l'ingénierie en STIC*<br>*STA 2. Machine Learning* |
| **Descripteurs** |
| **Nombre de publications (revues et conférences) en 2012** *38*<br>**Chaires et labos communs** *Chaire Machine Learning for Big Data*<br>**Montant des contrats de recherche en 2012** *597 k€*<br>**Brevets et Licences en 2012** *1 brevet et 1 licence logicielle* |
| **3. Interaction entre les activités humaines et le virtuel** |
| **Forces de recherche** |
| *6,5 EC, 18 thèses en cours en 2012* |
| **Expertises stratégiques impliquées** |
| *MM 2. Interactions et communications multimodales* |
| **Descripteurs** |
| **Nombre de publications (revues et conférences) en 2012** *38*<br>**Chaires et labos communs** *Participation à la chaire Modélisation des Imaginaires*<br>**Montant des contrats de recherche en 2012** *769 k€* |

TABLE C.8 – Axes stratégiques du département Traitement du signal et des images (TSI).

une vingtaine d'années. Néanmoins, cette thématique reste très fortement porteuse sur l'avenir, à la fois par les compétences présentes dans le département, et par la diversité des signaux à traiter et leurs applications. C'est véritablement notre «cœur de métier» : le développement de méthodes mathématiques, d'algorithmes et de méthodes de traitement pour des signaux de nature très variée. Nos compétences reconnues sur certaines de ces applications (imagerie médicale et satellitaire, informatique graphique, signaux audio, vidéo notamment) font elles aussi partie des éléments d'identité forts du département TSI.

Le deuxième axe stratégique est porté par des enseignants-chercheurs et chercheurs dont la compétence est reconnue et le rayonnement international. Il s'ouvre aujourd'hui vers les problématiques à fort enjeu du « Big Data » et des traitements distribués qui constituent un des enjeux identifiés au niveau de l'établissement. Au delà de l'équipe STA, cette axe stratégique fédère des compétences plus spécifiques à certains type de signaux ou de données, notamment au sein des équipes TII (pour ce qui relève des images) et AAO (pour ce qui a trait au multimedia et aux signaux multimodaux en général).

Le troisième axe stratégique est de dimension plus réduite mais il s'est fortement renforcé au cours de la période précédente dans deux directions distinctes. D'une part, le recrutement de Catherine Pélachaud (DR CNRS) en 2008 a apporté un thème entièrement nouveau au LTCI, celui de l'informatique affective (*affective computing*), qui s'est fortement développé depuis et a conduit au recrutement récent de Chloé Clavel (Maître de Conférences) en 2012. Ces travaux se focalisent sur la modélisation des aspects émotionnels (non verbaux notamment) de la communication homme-machine et se fédèrent autour de la plateforme logicielle GRETA. Par ailleurs, le recrutement d'Alexandre Gramfort au sein de l'équipe AAO en 2013 amène cette équipe à développer ses travaux sur le thème de l'interaction basée sur l'analyse de signaux physiologiques, notamment dans le cadre d'interface cerveau-machine (*brain-computer interface*) — travaux menés en collaboration avec une équipe du CEA Neurospin.

**Axe Stratégique 1. Modélisation : Méthodes et applications (images, 3D, vidéo, audio, signaux physiologiques)**

Cet axe est consacré au développement de méthodes mathématiques et d'algorithmes destinés à permettre le traitement (analyse, synthèse, reconnaissance, interprétation) de signaux, d'images, de vidéo ainsi que d'objets tri-dimensionnel. Les compétences et contributions reconnues du laboratoire dans le domaine portent notamment sur les techniques de séparation de sources, la modélisation mathématiques de images, des textures et des volumes ou l'estimation de mouvement dans les séquences d'images.

En parallèle, le département souhaite maintenir une présence forte sur des applications spécifiques sur lesquelles il a déjà eu un impact reconnu. On pense en particulier aux travaux sur l'imagerie médicale, l'imagerie satellitaire et radar, les signaux physiologiques, la vidéo et bien sûr les signaux audio, expertise historique de l'équipe AAO. Le département, à travers les équipes TII et MM, souhaite également de développer son action dans les domaines de la photographie numérique et des nouveaux formats de diffusion vidéo (vidéo HDR et 3D).

**Axe Stratégique 2. Machine Learning : Apprentissage statistique et intelligence artificielle**

Il s'agit ici de travaux dans le domaine de l'apprentissage automatique, plutôt avec des approches statistiques, principalement au sein de l'équipe STA, mais également avec des travaux sur la fusion de données et de connaissances, en lien notamment avec l'interprétation des images médicales (dans l'équipe TII). Cet axe stratégique est appelé à se renforcer dans la période qui vient compte tenu du nombre croissant de domaines (industries du Web, marketing, sciences du vivant et de l'univers, etc.) où la collecte de masses d'information est devenue routinière, générant une demande forte, tant en enseignement qu'en recherche, autour de l'analyse et de l'interprétation de données. Les domaines de compétences reconnus du laboratoire incluent notamment les modèles graphiques et les méthodes bayésiennes, le ranking, l'apprentissage par renforcement ainsi que la fusion de données. Sur cet axe, il est notamment envisagé de développer les

synergies avec l'équipe IC2 du département INFRES qui travaille sur des sujets connexes, mais avec des points de vue différents (mouvement qui a déja été inité dans le cadre du montage de la chaire consacrée au Machine learning).

**Axe Stratégique 3. Interaction entre les activités humaines et le virtuel**

Cet axe de recherche déjà évoqué précédemment regroupe essentiellement des compétences issues des équipes MM et AAO. Une évolution notable au cours de la période écoulée concerne la disparition progressive de recherches sur des aspects plus spécifiquement liés à la parole — reconnaissance de la parole ou du locuteur et synthèse de parole bas débit — du fait du départ en retraite de plusieurs membres du département qui travaillaient sur ces thèmes. A priori ces départs ne seront pas directement remplacés même si les travaux menés en informatique affective s'appuient bien entendu également sur l'utilisation de techniques de traitement de la parole. Nous maintenons au contraire une expertise de bon niveau sur l'analyse de document et la reconnaissance d'écriture manuscrite. Au cours de la période à venir, la plateforme GRETA devrait prendre de l'ampleur nous permettant d'expérimenter, dans différents contextes, l'apport des modèles émotionnels développés au sein de l'équipe MM dans le cadre de situations de dialogue entre des utilisateurs humains et l'agent virtuel GRETA.

# Chapitre D

# Stratégie des équipes

Ce chapitre rassemble les orientations stratégiques de chacune des équipes pour la période 2015–2019. Chaque fiche stratégique d'équipe comporte les **expertises stratégiques** qui correspondent aux lignes de force actuelles de l'équipe qui apparaissent comme stratégiques du fait de leur impact, leur portée, leur caractère fédérateur et leur pertinence. Les **objectifs stratégiques** correspondent à une projection vers le futur qui questionne le maintien, le renforcement, ou la réorientation des expertises stratégiques, voire le développement de nouvelles expertises. Enfin, chaque fiche stratégique se conclut par des **leviers** d'action privilégiés permettant d'atteindre les objectifs de l'équipe. Bien entendu ce dernier point, correspond à des pistes de réflexion qu'il conviendra, pour certaines, de préciser ou d'adapter au cours de la période à venir.

Par ailleurs, comme cela a été fait pour les axes stratégiques de granularité plus importante présentés dans le chapitre précédent, chaque expertise est étayée par des données quantitatives ou des faits caractéristiques qui sont destinés à donner une idée de son dimensionnement. Les chiffres présentés fournissent un ordre de grandeur mais n'ont pas nécessairement de vocation prédictive du fait de la variabilité d'un année sur l'autre ainsi que des évolutions envisagées. Enfin, il est bien entendu que la pertinence d'une expertise ne se mesure pas à l'aune de son dimensionnement, même si c'est une donnée pertinente. En particulier, il convient de tenir compte des différentes tailles (en terme de personnel) des équipes qui varient dans un rapport de un à trois (cf. table B.1 dans la partie I).

# D.1 Radiofréquences et microondes (RFM)

**Responsable** Xavier Begaud.

**Taille** 7 EC, 1 I, 3 postdocs, 15 doctorants.

## D.1.1 Expertises stratégiques

1. **Conception et Modélisation Conjointes de sous-systèmes RF, Antenne & Canal**

   **Force de Recherche** 8 permanents (30%), 1 post-doctorant, 6 doctorants.

   **Production de recherche en 2012** 10 publications ; 2 brevets ; montant agrégé des contrats de recherche commencés en 2012 : 677 k€.

2. **Large bande sans Fil, Antenne, Circuits, Métamatériaux**

   **Force de Recherche** 8 permanents (55%), 2 post-doctorants, 5 doctorants.

   **Production de recherche en 2012** 21 publications ; 1 brevet ; montant agrégé des contrats de recherche commencés en 2012 : 120 k€.

**Equipement Stratégique** Pour anticiper l'arrivée des technologies et réseaux « beyond 4G » le groupe s'appuie sur une plateforme de caractérisation de circuits et d'antennes millimétriques.

**Conception et Modélisation Conjointes de sous-systèmes RF, Antenne & Canal** Le groupe RFM est pionnier dans l'approche statistique des antennes. Il contribue aussi activement à des programmes pluridisciplinaires internationaux dans lesquels la conception et la modélisation conjointe sont mis en œuvre : (Spectra (circuit/antenne), Lexnet (capteur/canal), PhyLaws, Select). L'approche conjointe est aussi dans des travaux communs avec les références académiques et industrielles du domaine (CEA-Leti (BAN), Orange (Interaction ondes/personnes), COST IC1004 (Cooperative Radio Communications for Green Smart Environments), COST RFCSET (RF/Microwave Communication Subsystems for Emerging Wireless Technologies).

**Large bande sans Fil, Antenne, Circuits, Métamatériaux** RFM est aussi pionnier sur la conception d'antenne large bande à Métamatériaux. Il participe activement à des programmes pluridisciplinaires nationaux et internationaux (ANR (SAFAS), FP7 (Select), MIMiCRA EDA, NanoDesign) dans lesquels l'expertise en conception d'antennes ou de circuits large bande est recherchée et associée le plus souvent à la conception de métamatériaux pour repousser les limites de l'état de l'art. Cette reconnaissance se caractérise par l'organisation de travaux communs avec les références académiques (GDR Ondes, COST IC1004 (Cooperative Radio Communications for Green Smart Environments)) et industrielles du domaine.

**Remarque** L'équipe comporte d'autres activités de recherche qui n'apparaissent pas dans les expertises « stratégiques » car elles sont embryonnaires, soit finissantes. La plupart de ces compétences s'avèrent néanmoins importantes aussi pour les autres missions d'enseignement et de valorisation de Télécom ParisTech. Tout ceci explique l'écart entre le nombre cumulé de permanents et de doctorants impliqués dans les expertises stratégiques et les nombres homologues globaux cités dans la rubrique « Taille » du LEXOS. La nature « stratégique » d'une expertise est de toute façon « dynamique » et se revisite régulièrement au gré des évolutions scientifiques conjoncturelles et des besoins/demandes de nos partenaires nationaux et internationaux, tant académiques qu'industriels.

### D.1.2 Objectifs stratégiques

1. **Rapprocher les technologies RF de leurs limites grâce aux innovations issues de la physique : du bas coût/bas débit à la haute performance/haut débit pour l'homme connecté**
2. **Pousser l'optimisation des technologies et des réseaux « beyond 4G » par le développement de méthodologies et modèles comportementaux originaux**

L'équipe souhaite que ses deux expertises stratégiques soient **renforcées** pour accroître sa visibilité.

**Objectif 1** La réduction des dimensions et de la consommation sont des besoins grandissants dans le contexte internet des objets et réseaux de capteurs et des réseaux mobiles haut débit. Pour relever ces défis, il faut proposer des dispositifs ou sous systèmes où les composantes sont miniaturisées à l'aide de nouveaux matériaux (métamatériaux), intégrées voire intriquées pour minimiser les interfaces et optimiser l'efficacité.

**Objectif 2** L'optimisation des technologies et des réseaux nécessite une parfaite connaissance des éléments du système ou du sous-système et requiert une expertise multi-domaines. La capacité de RFM à travailler concurremment sur les divers fronts dans le co-design et l'intégration antenne-circuit et en conception conjointe antenne canal est donc essentielle pour répondre aux besoins d'architecture complexe.

### D.1.3 Leviers prioritaires

1. Lancement d'un Labo Commun avec Thales.
2. Lancement d'un **Labo Commun avec BLuWan** (programme ANR LabCom).
3. Renforcer l'activité par la recherche de « **Partenariats Technologiques** », tant dans l'IMT (TB, LTCC) que dans l'UPSa (NanoDesign).

Pour atteindre ses objectifs, le groupe RFM collabore depuis plusieurs années avec des industriels de premier plan et souhaite pérenniser et renforcer ces partenariats sous la forme de laboratoires communs. D'autre part pour être au plus proche de l'innovation, le groupe RFM doit accéder aux technologies up-to-date.

# D.2 Télécommunications optiques (GTO)

**Responsable** Didier Erasme.

**Taille** 6 EC (temps recherche 50%), 1 Ingénieur (100%), 1 sabbatique, 2-3 postdocs, 10 à 15 doctorants.

## D.2.1 Expertises stratégiques

1. **Traitements numériques et matériels du signal adaptés aux propriétés spécifiques et à l'architecture des systèmes optiques.**

   **Force de Recherche** 5 permanents impliqués à raison de 70% de leur charge moyenne de recherche, 5 à 7 doctorants.

   **Production de recherche en 2012** 10 publications ; montant agrégé des contrats de recherche commencés en 2012 : 210 k€ ; 1 brevet ; pas de laboratoire commun ni de chaire.

2. **Propriétés fonctionnelles des dispositifs photoniques.**

   **Force de Recherche** 5 permanents impliqués à raison de 60% de leur charge moyenne de recherche, 5 à 7 doctorants.

   **Production de recherche en 2012** 20 publications ; montant agrégé des contrats de recherche commencés en 2012 : 210 k€ ; 1 brevet depuis 2008 ; pas de laboratoire commun ni de chaire.

Les propriétés physiques des divers éléments d'un système optique — émetteurs, modulateurs, récepteurs ainsi que la fibre optique — établissent des limitations sur les performances de celui-ci, qui sont typiquement, pour les systèmes de communication, le débit d'information et la portée mais aussi, pour des capteurs, la qualité de la mesure. Longtemps, l'optimisation des systèmes s'est concentrée sur le perfectionnement des composants, des interfaces et l'architecture physique (multiplexage par exemple). Aujourd'hui, les techniques de traitement numérique du signal ont investi le domaine des communications optiques : nouveaux formats de modulation, traitement numérique des distorsions et interférences, etc. et ce grâce qux développements de circuits numériques extrêmement rapides. Une étape supplémentaire consiste à intégrer la problématique de l'architecture du réseau global par des solutions optimisées de façon multicouche. L'expertise du groupe GTO tient en une excellente connaissance des techniques historiques, fondée sur une bonne maîtrise des modèles de représentation physique des dispositifs et du canal de transmission, une compétence expérimentale reconnue et un laboratoire de pointe, ainsi qu'en une appropriation des problématiques de communications numériques aidé en cela par l'environnement exceptionnel offert par notre département et son groupe communications numériques, par les chercheurs en réseaux du département Informatique et réseaux et par les équipes complémentaires de l'Institut Mines Télécom.

Les contraintes imposées aux systèmes optiques de communications ne sont pas uniquement tournées vers des performances ultimes mais parfois, très concrètement, par des soucis de coût, de consommation, d'encombrement etc. Ils se rencontreront couramment sur des segments du réseau proches de l'utilisateur final, là où la mutualisation d'un même équipement est de plus en plus limitée. Tirer des composants existants leurs meilleures performances eu égard à l'application visée requiert une excellente connaissance des propriétés physiques de ceux-ci et du canal de transmission. Il s'agit par exemple d'adapter le signal issu d'un laser modulé ou d'une source suivie d'un modulateur spécifique en amplitude et en phase afin de limiter la dégradation amenée par la transmission dans une fibre optique dispersive. Identifier parmi les nouvelles solutions physiques proposées dans la littérature (nouveaux effets physiques tels que la plasmonique, nouvelles structures telles que les dispositifs à confinement quantique, la photonique sur silicium) celles qui s'adapteront aux contraintes d'un système relève des mêmes compétences. Celles-ci sont construites sur de solides connaissances théoriques dans le domaine de l'optoélectronique

et des communications optiques ainsi que sur une approche expérimentale indispensable à la validation des concepts et solutions proposées.

**Equipement Stratégique** Les 2 expertises s'adossent à un laboratoire unique de plateformes de caractérisation système, ainsi que de caractérisation de composants et dispositifs (40 à 100 Gbit/s).

## D.2.2 Objectifs stratégiques

1. **Proposer et démontrer expérimentalement l'utilisation de nouveaux algorithmes permettant des liaisons à longues distances à des débits 400Gbit/s, voire 1Tbit/s par longueur d'onde.**
2. **Identifier et évaluer (théoriquement, expérimentalement) les nouveaux types de sources optiques** répondant aux critères de coût, de consommation (« green photonics »), d'encombrement, de bande passante pour les futurs réseaux domestiques, d'accès, métropolitains ainsi que pour les liaisons au sein et entre data center.

Maintien des investissements dans les équipements de laboratoire et consolidation des collaborations avec l'équipe ComNum, pour l'expertise 1. Renforcement de l'expertise 2, grâce notamment au recrutement de F. Grillot.

**Objectif 1** L'accroissement continu des débits transportés sur le réseau fixe provenant des applications mobiles, des applications vidéo et des échanges de données massives, confronte en permanence les systèmes aux limites physiques de la propagation (effets linéaires et non-linéaires dans les fibres optiques) et du traitement du signal électronique. L'optimisation des systèmes tient en l'adéquation des ressources relevant des communication numériques avec les particularité du canal intégral (optique et électronique).

**Objectif 2** L'amélioration des technologies semi-conductrices couplée à la croissance de la nano-photonique conduit aujourd'hui à l'émergence de nouveaux émetteurs optoélectroniques. Les solutions actuellement étudiées, devront être évaluer à l'aune des problématique « systèmes » dans des architecture révélant du domaine des communications optiques.

## D.2.3 Leviers prioritaires

1. Mise en place de **Budgets Plateformes « Inter-départements »** et / ou « Inter-établissements » & Forte participation à **NanoDesign.**
2. Soutien à la synergie entre les Groupes « Optique » et communication numérique de Télécom ParisTech et de l'Institut Mines-Télécom.
3. Facilitation des échanges avec les plateformes technologiques fournisseurs de composants et dispositifs pour les télécom.
4. Préservation de l'envergure du groupe par le remplacement de P. Gallion (Départ en 2015).

# D.3 Circuits et systèmes de communication (C2S)

**Responsable** Patricia Desgreys.
**Taille** 4.1 EC, 1 Ingénieur, 1 Sabbatique, 2 postdocs, 7 doctorants.

## D.3.1 Expertises stratégiques

1. **Smart Analog & Mixed Signals (AMS) Design for wireless systems (based on Digital Signal Processing)**

   **Force de recherche** 5 permanents, 2 post-docs, 5 doctorants.

   **Production de recherche en 2012** 9 publications, 1 brevet ; montant agrégés des contrats commencés en 2012 : 507,46 k€.

2. **Design Methodologies for AMS NanoScale Systems**

   **Force de recherche** 1.1 permanent, 2 doctorants.

   **Production de recherche en 2012** 2 publications.

L'idée d'une gestion dynamique du spectre qui pourrait être décentralisée a été introduite il y a une quinzaine d'année afin de résoudre le problème de la pénurie de fréquences. Ce concept appelé radio intelligente est depuis l'objet d'une recherche très active. La détection du spectre est de loin l'une des tâches les plus importantes pour la mise en place de la radio intelligente en particulier pour les utilisateurs ayant une faible priorité. Dans la couche physique, actuellement, la détection de spectre pour les applications de radio intelligente suppose et exige un front-end RF de très haute performance, c'est à dire un taux d'échantillonnage élevée, un convertisseur analogique-numérique (ADC) de haute résolution avec une large plage dynamique, un circuit frontal analogique multiple, et des processeurs numériques à haute vitesse. Le principal verrou est le manque de reconfigurabilité, la bande limitée et le coût élevé des parties de traitement AMS & RF situées entre l'antenne et le traitement numérique. La suppression ou la diminution des contraintes sur ces composants entrainent l'apparition d'imperfections (bruit, non linéarités).

Nos expertises de recherche permettent la mise en œuvre de la radio logicielle et de la radio intelligente

**Rupture architecturale :** Le groupe C2S ajoute de l'intelligence dans les circuits AMS grâce à l'implémentation en numérique de nouveaux algorithmes de traitement du signal permettant de corriger les imperfections des circuits AMS & RF. Notre point fort est la conception de CAN multistandard pour la radio cognitive et des corrections numériques nécessaires pour atteindre la très haute performance.

Nos spécificités sont l'implémentation physique de puces en technologies CMOS avancées et le développement et l'implémentation d'algorithmes numériques. Et nous sommes un des leaders européens sur l'architecture Sigma-Delta aussi bien au niveau convertisseur que récepteur.

**Rupture technologique :** Une autre voie que nous investissons pour la montée en fréquence de nos conceptions, tout en maitrisant la consommation, est l'intégration des nanotechnologies.

Le groupe C2S propose des méthodologies pour l'intégration des nanotechnologies ce qui comprend l'enrichissement des simulateurs pour tenir compte des nouveaux comportements. Nous avons en particulier travaillé sur la prise en compte de la fiabilité dans les outils de simulation. Ces outils permettent de comparer (de choisir) des architectures en tenant compte de leurs performances et de leur fiabilité.

**Equipement stratégique :** Nous disposons d'une plateforme de caractérisation de nos circuits intégrés permettant la mesure large bande (100 MHz) et haute résolution (>16 bits).

### D.3.2 Objectifs stratégiques

1. **Smart, Green & Pervasive AMS for Wireless Systems**
2. **AMS NanoScale Systems Highly Reliable by Design for Advanced Manufacturing**

La nouvelle ère des communications, dans laquelle nous entrons, sera caractérisée par une croissance exponentielle du déploiement et de l'usage de services et d'applications.

Ces services et applications auront des supports différents (fréquences et débits) et des caractéristiques différentes (mobilité). La prolifération de ces applications nécessitera de concevoir des systèmes capables de gérer la coexistence de ces dernières. En outre, la quasi-omniprésence et la multiplication de ces systèmes communicants causent une augmentation du besoin en ressources spectrales.

Cependant, du point de vue de la conception de ces systèmes, nous constatons aussi une exigence croissante concernant à la fois les performances au niveau systèmes et au niveau circuit : la consommation d'énergie doit être aussi minimisée dans l'objectif d'obtenir des systèmes sobres en énergie ; et la bande passante doit être maximisée pour permettre la transmission de haut débits de données. Pour permettre la maîtrise et/ou la réduction de la consommation des équipements mobiles, des micro-cellules de communication autonomes sont envisagées. Les équipements mobiles pourront ainsi émettre à des niveaux de puissance réduits.

Afin de répondre aux défis sociétaux du Green IT : conception de systèmes faible consommation, gestion intelligente de l'énergie, et de la Sureté : conception robuste en technologie avancée, nous allons nous appuyer sur nos 2 expertises en élargissant leur champs d'action.

L'intelligence numérique ajoutée à nos conceptions AMS permettra d'offrir, en plus de la haute performance, la versatilité, la performance à la demande, la réduction de la consommation dans des systèmes sans fil omniprésents.

Nous continuerons à implémenter nos conceptions dans les nanotechnologies les plus avancées en développant les méthodes pour des systèmes fiables par conception. L'élargissement dans ce thème consistera à la prise en compte de plus de paramètres technologiques dans les conceptions systèmes pour assurer et accélérer la mise à profit dans les produits des avancées technologiques.

Grâce à ces objectifs stratégiques, nous positionnerons le groupe C2S comme un des acteurs majeurs en micro- et nanoélectronique de l'Université Paris Saclay, notamment en tant que contributeur et coopérateur de la Plateforme technologique Nano-Design et nous consoliderons notre visibilité internationale.

### D.3.3 Leviers prioritaires

1. **Recrutement** d'un jeune chercheur (MdF, CR) sur nos expertises
2. **Lancement d'un labo Commun**.
3. Participation à un M2 de l'UPSay.
4. Participation au projet NANODESIGN.

# D.4 Electronique des systèmes numériques complexes (SEN-LabSoC)

**Responsables** Jean-luc Danger & Renaud Pacalet.
**Taille** 2C, 10 EC, 1 I, 6 CDD, 23 doctorants.

## D.4.1 Expertises stratégiques

1. **Architecture et Méthodes de conception de Systèmes Intégrés et Embarqués**

   **Force de Recherche** 8 Permanents, atelier logiciel de validation de systèmes complexes, nombre de doctorants : 13.

   **Production de recherche en 2012** 23 publications ; 2 brevets ; montant moyen des contrats entre 2008 et 2012 : 600 k€.

2. **Analyse de la Sécurité et de la Sûreté des architectures des circuits et systèmes embarqués**

   **Force de Recherche** 5 Permanents, laboratoire de sécurité et sûreté des systèmes embarqués, nombre de doctorants : 10.

   **Production de recherche en 2012** 29 publications ; 2 brevets ; montant moyen des contrats entre 2008 et 2012 : 360 k€.

**Architecture et Méthodes de conception de Systèmes Intégrés et Embarqués** Cette expertise est essentielle pour répondre aux questions clés des futurs circuits et systèmes numériques : comment intégrer en un moins de temps possible des applications de plus en plus contraintes par ces enjeux primordiaux :

- La faible complexité, donc le coût
- la vitesse de calcul
- la faible consommation
- la fiabilité : pour faire face aux défauts de plus en plus probables dans les circuits
- la sécurité : pour déjouer les attaques physiques portées sur les systèmes embarqués
- la flexibilité : logicielle, ou matérielle par les circuits programmables

La réponse à cette question difficile passe par des méthodes de conception de plus en plus haut niveau, devant permettre une validation efficace, avec un partitionnement logiciel/matériel optimal, et la prise en compte des récentes technologies micro-électroniques.

**Analyse de la Sécurité et de la Sûreté des architectures des circuits et systèmes embarqués** Les contraintes de sûreté de fonctionnement et sécurité sont prioritaires dans de nombreuses applications sensibles. Ceci s'explique d'une part par la diminution significative de la fiabilité dans les nouvelles technologies micro-électroniques, et la recrudescence des attaques physiques dans les circuits détenant des informations secrètes. Toute action de protection nécessite de quantifier le degré de vulnérabilité des circuits, de façon à en mesurer son impact. Ainsi, outre des compétences en architectures électroniques, cette expertise fait largement appel aux mathématiques, pour valider formellement le gain en protection, et aux expériences laboratoire, pour la meilleure compréhension des phénomènes physiques.

## D.4.2 Objectifs stratégiques

1. **Atelier de conception de systèmes embarqués par raffinement encadré**
2. **Plate-forme d'analyse en sûreté/sécurité des systèmes embarqués**

Au vu du besoin croissant en architectures complexeses, les deux expertises stratégiques de l'équipe doivent être renforcées. Parmi les leviers de ce renforcement figurent d'une part un environnement de modélisation, conception et validation intégré pour les systèmes complexes dans les dernières technologies, et d'autre part des outils d'analyse afin de valider la sécurité et la sûreté de fonctionnement des circuits et systèmes embarqués.

**Atelier de conception de systèmes embarqués par raffinement encadré** Afin d'accélérer la validation d'un système électronique complexe, un premier objectif est de cibler un atelier logiciel permettant le partitionnement logiciel/matériel de systèmes embarqués complexes. Sur le thème spécifique de la radio logicielle, l'équipe vise à proposer un premier processeur de traitement du signal, accessible aux partenaires académiques et industriels. Dans ce contexte une action incontournable est l'acquisition constante des méthodes de conception pour la maîtrise des dernières technologies « deep submicron », qui passe par le développement de circuits prototypes, permettant du me coup de valider des nouvelles architectures.

**Plate-forme d'analyse en sûreté/sécurité des systèmes embarqués** Cet objectif très pratique et démonstratif est avant tout la mise en place d'un environnement de laboratoire et de plate-formes pour une meilleure analyse et compréhension de la la sûreté de fonctionnement et de la sécurité. Aussi il devient possible de fournir des démonstrateurs, dont celui d'un premier calculateur de confiance, prouvant la faisabilité du « trusted cloud computing » et du tiers de confiance matériel distant. Toujours dans l'esprit de démonstration et dissémination, il est stratégique de lancer de nouvelles version du "DPA contest" , concours international organisé par l'équipe et contribuant à la visibilité de notre savoir-faire en sécurité des systèmes embarqués.

### D.4.3 Leviers prioritaires

1. **CDI Ingénieur de Recherche** pour la conception et la validation de circuit et systèmes complexes.
2. **CDI Chercheur** en sûreté de systèmes embarqués.
3. **Site Web pour la diffusion/valorisation** d'outils libres de conception de systèmes embarqués.

# D.5 Communications numériques (ComNum)

**Responsable** Philippe Ciblat.
**Taille** 2C, 7 EC, 4 postdocs, 13 doctorants.

## D.5.1 Expertises stratégiques

1. **Codage algébrique et théorie des réseaux de points : codage de réseau, sécurité par la couche physique, MIMO, stockage distribué**

   **Force de recherche** 4 permanents (66%), 5 doctorants.

   **Production de recherche en 2012** 11 publications ; montant des contrats commencés en 2012 : 363 k€.

2. **Théorie de l'information : gestion de l'interférence, communications interactives, grandes matrices aléatoires**

   **Force de recherche** 7 permanents (66%), 4 doctorants.

   **Production de recherche en 2012** 17 publications ; montant des contrats commencés en 2012 : 85 k€.

## D.5.2 Objectifs stratégiques

1. **Traitement distribué de l'information** (codage pour le stockage distribué, codage de source distribué, optimisation distribuée)
2. **Codage et allocation de ressources pour la gestion de l'interférence** (nouvelles méthodes d'allocation inter-couches, codage tirant parti de l'interférence tel le compute-and-forward, utilisation de la voie de retour)

Les deux objectifs stratégiques sont très clairement un renforcement et un élargissement des expertises 1 et 2 puisque nous y utilisons les mêmes outils mathématiques (réseaux de points, optimisation convexe, matrices aléatoires).

L'objectif stratégique 1 devient de plus en plus essentiel en raison de masses de données importantes qu'il faut stocker (ex. le "cloud computing") et aussi parfois l'absence de points centralisateurs de calculs (comme en réseau de capteurs ou en réseau ad hoc). Quant au deuxième objectif stratégique, nous considérons que les prochains gains substantiels dans un système de communications viendront de l'amélioration de la gestion de l'interférence puisqu'elle est devenue le facteur limitant (en effet, sans interférence, on atteint maintenant presque la limite de Shannon). Nous avons la volonté d'inclure nos techniques de gestion de l'interférence dans la prochaine 5G (et donc pas uniquement de la coordination de station de base -CoMP- et du relayage comme fait dans le LTE-A).

## D.5.3 Leviers prioritaires

1. Lancer un **laboratoire Commun avec Thalès** « Coding & Ressource Allocation for Interference Management ».
2. Recherche de très bons étudiants (qui s'avère actuellement très difficile en raison d'une attractivité assez faible du domaine) & **Ressources propres plus pérennes**, comme un **ERC.**

# D.6 Réseaux, mobilité et services (RMS)

**Responsable** Jean-Louis Rougier.
**Taille** 11 EC, 1 prof émérite, 1 prof associé, 25 doctorants.

## D.6.1 Expertises stratégiques

1. **Pervasive Access (Wireless & Optical Networks)**

   **Force de recherche** 3.5 EC, 8 doctorants.

   **Production de recherche en 2012** 17 publications ; montant agrégé des contrats de recherche commencés en 2012 : 215 k€.

2. **Very Large Networks (Future Internet, Cloud, Internet of Things, Smart Grid)**

   **Force de recherche** 4 EC, 10 doctorants.

   **Production de recherche en 2012** 28 publications ; montant agrégé des contrats de recherche commencés en 2012 : 653 k€ ; labos communs : Seido Lab (EDF), labo commun Thales.

3. **Modeling and Performance Evaluation (Traffic Engineering, Optimization, Metrology & Testbed)**

   **Force de recherche** 3.5 EC, 7 doctorants.

   **Production de recherche en 2012** 17 publications ; montant agrégé des contrats de recherche commencés en 2012 : 516 k€.

Les deux premières expertises stratégiques ont été regroupées de manière cohérente avec la stratégie présentée à la section suivante, afin de bien mettre en évidence les forces mises en oeuvre et les initiatives (laboratoires communs etc.) associées à chacun des objectifs stratégiques.

La première expertise correspond à l'ensemble des évolutions technologiques permettant l'accroissement des capacités et l'omniprésence de la connectivité réseau, aussi bien par le biais des réseaux filaires et sans fils. Cet axe englobe les expertises du groupe sur les réseaux sans-fils et cellulaires (notamment, sur les méthodes d'accès, la gestion dynamique de spectre, la radio cognitive, la gestion de la mobilité, le codage réseau) et les réseaux optiques (notamment, les réseaux WDM transparents, commutation de paquets tout-optique, radio sur fibre).

La seconde expertise correspond aux évolutions technologiques nécessaires pour faire face à la complexité des réseaux (taille, nombre de terminaux connectés, etc.). Elle regroupe les compétences de l'équipe sur les évolutions architecturales de l'Internet du Futur (routage multi-chemin, LISP, Content Centric Networks), les réseaux P2P, le Cloud Computing, la classification automatique des flux et l'Internet des objets.

Finalement, la dernière expertise correspond à des compétences "support", autrement dit les méthodes d'analyse pour l'évaluation de performance et le dimensionnement de réseau, la simulation ou la réalisation de mesures réelles, qui peuvent s'appliquer à différentes technologies. Plus précisément, cette expertise porte sur les modèles analytiques (théorie des files d'attente, topologie algébrique, théorie des jeux, statistiques et optimisation combinatoire), la simulation, la métrologie sur des réseaux réels ou expérimentaux.

## D.6.2 Objectifs stratégiques

Les réseaux ont acquis ces dix dernières années une importance stratégique, avec un fort impact socio-économique, soutenue par des évolutions technologiques et architecturales majeures qui ont permis une augmentation significative des capacités de transfert et la fourniture d'une multitude de nouveaux services.

Si leur succès est indéniable, les réseaux font face à des défis majeurs, liés à leur croissance, leur complexité, l'évolution de leurs usages et l'accès transparent aux services offerts, qui mettent potentiellement en péril les paradigmes traditionnels.

L'équipe vise deux principaux objectifs stratégiques :

1. **Développer de nouvelles technologies pour une connectivité omniprésente.** Un aspect essentiel est d'assurer une connectivité omniprésente, par le biais des technologies de réseaux filaires et sans-fils. Cet objectif englobe en premier lieu la montée en débit, les réseaux actuels montrant des signes de congestion sévère, plus particulièrement dans les réseaux cellulaires. La solution réside par une gestion optimisée des ressources (radio et optiques). L'omniprésence nécessite également une gestion de la mobilité généralisée. Les investissements dans les réseaux sont considérables, particulièrement à l'accès avec le grand nombre d'équipements à déployer au plus près des utilisateurs. Les coûts de gestion de ces réseaux pourraient être réduits par une plus grande autonomie (auto-organisation). Finalement, une meilleure maîtrise de la consommation énergétique de ces réseaux est nécessaire, à la fois pour raisons économiques et environnementales.
2. **Gérer la complexité et les performances des très grands réseaux.** Le second objectif porte sur la gestion de très grands réseaux. La difficulté est d'assurer les performances, la robustesse et la résilience de ces réseaux, ce qui est rendu particulièrement complexe par la taille des réseaux considérés et le nombre d'acteurs mis en jeu , comme dans l'Internet par exemple, ou au niveau du volume de trafic transporté (notamment du trafic vidéo qui devient prépondérant). La maîtrise de la complexité doit également répondre à une demande croissante pour une plus grande flexibilité des réseaux afin de pouvoir déployer de nouveaux services de manière beaucoup plus simple et rapide. Nous comptons explorer aussi bien des solutions de rupture (virtualisation des fonctions réseaux, software defined network, information centric networking, ...) que des solutions évolutives (utilisation de LISP, ...). La complexité vient également du nombre de terminaux connectés, qui va littéralement exploser avec le déploiement extrêmement rapide de capteurs et de multiples objets connectés. Dans ce contexte de l'Internet des Objets, il est indispensable de prendre en compte de nouvelles contraintes, liées à l'élargissement des champs d'application des réseaux, comme par exemple, les véhicules électriques connectés, ou les réseaux de distribution d'électricité auto-adaptatifs (smart grid).

Ces défis ne pourront être relevés que par une connaissance approfondie à la fois des technologies actuelles et des outils théoriques les plus avancés, permettant de concevoir des solutions innovantes, potentiellement en rupture avec l'existant. C'est pourquoi l'équipe a la volonté de consolider sa spécificité dans la double compétence en réseaux (architectures, protocoles, algorithmes) et études de performance (optimisation, modèles analytiques, expérimentation et métrologie). Nous comptons ainsi maintenir et pérenniser notre expertise stratégique 3 ("modélisation et étude de performances").

### D.6.3 Leviers prioritaires

1. **CDI d'ingénieur de recherche** pour développer et valoriser développements logiciels et plateformes.
2. **Renforcer la présence** du groupe dans les grandes initiatives locales (DigiCosme) et nationales (Allistene) et laboratoires communs (LINCS, SystemX, SeidoLab, Thales).
3. Renforcer la relation avec des industriels clés du domaine (notamment Cisco, EDF).
4. Renforcement des liens **académiques internationaux** (Chine, Inde, USA).
5. **Mise en place du master M2 Advanced Communication Networks (ACN) porté par X/Telecom (ouverture en septembre 2014)**.

# D.7 Systèmes, logiciels et services (S3)

**Responsable** Elie Najm.
**Taille** 10 EC, 1 I, 14 doctorants.

## D.7.1 Expertises stratégiques

1. **Systèmes Répartis** Informatique Autonomique, Génie Intergiciel, Algorithmique Répartie, Sûreté, Langages et Modèles, Vérification

   **Force de recherche** 7 permanents, 8 doctorants.

   **Production de recherche en 2012** 14 publications ; montant agrégé des contrats commencés en 2012 : 408 k€ ; chaire ISIC (Systèmes Complexes) ; Laboratoire Commun avec EDF (SEIDO).

2. **Systèmes Embarqués Critiques** Ingénierie des Modèles, Systèmes de Systèmes, Sûreté, Vérification, Temps Réel (Avionique, Espace, Ferroviaire)

   **Force de recherche** 4 permanents, 6 doctorants.

   **Production de recherche en 2012** 11 publications ; 3 brevets/Licences ; montant agrégé des contrats commencés en 2012 : 179 k€ ; chaire Systèmes Complexes ; laboratoire commun SEIDO avec EDF ; laboratoire commun avec le CEA-LIST en cours ; démarrage de l'activité dans l'IRT SystemX.

Grâce à une dynamique d'embauche soutenue, l'équipe a pu progressivement faire émerger et renforcer les deux axes d'expertises stratégiques données ci-dessus. Ainsi, depuis 2008, deux ECs sont venus renforcer les compétences en systèmes embarqués, ingénierie des modèles, et sûreté de fonctionnement, et deux autres ECs ont apporté leurs compétences en informatique distribuée et autonomique. L'équipe a ainsi acquis une visibilité à la fois notionale et internationale, dans le domaine de l'embarqué critique et de l'informatique répartie et autonomique, et qui se réflète par la grande activité en publications, ouvrages de références, contrats de recheche publics et industriels, chaire et labos communs, et plateformes logicielles. L'équipe s'est vu aussi renforcer récemment par l'arrivée d'un professeur (début 2013) avec des compétences fortes et reconnues dans les fondements théoriques de l'algorithmique distribuée.

L'équipe poursuivra son investissement dans ses axes stratégiques et en amplifiant son niveau d'expertise, grâce, notamment, aux domaines d'application visés qui sont d'importance majeure (Centrale Nucléaire, Smart Grid, Smart Home, Internet des Objets, Transports, Automotive, Avionique). Cette stratégie est déjà mise en oeuvre. Outre les relations de coopération qu'elle entretient avec les grands industriels et PME, l'équipe est actuellement impliquée dans des grands projets (Connexion, Medical, Corac, PISCO), programmes (SystèmeX, Institut de la Société Numérique), labos communs (SEIDO avec EDF, avec le CEA-List en cours) et Chaires (ISIC - Systèmes Complexes). L'ensemble de ces structures sont un cadre avantageux pour mener des recherches théoriques et appliquées. Cela permetta un positionnement fort de l'équipe dans ses domaines d'expertise lors de la future implantation du laboratoire et l'école sur le plateau de Saclay.

**Systèmes répartis** Les fondements théoriques de l'informatique répartie visent à sépaprer ce qui est réalisable par l'algorithmique distribuée de ce qui ne peut pas l'être. Un défi important est d'équilibrer l'execution correcte des systèmes avec leur disponibilité et leur efficacité, et ce en présence d'adversaires tels que le comportement défaillant des composants du système ou de l'environnement. Les difficultés pour relever ce défi émanent du foisonnement des modèles existants, sans lien apparent entre eux, et du grand nombre d'abstractions pour la programmation distribuée. Stratégiquement, nous envisageons de poursuivre nos travaux sur de nouveaux paradigmes prometteurs de programmation concurrente, comme la mémoire transactionnelle, et aussi l'application de la méthode transactionnelle aux modèles SDN (réseau définis par logiciel)

qui exposent de nouvelles formes de concurrence. Cette recherche traietra aussi des problèmes d'algorithmiques qui surviennent dans la construction des systèmes embarqués et des systèmes électriques sûrs.

L'Internet des Objets (IdO) est une bonne illustration d'un système complexe de par la variété des objets du monde réel susceptibles d'être connectés et de par la combinatoire des compositions et des usages qui peuvent potentiellement en être faits. Les Systèmes Electriques Intelligents (SmartGrids) constituent une forme remarquable d'IdO. A l'instar des objets de l'Internet des Objets, les composants de la chaîne électrique ont une grande variété allant des grands centres de production aux radiateurs électriques chez les particuliers (SmartCity, SmartHome) en passant par les compteurs intelligents et les réseaux de transport et de distribution. A la complexité de l'infrastructure des SmartGrids, se superpose la complexité et l'intrication des fonctions qu'ils assurent. Notamment, la fonction d'optimisation de la production et de la consommation de l'énergie qui requiert des leviers multiples et multi-échelles (temps et espace) et implique la coordination et la coopération d'une multitude de partenaires et d'acteurs autonomes.

L'équipe poursuivra ses efforts vers la conception de solutions algorithmiques, architecturales et logicielles au domaine des IdO et des Smart Grids. Ce domaine est typique du champ d'application de l'informatique autonomique. Mais de nouveaux défis sont à relever car ces systèmes nécessitent une logique de contrôle autonomique complexe dû essentiellement à la nécessité de prendre en compte leur grande échelle, leur caractère distribué, leur hétérogénéité, leur caractère dynamique et le fait qu'ils s'attaquent à de multiples objectifs de gestion. L'objectif de notre recherche est d'identifier et de développer un ensemble d'outils et pour répondre à ce défi. Ceci inclut des outils conceptuels - tels que des paradigmes et des modèles abstraits - ainsi que des outils plus concrets - tels que des architectures, des cadriciels et des langages dédiés. Les méthodes d'Ingénierie basée Modèles (IdM) des systèmes classiques sont pratiquées déjà depuis une décennie et les avantages et apports de leur mise en oeuvre sont maintenant avérés. L'approche de développement par la modélisation des Systèmes d'Information de systèmes complexes, tels l'IdO, reste, quant à elle, un défi majeur. Elle nécessite de nouvelles approches et des cadres de modélisation adaptés.

Une thèse qui porte sur la modélisation en vue de la validation *métier* des Smarts Grids vient d'être lancée par l'équipe et dans le contexte du labo SEIDO. D'autres thèses sont en cours dont une en collaboration avec l'Université de Grenoble et une avec EDF Clamart (CIFRE) ainsi que des travaux au sein du projet de recherche national («Medical» - `http://medical.imag.fr/` - financé par Minalogic). Toujours dans les domaines applicatifs de types grille électrique intelligente, maison et quartiers intelligents, un projet vient de démarrer (Septembre 2013) et qui est co-financé par l'Institut de la Société Numérique (ISN) et l'Institut Mines Telecom (IMT), et associant deux thèses l'une au sein de l'équipe S3 en tandem avec une seconde au département Sciences économiques et sociales de Télécom ParisTech. Ce projet est dévolu à l'interaction avec l'humain du point de vue de l'acceptation, de la temporalité, de la dynamicité et de la qualité de la collaboration (entre humains ou humains-machines) dans un contexte où l'on vise l'autogestion autonomique. Ce projet pilote doit déboucher sur des expertises pluridisciplinaires qui s'intégreront à terme au sein de l'ISN. Ces expertises encore peu fréquentes, si elles s'avèrent fructueuses, seront indéniablement un levier pour le financement de nouveaux projets pluridisciplinaires. L'équipe poursuivra aussi ses travaux menés dans le projet d'envergure Connexion (2012-2016) sur la conception d'un intergiciel vérifiable pour le contrôle commande de centrale nucléaire (fortes contraintes temps réel et de sûreté).

**Systèmes embarqués critiques** La recherche dans le domaine des systèmes embarqués critiques a connu un essor considérable notamment au travers des investissements d'avenir. Cela s'est traduit par le démarrage dans le cadre de l'Institut de Recherche et Technologie des Systèmes Complexes (IRT-X) de deux projets dans lesquels nous sommes impliqués. Le projet de Fiabilité et Sûreté de Fonctionnement couvre le domaine du Ferroviaire grâce à Alstom et celui de Electronique et Logiciel pour l'Automobile couvre le domaine de l'Automobile grâce à Peugeot et Renault. D'autres programmes d'investissements sont concernés comme COnseil pour

la Recherche Aéronautique et Civile dans lequel nous sommes impliqués notamment en matière de sécurité et sûreté de fonctionnement. Scientifiquement, ces travaux visent à répondre aux nouveaux défis que posent les récentes générations de processeurs (multi et many cores) ou les demandes de nouvelles fonctionnalités dans les systèmes embarqués critiques (Advanced Driver Assistance Systems, par exemple). Nous avons été également sollicités pour des actions sur le plateau de Saclay. A titre d'exemple, la Chaire Systèmes Complexes avec l'X et l'ENSTA nous a permis de démarrer des travaux de recherche sur la conception des drones (conception très différentes des systèmes avioniques). Nos travaux avec le CEA reconnus par une publication dans un journal réputé dans le domaine des systèmes temps réel (RTS) ont donné lieu au montage d'un laboratoire commun avec le CEA/LIST. De même, le laboratoire commun SEIDO avec EDF nous permet de faire reconnaître nos travaux autour de la sûreté de fonctionnement appliqués à la cybersécurité des nouveaux systèmes électriques d'EDF.

Cet axe concerne 1 professeur, 2 maîtres de conférences et 1 ingénieur d'étude. Jusqu'en juin 2013, il accueillait 5 thésards dont 3 en CIFRE (2 THALES, 1 AdaCore) et 1 avec le CEA/LASTRE. Depuis le démarrage de l'IRT Systèmes Complexes, grâce à la Chaire Systèmes Complexes et au laboratoire SEIDO, cet axe encadre 5 nouveaux thésards. Le renforcement de notre activité sur cet axe se traduit par une implication forte dans des projets de recherche de grande envergure, autant que par le nombre croissant de doctorants encadrés. Cette situation favorable s'explique par la qualité des publications scientifiques, mais aussi par la mise à disposition de RAMSES, plate-forme de modélisation, d'analyse et de génération de code par raffinement pour AADL. A la demande du SEI/CMU, nous avons été conduits à intégrer ces travaux à leur environnement historique de développement pour AADL, OSATE. Cette intégration a permis de démarrer des travaux de recherche dans le contexte du programme System Architecture Virtual Integration qui regroupe tous les plus grands intervenants du domaine de l'Avionique ainsi que la NASA.

### D.7.2 Objectifs stratégiques

1. **Systèmes répartis** Recherche en algorithmique distribuée ; en informatique autonomique ; en modélisation et architecture ; et en génie intergiciel. Application à l'Internet des Objets et aux Systèmes Electriques
2. **Systèmes embarqués critiques** Méthodologie de modélisation et de conception

### D.7.3 Leviers prioritaires

1. 2 CDD / CDI Ingénieur « Plateformes ».
2. **Réduire la charge d'enseignement des ECs** pour dégager du temps recherche et faciliter l'atteinte des objectifs de recherche ambitieux.
3. **Consolider les financements** externes et futurs et ruptures.
4. Participations aux Masters (pré)-Saclaisiens (MPRI, Comasic, SETI).

# D.8 Interaction, cognition et complexité (IC2)

**Responsable** Talel Abdessalem

**Taille** 1 C, 8 EC, 13 doctorants, 1 ingénieur de recherche.

## D.8.1 Expertises stratégiques

1. **Web (big) Data Management & Mining**

   **Force de recherche** 4 permanents, 5 doctorants, 1 ingénieur de recherche.

   **Production de recherche** 20 publications durant l'année 2012. Montant agrégé des contrats de recherche commencés en 2012 : 106 k€. Une Chaire « Big Data for E-Commerce » en cours de montage.

2. **Human-Computer Interaction and Visualization**

   **Force de recherche** 3 permanents, 4 doctorant, 1 postdoc.

   **Production de recherche** 7 publications durant l'année 2012. Montant agrégé des contrats de recherche commencés en 2012 : 243 k€. Participation au laboratoire commun UBIMEDIA avec Alcatel-Lucent Bell Labs et l'Institut Télécom. 1 brevet avec A-L. Bell Labs. Participation à l'Equipex DIGISCOPE.

L'équipe a choisi depuis 2007 de se renforcer sur les deux axes stratégiques cités ci-dessus. Ceci s'est réalisé par la création de deux sous groupes de recherche de premier plan : l'un, DBWeb, est spécialisé dans les fondements théoriques des bases de données, la fouille de données à large échelle et la gestion des données du Web, et l'autre VIA est spécialisé dans les nouvelles techniques d'interaction et leurs fondements.

Le groupe DBWeb (`dbweb.enst.fr`) s'est renforcé progressivement par des recrutements ciblés : Bogdan Cautis en 2007, Pierre Senellart en 2008 et Mauro Sozio en 2011. Son niveau de publication, aussi bien en terme de qualité (publications dans les revues et conférences les plus prestigieuses du domaine, TODS, TOIS, SIGMOD, PVLDB, ICDE, etc.) qu'en nombre (20 publications en 2012 pour 5 EC) font de ce groupe l'un des meilleurs groupes de recherche en bases de données en France.

Le groupe VIA (`http://www.telecom-paristech.fr/~via/`) a significativement gagné en visibilité pendant cette période avec l'arrivée de deux jeunes chercheurs prometteurs : James Eagan (Maître de Conférences) en 2011, puis Gilles Bailly (CR CNRS) en octobre 2013. Le goupe a également participé à de nombreux projets collaboratifs, notamment le laboratoire commun Ubimedia ou l'Equipex Digiscope, une infrastructure de visualisation interactive et collaborative unique au monde. Le groupe dispose enfin d'un bon rythme de publication dans les meilleurs médias du domaine (qui sont principalement des conférences ACM) et fait partie des rares équipes françaises à publier régulièrement dans la prestigieuse et sélective conférence ACM (SIG)CHI (9 articles en catégorie principale sur la période, 13 tout compris).

Le renforcement de ces deux axes nous a permis aussi de proposer de nouveaux enseignements à nos élèves (gestion de données du Web, traitement de données à large échelle, interaction homme-machine, visualisation de données) et d'élargir notre participation aux Masters Parisiens (avec l'UPMC) et Saclaisiens (futurs Masters of Science de l'UPSay).

**Remarque** L'équipe comporte d'autres expertises reconnues en statistiques (1 EC) et science cognitive (1 EC), notamment les travaux de Jean-Louis Dessalles sur l'étude de l'origine du langage, et la pertinence et ses origines cognitives (`http://perso.telecom-paristech.fr/~jld/`). Ces expertises demeurent importantes pour les activités de recherche, d'enseignement et de valorisation de Télécom ParisTech, même si elles n'apparaissent pas dans les expertises «stratégiques» du groupe. Cela explique aussi l'écart entre le nombre cumulé de permanents et de doctorants impliqués dans les expertises stratégiques et les nombres homologues globaux cités dans la rubrique «Taille»» de l'équipe.

## D.8.2 Objectifs stratégiques

1. **Large scale data and knowledge management (theoretical foundations and practical solutions)**
2. **Body Centred Interaction (Augmented Human)**

L'équipe souhaite continuer à renforcer et élargir l'expertise 2, notamment sur les interfaces miniatures, embarquées et implantées, avec la prise en compte d'indicateurs physiologiques et émotionnels.

Il est également envisagé de compléter le spectre de l'expertise 1 au Web Sémantique et aux challenges liés au passage à l'échelle (Big Data) des méthodes de traitement, de fouille, d'extraction et de représentation des connaissances. L'équipe a la volonté de consolider sa spécificité dans les BD fondée sur une combinaison unique des aspects théoriques et systèmes.

**Large scale data and knowledge management** L'évolution technologique que nous vivons a permis la multiplication des sources d'informations, aussi bien les personnes physiques que les entités socio-économiques : systèmes d'information d'entreprises, open data, web, caméras et autres capteurs qui prennent de plus en plus de place dans notre environnement, public ou privé. L'exploitation des masses de données (Big Data) provenant de ces sources (récolte et transmission des données, stockage, analyse à la volé ou différée, etc.) peut permettre l'extraction de connaissances précieuses et constituer un levier important pour le développement et la compétitivité de nombreuses entreprises. Cependant, les volumes considérables de ces données, leur diversité et leur dynamicité (évolution continue) limitent l'efficacité des techniques de gestion et d'analyse de données actuelles et les rendent incapables de répondre aux défis scientifiques que nous pose l'exploitation de ces masses de données. Ces défis sont multiples et nous voudrions travailler en particulier sur le problème du passage à l'échelle des algorithmes de traitement et de fouille de données (grands graphes, données hétérogènes, données incertaines, flux de données, etc.), ainsi que sur les méthodes d'extraction et de représentation des connaissances (ontologies, extraction d'information à partir du Web, analyse de réseaux sociaux, etc.).

**Body Centered Interaction** L'évolution de l'informatique depuis 50 ans pourrait presque se résumer à une phrase : toujours plus puissant, plus petit, plus mobile, plus personnel, plus près du corps. Le smartphone en est aujourd'hui l'illustration évidente, mais il ne constitue qu'une étape de cette évolution qui va conduire à l'émergence de nouveaux dispositifs et de nouveaux paradigmes interactionnels, aujourd'hui à peine esquissés. Les interfaces futures seront vraisemblablement de plus en plus multiformes et pour certaines d'entre-elles évanescentes, distribuées et embarquées sur (voire dans) le corps, ce que l'on peut résumer par le terme anglais «Body Centred Interaction» au sens de la thématique «Augmented Human». La proximité avec le corps, le besoin d'aller vers plus de personnalisation, sans parler des évolutions sociétales liées à l'âge croissant de la population, conduira certainement à une exploitation accrue des indicateurs physiologiques et émotionnels. Ce corps ainsi augmenté pourra aussi à terme interagir d'autant plus facilement avec les dispositifs et environnements communicants qui l'entoureront. De par son expérience en IHM dans les domaines de l'interaction mobile, de l'interaction gestuelle, des lois de mouvements et des environnements multi-dispositifs et multi-surfaces du groupe VIA est particulièrement bien placée pour travailler sur ces sujets, et en particulier ceux concernant l'interaction avec des petits dispositifs corporels et avec des environnements augmentés. Des collaborations seront ensuite à mener, à l'intérieur et à l'extérieur du LTCI, pour prendre en compte les aspects physiologiques et émotionnels, voire médicaux, et ainsi permettre à l'équipe de maîtriser ces nouvelles thématiques.

## D.8.3 Leviers prioritaires

1. Finalisation et lancement de la **Chaire Big Data for E-Commerce** (portée par Talel Abdessalem).

2. Participation à la **Chaire Machine Learning** (Pierre Senellart y représente le groupe dans le comité de pilotage de la Chaire).
3. Renforcer les financements contractuels externes.
4. L'équipe est en phase de recrutement sur les deux objectifs stratégiques (un chargé de recherche CNRS, Gilles Bailly, qui rejoint le groupe en octobre 2013, et un enseignant-chercheur, Fabian Suchanek, qui arrive en novembre 2013).
5. Participation à des **Masters Saclaisiens** (parcours IHM et DataSense de la mention informatique).
6. Participation à l'Equipex Digiscope.

# D.9 Sécurité et réseaux (SR)

**Responsables** Isabelle Zaquine & Jean Leneutre.
**Taille** 2C, 6 EC, 1 ingénieur, 28 doctorants.

## D.9.1 Expertises stratégiques

1. **Information Quantique**

   **Force de recherche** 4 permanents, 7 doctorants.

   **Production de recherche en 2012** 6 revues internationales, 10 conférences internationales, Montant agrégé des contrats commencés en 2012 : 252 k€.

2. **Sécurité des Réseaux**

   **Force de recherche** 5 permanents, 21 doctorants.

   **Production de recherche en 2012** 4 revues internationales, 12 conférences internationales, Montant agrégé des contrats commencés en 2012 : 181 k€ ; 1 laboratoire commun (SEIDO avec EDF).

La cryptographie quantique à variable continue est un domaine important pour accéder à la sécurité “inconditionnelle” avec des flux lumineux compatibles avec des méthodes classiques de détection. Les derniers travaux de l'équipe dans ce domaine en constituent l'état de l'art. De plus, l'ensemble de l'équipement présent au laboratoire, associant sources de photons intriqués dans le visible, dans l'infra-rouge de régimes temporels et de largeurs spectrales différentes, ainsi que des systèmes de distribution de clés en variables discrètes et continues, en fait une plateforme unique en France pour tester de nouveaux protocoles de cryptographie quantique.

Un autre aspect important est le développement de nouveaux protocoles. D'une part, on étudie les fondements de la physique quantique, comme la non-localité et la contextualité, en particulier dans le cas de l'intrication à plusieurs particules, pour dégager les avantages quantiques (il est intéressant de noter que les protocoles les plus marquants ont émergé de considérations purement fondamentales). D'autre part, nous nous intéressons à ce que le traitement quantique de l'information peut nous apprendre sur les différences entre la physique classique et la physique quantique. Ces axes de recherche sont nécessairement pluri-disciplinaires, ce qui se retrouve dans la nature inter-disciplinaire de notre équipe, ainsi que nos nombreuses collaborations avec des physiciens expérimentalistes et théoriciens, ainsi que des informaticiens.

L'expertise 2 couvre un spectre relativement large de la sécurité des réseaux. L'activité de recherche porte sur la définition d'architectures, de services sécurisés ainsi que de méthodes d'évaluation de la sécurité pour les réseaux. Dans le cadre de la sécurité des communications et des applications, un accent est mis sur le renforcement et l'optimisation de protocoles de sécurité existants tout en préservant l'interopérabilité. Un autre effort est fourni sur l'intégration d'éléments de confiance (cartes à puces) pour augmenter le niveau de sécurité d'une solution. Outre les réseaux classiques, le domaine d'application de ces travaux concerne également la sécurisation des infrastructures pervasives (internet des objets, réseaux véhiculaires) et des infrastructures critiques (réseaux électriques intelligents). Depuis septembre 2012, l'équipe a initié des activités dédiées à la cybersécurité pour les systèmes électriques dans le cadre du laboratoire commun SEIDO avec EDF. Cette collaboration est une opportunité significative qui permettra de développer, valider et augmenter la visibilité de certains de nos travaux. En particulier, l'utilisation de la théorie des jeux non coopérative pour la conception de stratégies de sécurité optimales semble être une approche prometteuse dans ce contexte. Par ailleurs, une nouvelle problématique importante abordée dans ce laboratoire porte sur l'étude des interdépendances entre propriétés de sécurité et propriétés de sûreté de fonctionnement. Ces derniers travaux sont abordés en collaboration avec des collègues de l'équipe S3.

## D.9.2 Objectifs stratégiques

1. **Information (communication et calcul) quantique**
2. **Sécurité des Réseaux, des Infrastructures critiques et des Systèmes et Applications Mobiles**

L'équipe souhaite

– élargir l'expertise 1 au calcul quantique et consolider son double ancrage sur les aspects expérimental et théorique
– renforcer l'expertise 2 sur la sécurité des infrastructures critiques et l'élargir à la sécurité des applications mobiles embarquées.

**Information (communication et calcul) quantique** En information quantique, l'équipe souhaite consolider son positionnement relativement unique en France, avec la combinaison de compétences théoriques sur l'intrication et le calcul quantique et de compétences expérimentales sur les communications quantiques à la fois en termes de variables discrètes et de variables continues.

**Sécurité des Réseaux, des Infrastructures critiques et des Systèmes et Applications Mobiles** En sécurité réseaux, l'équipe souhaite renforcer ses activités sur la cybersécurité et les infrastructures critiques (sécurité des réseaux électriques intelligents au sein du laboratoire commun SEIDOLAB avec EDF, sécurité des systèmes de transport intelligents dans le cadre du projet IEED VeDeCoM et IRT System X). Par ailleurs, l'équipe désire élargir ses activités présentes autour de l'informatique de confiance à la sécurisation des systèmes et applications mobiles.

## D.9.3 Leviers prioritaires

1. en information quantique, le besoin d'environ 2 à 3 bourses de thèses par an pour maintenir une visibilité élevée au niveau expérimental et théorique
2. vigilance sur l'interaction avec les masters et les écoles doctorales de l'UPSay pour permettre le recrutement de bons doctorants.
3. besoin de renforcer l'équipe en sécurité réseaux
4. collaboration avec EDF dans le cadre du laboratoire commun

# D.10 Mathématiques de l'information, des communications et du calcul (MIC2)

**Responsable** Olivier Hudry.
**Taille** 1C, 7EC, 7 doctorants.

## D.10.1 Expertises stratégiques

1. **Combinatoire & codage**
   **Force de recherche** 6 Permanents, 3 doctorants.
   **Production de recherche en 2012** 6 articles dans des revues avec comité de lecture, 7 contributions à des conférences internationales, publication de 2 numéros spéciaux de revue ; 1 contrat de recherche d'un montant de 73 k€ ; laboratoire commun avec Morpho « Identity & Security Alliance ».
2. **Modèles Stochastiques & Géométrie Aléatoire**
   **Force de recherche** 2 Permanents, 4 doctorants.
   **Production de recherche en 2012** 3 articles dans des journaux avec comité de lecture, 3 contributions à des conférences internationales, 1 livre, publication de 1 numéro spécial de revue.

## D.10.2 Objectifs stratégiques

1. **Développer les outils théoriques et applicatifs de la topologie algébrique en milieu aléatoire en vue des applications aux réseaux radio-mobiles et à la classification**
2. **Développer de nouveaux concepts algébriques appliqués à la biométrie et/ou la protection et la sécurité des données**

En collaboration avec l'équipe RMS, nous sommes pionniers dans l'utilisation des concepts avancés tels que la topologie algébrique et la géometrie stochastique pour l'analyse et le dimensionnement des systèmes « ambiants » : mobiles, capteurs et plus généralement informatique pervasive. Les défis sont nombreux et il nous semble nécessaire d'étoffer l'équipe tant par un chercheur permanent, spécialisé dans les grands graphes aléatoires, qui s'insérerait idéalement en interaction avec d'autres équipes que par une sécurisation des financements de doctorants et post-doctorants par l'intermédiaire d'une chaire.

L'importance toujours plus grande des technologies numériques dans notre quotidien soulève de nombreux problèmes de confiance liés tant à la sécurité des données qu'à la gestion de l'identité des utilisateurs. Les solutions technologiques à ces problèmes reposent principalement sur l'utilisation de méthodes cryptographiques et biométriques. Pour ce qui est de l'équipe, elle dispose d'une expertise reconnue dans un domaine très proche et intimement lié, la théorie du codage. C'est par ce biais qu'elle a pu investir aussi ces nouveaux champs et y obtenir un premier corpus de résultats. Car non seulement les codes correcteurs trouvent des applications directes en cryptographie et en biométrie, mais aussi ces domaines partagent-ils des bases mathématiques communes : théorie de l'information, combinatoire, corps finis, fonctions booléennes, théorie des nombres, géométrie algébrique... L'équipe est formée principalement de mathématiciens théoriciens. Elle considère qu'il est d'une importance stratégique de maintenir ses compétences et de pérenniser sa capacité de recherche fondamentale. Cependant, cela doit aller de pair avec un renforcement de l'ouverture sur les applications en cryptographie et biométrie qui, d'une part, offrent des débouchés naturels aux méthodes mathématiques, et d'autre part, proposent en retour des problèmes originaux susceptibles de donner lieu à de nouvelles avancées théoriques. Un moyen privilégié pour cela est le laboratoire commun né de l'alliance avec Morpho. L'équipe possède les compétences qui permettent de contribuer de façon significative aux théories dont les applications, déjà réelles et importantes, vont connaître un essor exponentiel dans les années à venir.

### D.10.3 Leviers prioritaires

1. Pérenniser le Labo Commun avec Morpho « Identity & Security Alliance ».
2. Monter une Chaire sur la Géométrie des Réseaux Cellulaires.
3. 1 CDI EC / C dans le domaine des grands graphes aléatoires.

# D.11 Audio acoustique et ondes (AAO)

**Responsable** Gaël Richard.
**Taille** 6 EC, 11 doctorants.

## D.11.1 Expertises stratégiques

1. **Analyse, modèles et représentations pour le traitement des signaux Audio**

   **Force de recherche** 4 permanents, 8 doctorants.

   **Production de recherche annuelle moyenne** 28 publications, montant annuel des contrats 347 k€(lissés sur la période 2008–2013).

2. **Méthodes et modèles pour le traitement des signaux multimodaux et physiologiques**

   **Force de recherche** 2 permanents, 3 doctorants.

   **Production de recherche annuelle moyenne** 13 publications, montant annuel des contrats 173 k€(lissés sur la période 2008–2013).

**Equipements stratégiques** Studios Audio, studio de capture multimodale et une chambre sourde.

L'objectif de l'équipe AAO est de développer des méthodes de traitement du signal numérique avec application aux signaux audio, musicaux, multimodaux et physiologiques. Cette activité est menée sur un plan aussi bien méthodologique (*machine learning* pour le traitement du signal, représentations parcimonieuses, modèles de signaux, méthodes d'optimisation, séparation de sources) que sur un plan plus applicatif avec l'application aux signaux audio (parole, musique) et aux signaux multimodaux et/ou physiologiques (signaux vidéos, EEG, MEG, ...). L'objectif est ainsi de développer des modèles avancés et dédiés pour les signaux d'intérêt traités.

La première expertise stratégique de l'équipe qui ressort est ainsi sur **l'analyse, modèles et représentations pour le traitement des signaux audio**. Cette expertise inclue notamment les nombreux travaux sur les décompositions parcimonieuses pour les signaux audio (Factorisation en matrices non-négatives, modèles probabilistes, décomposition gloutonne, ...) et les travaux en apprentissage pour l'indexation audio ou l'audition des robots. L'équipe possède une forte reconnaissance internationale sur cette expertise.

La seconde expertise stratégique qui repose en partie sur des modèles et méthodes de décompositions similaires est orientée vers les **méthodes et modèles pour le traitement des signaux multimodaux et physiologiques**. Cette expertise est plus récente mais prend régulièrement de l'ampleur avec l'implication de l'équipe dans plusieurs projets collaboratifs nationaux et européens et le recrutement d'un maître de conférences en 2012.

## D.11.2 Objectifs stratégiques

1. **Consolider l'expertise en Modèles et Représentations pour le traitement des signaux (audio, physiologiques et multimodaux)**
2. **Renforcer les aspects méthodologiques (optimisation, méthodes parcimonieuses, modèles probabilistes pour passage à l'échelle, modèles de fusion adaptés aux données hétérogènes...) pour application aux signaux multimodaux et/ou physiologiques (EEG, MEG, ECG, EMG)**

L'équipe souhaite maintenir l'expertise 1 et renforcer la seconde. L'équipe souhaite développer un axe méthodologique autour des méthodes d'optimisation en grande dimension, de la résolution de problèmes inverses, avec un souci d'application aux signaux audio, multimodaux et physiologiques.

L'équipe considère qu'il est essentiel de consolider sa reconnaissance internationale en modèles et représentations pour le traitement des signaux. Concernant les **signaux audio**, l'équipe est largement reconnue internationalement et il apparaît primordial de conserver le niveau de cette expertise stratégique dans la période à venir avec toutefois un effort particulier consenti pour la résolution de problèmes inverses sur des données de grande dimension. Tout en conservant un axe fort sur les modèles et représentations des signaux de musique et parole, nous souhaitons élargir l'application de nos travaux à une classe de signaux audio plus variée (signaux environnementaux, signaux acoustiques pour la bio-diversité notamment).

Concernant les **signaux multimodaux et physiologiques**, l'idée est de monter en puissance à l'appui de collaborations internes (TII, MM, STA) et externes (CEA, Queen Mary University). Cet axe de recherche est présent depuis de longues années au sein d'AAO mais a reçu un nouvel élan avec l'arrivée d'un maître de conférences en septembre 2012. Le potentiel de cet axe de recherche est élevé et justifie qu'il soit placé au cœur des objectifs stratégiques de l'équipe. Dans ce but, il nous faut notamment renforcer l'expertise sur des aspects méthodologiques. En particulier, nous devons élargir nos compétences en analyse de scènes multimodales complexes («Robot audition/vison ou Multimodal machine listening») pour mieux appréhender la taille et la complexité des données à analyser. Nous devrons développer nos compétences autour des méthodes d'optimisation en grande dimension pour un meilleur passage à l'échelle, en résolution de problèmes inverses notamment pour les signaux physiologiques et en traitement de données fortement hétérogènes pour les signaux multimodaux. Notons, qu'un élargissement de nos compétences sur ces aspects aura également un apport sur notre expertise stratégique 1 et renforcera l'identité de l'équipe.

### D.11.3 Leviers prioritaires

1. **CDI EC / C** sur des aspects méthodologiques et de modélisation pour l'analyse des signaux multimodaux et physiologiques.
2. **Monter un Laboratoire commun** avec Aldebaran autour de «l'analyse et interprétation de scènes multimodales pour la robotique» dans le but de renforcer l'axe *multimodal machine listening*.
3. **Collaboration et montage de projets communs avec les acteurs de l'Université Paris-Saclay** avec notamment le CEA (Neurospin) sur l'axe stratégique 2 avec lequel une collaboration poussée a déjà lieu et le L2S (Supélec) pour des collaborations aussi bien en recherche (un projet de thèse en-cotutelle vient d'être accepté) qu'en enseignement (un module commun est défini pour la refonte de la spécialité de master ATSI (Automatique et Traitement du Signal et des Images) de l'Université Paris-Saclay).

# D.12 Traitement et interprétation des images (TII)

**Responsable** Isabelle Bloch.
**Taille** 6 C, 9 EC, 1 professeur émérite, 5 postdocs, une quarantaine de doctorants.

## D.12.1 Expertises stratégiques

1. **Modèles pour les images et le 3D**

   **Force de recherche** 15 permanents (60%).

2. **Large spectre d'applications : biomédical, télédétection, photographie numérique, infographie**

   **Force de recherche** 15 permanents (30%).

   **Force de Recherche cumulées pour les expertises stratégiques 1 & 2** 40 doctorants.

   **Production de Recherche cumulées pour les expertises stratégiques 1 et 2 en 2012** 71 publications ; montant agrégé des contrats commencés en 2012 : 707 k€ ; laboratoires communs : WHIST, ISA ; chaire : Modélisation des Imaginaires (MODIM).

3. **Indexation, apprentissage et reconnaissance des formes pour les images et volumes numériques**

   **Force de recherche** 7 permanents (10%) ; 3 doctorants.

   **Production de recherche en 2012** 6 publications ; montant des contrats commencés en 2012 : 89 k€.

Les thèmes détaillés dans la partie bilan de ce rapport font ressortir des expertises qui assurent la spécificité du groupe et que nous souhaitons mettre en avant ici. Il s'agit de la **modélisation, pour les images, les volumes numériques et les objets à trois dimensions**. La modélisation concerne aussi bien les modèles mathématiques des images et des informations qu'elles contiennent, que les modèles utilisés pour leur synthèse, ou encore les modèles de représentation de connaissances et de raisonnement pour inférer des informations de plus haut niveau. Notre expertise porte ainsi sur des modèles statistiques (ensembles aléatoires, modèles a contrario, *patches*), analytiques (modèles déformables, EDP), topologiques et géométriques (maillages, reconstruction, par exemple), structurels (graphes, hypergraphes, ontologies), algébriques (par exemple étendant les propriétés de la morphologie mathématique ou de différentes formes de logique). Cette expertise est associée de manière très étroite à une expertise sur un **large spectre d'applications**, qui d'une part renouvelle les problématiques de recherche en offrant des défis nouveaux, et d'autre part permet de confronter ces modèles à des données réelles de grande ampleur, puis à faire évaluer leurs qualités et performances par des experts thématiciens (médecins, géographes, etc.). Les spécificités de ces applications et nos contributions sont décrites dans la partie bilan de ce rapport, pour les images naturelles, la photographie numérique, les images médicales et biologiques, la télédétection, l'image de synthèse et l'infographie.

Ces expertises impliquent l'ensemble des chercheurs et enseignants-chercheurs permanents de l'équipe, soit 15 permanents (et environ 40 doctorants et 5 chercheurs post-doctorants), dont on peut estimer l'activité à 60% sur les aspects de modélisation et 30% sur les applications, en moyenne. On compte, en 2012, 71 publications et un montant agrégé des contrats commencés en 2012 de 707 k€. L'équipe participe aux laboratoires communs WHIST [1] (création, comité de pilotage, projets communs, co-encadrement de thèses) et ISA [2] (co-encadrement de thèses), ainsi qu'à la chaire modélisation des Imaginaires (MODIM).

Enfin, mentionnons une expertise en **indexation, apprentissage et reconnaissance de formes**, impliquant 7 personnes (et 3 doctorants), pour environ 10% de l'activité de recherche du groupe, avec des contributions en recherche d'images ou d'objets à trois dimensions. Si cette

1. Laboratoire commun de l'Institut Mines-Télécom et de France Télécom, créé en 2009, dédié à l'homme communicant et aux interactions entre ondes et personnes.
2. IDentity & Security Alliance, laboratoire commun de Télécom ParisTech et Safran-Morpho.

activité a diminué en imagerie de télédétection avec l'arrêt du CoC, elle continue à se développer avec des compétences aussi bien pour les images que pour les objets tridimensionnels. On compte, en 2012, 6 publications et un montant des contrats commencés en 2012 de 89 k€.

## D.12.2 Objectifs stratégiques

1. **Renforcer l'expertise en modèles pour les images et le 3D, en explorant des champs émergeants**
2. **Renforcer les compétences dans les champs d'application suivants : biomédical, télédétection, photographie numérique, infographie, pour accompagner les évolutions de ces domaines**
3. **Maintenir les expertises en apprentissage, indexation et reconnaissance**

L'équipe souhaite faire évoluer ses activités surtout autour des deux premières expertises, en modélisation et sur nos domaines principaux d'applications (imagerie biomédicale, télédétection, photographie numérique et computationnelle, informatique graphique), en en renforçant certains axes. Nous souhaitons également conserver une expertise forte en indexation, apprentissage et reconnaissance des formes, qui fut centrale et fédératrice en son temps, mais dont le maintien nous semble important.

Ces choix permettent de mettre en évidence les axes théoriques et méthodologiques d'une part (sur tous les axes de recherche), et les applications d'autre part. Ils sont en accord avec les évolutions du domaine du traitement d'images et soulignent la pertinence de nos choix antérieurs : sur de nombreux points, nous disposons d'un positionnement original et d'un rôle moteur pour la communauté. C'est le cas dans les domaines traditionnels de l'imagerie médicale ou de l'imagerie satellitaire, mais aussi dans des domaines émergeants comme la photographie computationnelle qui fait naître de nouveaux besoins, à la fois en amont sur les modèles et les aspects théoriques et méthodologiques, et sur les applications pour répondre aux besoins très divers de la société (du professionnel au grand public). Nous servirons ainsi des intérêts très opposés comme, d'une part, la quête d'une plus grande précision et d'une meilleure qualité pour la surveillance de l'environnement (avec de très gros volumes de données et des capteurs dédiés très spécifiques), ou les usages de masse du grand public, utilisant des capteurs banalisés et à faible coût mais en très grand nombre (téléphone portable par exemple).

Donnons quelques exemples et propositions de pistes de recherche.

Les évolutions récentes de la photographie numérique nécessitent de nouveaux modèles mathématiques permettant la restauration, la reconstruction et l'analyse d'images de très haute résolution, ainsi que la combinaison d'acquisitions multiples. Dans cette thématique, plusieurs directions retiennent particulièrement notre attention. Les méthodes par *patchs* se sont imposées dans le domaine du débruitage, mais ont été relativement peu exploitées pour d'autres tâches de restauration, en particulier dans le domaine de la photographie computationnelle et de la restauration multi-images. La prise en compte des processus d'acquisition, de modèles de bruit réalistes, de l'optique ou de la spécificité des capteurs renouvelle ce type d'approches et ouvre de nombreuses perspectives applicatives. Citons en particulier l'imagerie à haute gamme dynamique, la super-résolution ou la restauration de vidéos, entre autres. Dans une autre direction, de nombreux problèmes théoriques, avec de forts enjeux pratiques, sont soulevés par les approches par *patchs* : articulations avec les approches multi-échelles, optimalité de dictionnaires adaptatifs, en particulier parcimonieux, ou propriétés d'invariance géométrique ou radiométrique. Enfin, la prise en compte des spécificités statistiques des images naturelles, par l'utilisation de modèles de textures ou par des approches variationnelles, permet des développements qui vont au-delà des approches traditionnelles visant à optimiser le PSNR, en particulier pour la restauration d'images.

En informatique graphique, de nouveaux modèles topologiques et géométriques pour la modélisation 3D réaliste, statique et dynamique, le rendu et la recherche rapide dans des bases de données doivent évoluer pour la manipulation et la visualisation de gros volumes de données. Nous proposons ainsi de développer la géométrie instantanée (“rendre l'informatique graphique

3D 1000 fois plus rapide"), ce qui nécessite de repenser les fondements algorithmiques et les implémentations des opérateurs de filtrage, ré-échantillonnage, analyse. Dans le domaine du rendu factorisé ("ne plus jamais synthétiser deux fois le même pixel"), il s'agira d'exploiter les masses de données, les techniques avancées de reconstruction d'image et de photographie computationnelle ainsi que l'apprentissage automatique pour que le résultat d'un calcul (éclairage, reflectance, effet optique, etc.) soit réutilisable dans un système interactif dynamique pour plus d'une image, sur plus d'un objet, avec plus d'un ordinateur. Enfin l'interaction de haut niveau pour la modélisation vise à "mettre du calcul dans l'interaction elle-même", pas seulement dans les processus de traitement/analyse/synthèse.

Le raisonnement spatial pour l'interprétation des images, une de nos spécificités, va évoluer vers le développement de modes de représentation des connaissances combinant de manière originale ontologies, hypergraphes et treillis de concepts, dans le cadre algébrique de la morphologie mathématique et des ensembles flous, et l'intégration de modes de raisonnement multiples (abduction, révision, fusion), dans ce même cadre algébrique. L'objectif est d'enrichir les outils d'interprétation d'images à partir de modèles, en combinant logiques formelles pour la représentation et le raisonnement sur des connaissances et informations qualitatives d'une part, et informations quantatives extraites des images d'autre part. Ces approches seront appliquées en particulier en imagerie médicale, pour l'interprétation d'images à partir de modèles, d'une part dans des cas où les modèles sont imparfaits ou partiels comme pour les images de bébés ou de très petits enfants, ou dans le cas où les données peuvent s'écarter significativement des modèles (interprétation d'images pathologiques et suivi dans le temps).

### D.12.3 Leviers prioritaires

Le recrutement d'un ou deux chercheurs ou enseignants-chercheurs venant contribuer à nos objectifs en modélisation permettra de développer les axes envisagés dans les domaines émergeants du traitement d'images, de la vision par ordinateur et de l'informatique graphique, ainsi que de répondre aux meilleures sollicitations de nos partenaires académiques et industriels, en France et à l'étranger. En particulier, nous souhaitons renforcer nos compétences en optimisation et calcul numérique, en lien avec nos activités en modélisation.

Enfin, des sources d'inspiration bénéfiques viennent des séjours sabbatiques, soit de chercheurs étrangers que nous accueillons dans l'équipe, soit de séjours dans d'autres laboratoires de permanents de l'équipe. Nous souhaitons donc continuer à susciter de telles possibilités d'échanges.

# D.13 Multimedia (MM)

**Responsable** Béatrice Pesquet-Popescu.
**Taille** 4 C, 7 EC, 1I, 25 doctorants.

## D.13.1 Expertises stratégiques

1. **Nouveaux modes de compression, représentation et diffusion multimédia immersif**
   **Force de recherche** 5 permanents, 10 doctorants.
   **Production de recherche en 2012** 30 publications ; 2 licences ; montant agrégé des contrats commencés en 2012 : 949 k€ ; laboratoire commun Ubimedia avec Alcatel-Lucent.
2. **Interactions et communications multimodales**
   **Force de recherche** 7 permanents, 15 doctorants.
   **Production de recherche en 2012** 40 publications ; montant agrégé des contrats commencés en 2012 : 1143 k€ ; laboratoire commun Ubimedia avec Alcatel-Lucent ; chaire : MODIM, modélisation des imaginaires.

## D.13.2 Objectifs stratégiques

1. **Traitement et optimisation distribués des nouveaux formats vidéo ubiquitaires et immersifs**
2. **Interactions multimodales, streaming et technologies web**

L'équipe souhaite **renforcer et élargir l'expertise 1** vers des approches théoriques de représentation et de compression des signaux multimédia de type immersif, représentations parcimonieuses des signaux vidéo et optimisation convexe distribuée. Il est envisagé **renforcer aussi l'expertise 2** afin de répondre à des sollicitations extérieures pour des projets innovants sur le streaming et l'interactivité.

**Traitement et optimisation distribués des nouveaux formats vidéo ubiquitaires et immersifs** L'équipe Multimédia souhaite élargir et renforcer ses compétences dans le domaine du Traitement et Optimisation distribués des nouveaux formats vidéo ubiquitaires et immersifs pour le Big Data et le Cloud Computing, en allant plus vers des approches théoriques de représentation et de compression des signaux multimédia de type immersif, représentations parcimonieuses des signaux vidéo et optimisation convexe distribuée. Ces compétences plus théoriques permettront l'élargissement des méthodes et de leur champ d'application.

**Interactions multimodales, streaming et technologies web** Au même temps, l'interactivité, le streaming, les technologies web, les interactions multimodales en particulier pour la modélisation des émotions et l'interactions avec les avatars, continuent à se développer dans les domaines du Big Data, Cloud, Internet des objets, ce qui nous pousse à maintenir et renforcer nos compétences dans ces thématiques. Avec le passage en « émérite » d'un chercheur moteur dans le domaine de la biométrie, cette thématique réduit sa portée, mais le récent recrutement d'un EC permet recentrer nos activités dans cet objectif stratégique sur le dialogue multimodal humain-machine.

## D.13.3 Leviers prioritaires

1. Recrutement CDI EC / C pour l'objectif 1. En effet, cette compétence plus théorique est complémentaire de l'expertise de l'équipe, et permettra de proposer de nouveaux algorithmes. Au même temps, en renforçant l'aspect méthodologique de cet axe, cela nous permettra d'unifier les thématiques et d'aborder de nouveaux champs d'application.

2. Pérennisation du CDD d'un EC pour l'objectif 2. Dans le domaine de l'interactivité, du streaming, des technologies web interactives, notre expertise est reconnue au niveau international, dans les organismes de standardisation, ainsi que dans le milieu industriel. Nous sommes très sollicités pour de nombreux projets collaboratifs français et européens, ainsi que pour des contrats bilatéraux par des industriels du monde entier, et un des piliers de cette activité se trouve actuellement en CDD.
3. **Labo Commun** en compression sécurisée. Dans ce laboratoire commun, l'Institut Mines-Télécom et en particulier notre équipe apporte sa maitrise académique de la compression vidéo et du tatouage, Doremi qui est aujourd ?hui le leader mondial des serveurs de cinéma numérique, et Secure-IC qui apporte son expertise de design de composants de sécurité.
4. **Lancement d'un M2 – projet en cours** « Multimedia et Réseaux » UPSay, comme une spécialité du master Information, Systèmes et Technologie. Malgré un tissu industriel fort dans ce domaine, et une demande en formation continue soutenue, nous constatons aujourd'hui l'absence d'un master recherche spécialisé dans le multimédia. Nos contacts sur Saclay, et en particulier la collaboration de longue date avec le LSS nous permet de lancer les travaux d'un futur M2 de ce type. Les partenaires principaux seraient TPT, TSP, Supélec, Paris-Sud, Cachan, éventuellement UVSQ.

# D.14 Statistiques et applications (STA)

**Responsable** Stéphan Clémençon.
**Taille** 3 C, 7 EC, 17 doctorants.

## D.14.1 Expertises stratégiques

1. **Statistique pour l'Ingénierie en STIC**

   **Force de recherche** 5 permanents (30 %), 9 doctorants.

   **Production de recherche en 2012** 18 publications ; montant agrégé des contrats de recherche commencés en 2012 : 180 k€.

2. **Machine Learning**

   **Force de recherche** 5 permanents (40%), 4 doctorants.

   **Production de recherche en 2012** 10 publications ; 1 brevet ; montant agrégé des contrats commencés en 2012 : 355 k€ ; 1 chaire.

3. **Modélisation et Simulation**

   **Force de recherche** 4 permanents (30%), 4 doctorants.

   **Production de recherche en 2012** 16 publications ; montant agrégé des contrats commencés en 2012 : 543 k€.

L'expertise 1, originale au niveau national, et sur laquelle s'appuie de nombreux contrats du groupe avec des partenaires industriels, consiste en la capacité à développer/utiliser une très large panoplie de techniques relatives à la modélisation aléatoire et au traitement statistique de l'information (e.g. séries temporelles, statistique spatiale, théorie des valeurs extrêmes) pour résoudre des problèmes industriels (e.g. plans d'expérience, évaluation des risques, fingerprinting, détection d'anomalies) dans le domaine des STIC.

La recherche menée par le groupe en machine-learning consiste en l'élaboration d'algorithmes originaux et en l'analyse mathématique/empirique de leur validité (théorie de l'apprentissage et études expérimentales), en particulier dans les domaines du ranking et de l'apprentissage par renforcement (cadre requérant que l'algorithme d'apprentissage réalise de façon séquentielle un compromis entre l'exploration des possibles et l'exploitation des données disponibles). Cette recherche s'incarne aussi dans des applications menées en collaboration avec des industriels (e.g. planification d'expériences, design de moteurs de recherche/recommandation, aide au diagnostic médical, prédiction de séries financières).

L'activité de recherche dans le domaine de la simulation consiste principalement en le développement de techniques avancées de type Monte-Carlo et en leurs applications à l'inférence bayesienne (e.g. modèles statistiques à variables latentes, processus stochastiques). Cette expertise recouvre aussi les activités du groupe dans les domaine de la modélisation aléatoire (e.g. processus à mémoire longue, processus markoviens/ponctuels, théorie des valeurs extrêmes, matrices aléatoires), de la séparation de sources (avec des applications en traitement des données audio et des données astrophysiques) et de l'optimisation, dans un cadre «distribué» en particulier, avec pour champ d'application le traitement de l'information transmise par des réseaux de capteurs par exemple.

## D.14.2 Objectifs stratégiques

1. **Machine Learning for Big Data**
2. **Modélisation Probabiliste, Simulation et Calcul**

Le groupe souhaite maintenir l'expertise 1, très différenciante à l'échelle nationale et véritable «marqueur» du groupe. Elle souhaite également renforcer l'expertise 2 avec une nouvelle orientation dans le contexte Big Data. Le caractère massif et le format semi-structuré des données modernes ainsi que les usages pressentis dans de nombreux domaines d'application du machine-learning (e.g. défense, sécurité, médecine individualisée, finance, e-commerce) requierent le développement de méthodologies nouvelles, permettant en particulier le passage à l'échelle, l'apprentissage séquentiel («on-line») à partir de systèmes de fichiers distribués. L'expertise 3 sera réorientée vers d'autres applications que l'inférence statistique, le calcul scientifique en particulier, la simulation de processus complexes ou d'événements rares.

**Machine Learning for Big Data** Le développement de l'expertise Big Data correspond à un contexte national prioritaire en matière de politique numérique. En interne, il conduit à une augmentation de l'offre de formation (un Mastère Spécialisé «Big Data» et un Certificat d'Etudes Spécialisées «Data Science»), lesquels amènent le groupe à renforcer les collaborations avec le groupe IC2 du département INFRES sur les aspects liés au bases de données. Sur Saclay, le groupe participera à une nouvelle spécialité de master «Data Science» en cours d'élaboration ainsi qu'à des projets de recherche transversaux.

**Modélisation Probabiliste, Simulation et Calcul** La simulation et son application au calcul scientifique est un thème insuffisamment développé à l'école compte tenu des applications traitées (risque, évaluation de performance, recherche opérationnelle). Le calcul hautes performances est également un des trois axes prioritaires de la politique numérique en France. La recherche menée par le groupe dans ce domaine pourra s'appuyer sur la mutualisation des moyens (infrastructures informatiques) sur le campus Paris- Saclay, avec l'INRIA et le CMAP en particulier.

### D.14.3 Leviers prioritaires

1. **Chaire Machine Learning** L'animation de la recherche menée dans le cadre de la chaire industrielle avec les partenaires Safran, BNP, PSA et Critéo permettra d'accéder à des problématiques industrielles et de mener une recherche avec un fort impact sur le plan des applications. La plate-forme BADAP de l'Institut Mines-Télécom pourra être utilisée afin de tester les algorithmes élaborés en situation réelle.
2. Le développement d'un programme de recherche transversal au sein de Télécom ParisTech permettrait également d'aborder les problèmes posés par le Big Data dans sa globalité (*e.g.* acquisition, indexation et analyse sémantique, traitement statistique distribué des données).
3. Le fort impact sociétal des thèmes scientifiques évoqués appelle aussi une évolution profonde des enseignements de niveau master sur le campus Paris-Saclay, avec une tendance à la pluridisciplinarité (avec des parcours portant la mention «Mathématique et Informatique» par exemple), formant ainsi de nouvelles générations d'experts aux compétences plus complètes et aptes à aborder les challenges techniques et scientifiques actuels et à venir.
4. Le montage en cours de projets saclaisiens sur les thématiques «Big Data» et «Simulation-Calculs» permettra d'atteindre une complémentarité et une masse critique susceptible de conduire à une recherche compétitive à l'échelle internationale.
5. La répartition des (enseignant-) chercheurs du groupe STA sur les deux écoles doctorales «STIC» et «Maths» de l'université Paris-Saclay offrira enfin la possibilité d'une large couverture des thèmes de mathématiques appliquées.

# Sixième partie

# Annexes

# Chapitre E

# Règlement intérieur

## E.1 Réglement intérieur

Le règlement intérieur adopté en février 2006 (note : le GET est depuis 2006 devenu l'Institut Mines-Télécom et l'ENST Télécom ParisTech).

14/02/2006

# Règlement Intérieur

## GET/ENST – CNRS
## UMR 5141

## Laboratoire Traitement et Communication de l'Information (LTCI)

**Dispositions générales**

Le présent règlement s'applique à tous les agents CNRS ainsi qu'à tous les agents mis à la disposition du CNRS et intervenant dans les locaux du LTCI. Les agents de l'ENST, ainsi que les agents mis à la disposition de l'ENST et intervenant dans les locaux du LTCI sont régis par le règlement intérieur de l'Ecole Nationale Supérieure des Télécommunications, attaché en annexe.

Le personnel du LTCI ainsi que toute personne extérieure au LTCI intervenant dans les locaux du LTCI doit respecter les règles générales et permanentes relatives à la discipline ainsi que les mesures d'hygiène et de sécurité en vigueur à l'ENST et signifiées dans les notes de service et les instructions de l'ENST ou du GET.

**1- Conseil d'unité – Assemblée Générale**

**Le conseil de laboratoire :** il est présidé par le directeur de l'Unité. Il a un rôle consultatif et émet un avis sur toutes les questions relatives à la politique scientifique, la gestion des ressources, l'organisation et le fonctionnement de l'Unité.

Sa composition et ses modalités de fonctionnement sont prévues en application de la décision CNRS n° 920368SOSI du 28/10/1992 et de celle portant création du conseil de laboratoire du 07/02/2002 (DEC020008DR01) annexée au présent règlement intérieur.

**L'assemblée générale** comprend tous les personnels de l'Unité. Elle est réunie dans les conditions suivantes :

- 1 fois par an au moins,
- à la demande du directeur de l'Unité ou de la majorité qualifiée du conseil de laboratoire, avec un préavis de 15 jours.

14/02/2006

**2- Horaire, congés, absences**

La durée annuelle de travail effectif est de 1607 heures. Les modalités de mise en œuvre dans l'Unité pour les agents CNRS prennent en compte les dispositions figurant dans le décret n° 2000-815 du 25/08/00, 2004-1307 du 26/11/04 et du 22/11/05 (fixant la journée dite « de solidarité ») ainsi que celles énoncées d'une part dans l'arrêté du 31/08/01 et d'autre part dans le cadrage national du CNRS.

**2.1- Horaire de travail**

**- Durée hebdomadaire :**

La durée hebdomadaire du travail effectif pour chaque agent CNRS de l'Unité travaillant à plein temps, est de 38 heures 30 minutes sur cinq jours.
Les personnels autorisés à accomplir un service à temps partiel d'une durée inférieure ou égale à 80 % peuvent travailler selon un cycle hebdomadaire inférieur à 5 jours.
Le temps de travail correspond à un temps de travail « effectif ». Il ne prend pas en compte la pause méridienne obligatoire qui ne peut être inférieure à 45 minutes ni supérieure à 2 heures.
Les horaires, congés et absences des autres personnels sont soumis aux réglementations de leur organisme d'appartenance.

**- Horaires journaliers, ouverture du laboratoire, accès aux locaux**

La plage horaire de travail de référence commence à 8 h 45 et se termine à 17 h 30 du lundi au vendredi. La durée quotidienne du travail effectif ne peut excéder dix heures. L'amplitude maximale de la journée de travail ne peut excéder onze heures. Les agents bénéficient d'un repos minimum quotidien de onze heures consécutives.

L'accès aux locaux, pour tous les personnels, est normalement autorisé entre 7 h 45 et 19 h 45 du lundi au vendredi sur le site « Barrault » et de 7 h à 20 h sur le site « Dareau ». En dehors de ces horaires les plages d'ouverture des sites « Barrault » et « Dareau » du LTCI font l'objet d'un affichage sur les panneaux d'information interne prévus à cet effet.

**2.2 -Congés annuels**

Le nombre de jours de congés est de 45 jours ouvrés (c'est-à-dire du lundi eu vendredi) par année civile. Il prend en compte le nombre de jours de congés annuels (32 pour les personnels CNRS) et les 13 jours de congés accordés au titre de l'Aménagement de la Réduction du Temps de Travail (jours RTT) compte tenu de la durée hebdomadaire du travail adoptée dans l'Unité.
Les jours RTT sont utilisés dans les mêmes conditions que les jours de congés annuels.

Les personnels peuvent bénéficier de 2 jours de fractionnement des congés annuels : 1 jour si l'agent prend 5, 6 ou 7 jours en dehors de la période du 1er mai au 31 octobre et de 2 jours si ce nombre est au moins égal à 8 jours.

Les jours de congés sont accordés, après avis du responsable hiérarchique, sous réserve des nécessités de service.

Le report des jours de congés annuels ainsi que les jours RTT non utilisés, est autorisé jusqu'au 28 février de l'année suivante. Les jours qui n'auront pas été utilisés à cette date seront définitivement perdus.

**- Fermeture de l'Unité**

Les périodes de fermeture sont décidées en début de chaque année par le directeur d'Unité après avis du conseil. Les jours de fermeture sont déduits des congés annuels.

**- Compte - épargne temps**

En application du décret n° 2002-634 du 29 avril 2002 portant création du compte épargne temps dans la fonction publique de l'Etat, il est institué un compte épargne temps, dont la circulaire CIR040001DRH du 05/03/2004, annexée au présent règlement intérieur, précise les modalités de mise en œuvre.
Ce CET permet à son titulaire d'accumuler des droits à congés rémunérés.
La possibilité de bénéficier d'un CET est ouverte à l'ensemble des personnels (titulaires de l'Etat ou non titulaires ayant accompli plus d'un an de service de manière continue) exerçant leurs fonctions dans l'unité (y compris les agents détachés ou mis à la disposition de l'ENST).

**- Durée des absences de service pour congés**

L'absence de service ne peut excéder 31 jours consécutifs (la durée de l'absence est calculée du premier au dernier jour sans déduction des samedis, dimanches et jours fériés).

**- Suivi des congés**

Afin de pouvoir adapter l'organisation du travail, l'agent doit effectuer ses demandes de congé auprès du Directeur de l'Unité ou d'une personne désignée par lui, avec un délai de prévenance de quinze jours pour un congé supérieur à 15 jours, de huit jours pour un congé inférieur.
Le suivi des congés (annuels et RTT) est réalisé dans l'Unité à l'aide de formulaires prévus à cet effet sous la responsabilité du directeur, et transmis à la délégation (notamment pour la mise en œuvre du CET).

**2.3- Absence**

**- Absence pour raison médicale :**

Toute indisponibilité consécutive à la maladie doit, sauf cas de force majeure, être dûment justifiée et signalée au responsable de l'Unité dans les 24 heures. Sous les 48 heures qui suivent l'arrêt de travail le salarié doit produire un certificat médical indiquant la durée prévisible de l'indisponibilité.
Tout accident corporel survenant dans le cadre de l'activité professionnelle sera immédiatement déclaré auprès de l'Unité.

**- Mission**

Tout agent se déplaçant pour l'exercice de ses fonctions, doit être en possession d'un ordre de mission établi préalablement au déroulement de la mission. Ce document est obligatoire du point de vue administratif et juridique ; il assure la couverture de l'agent au regard de la réglementation sur les accidents de service.

L'agent amené à se rendre directement de son domicile sur le lieu de travail occasionnel sans passer par sa résidence administrative habituelle, est couvert en cas d'accident du travail sous réserve de remplir l'une des deux conditions suivantes :

- être en possession d'un ordre de mission sans frais,
- avoir une attestation de son directeur de laboratoire.

## 3 – Hygiène et Sécurité

Le personnel du LTCI est tenu d'observer les mesures d'hygiène édictées dans le cadre des dispositions légales et réglementaires en vigueur, et notamment dans le décret n°82-453 du 28 mai 1982 modifié, en annexe, ainsi que dans l'instruction générale n° 030039IGHS du 24 juin 2003, relative à l'hygiène et la sécurité ainsi qu'à la santé au travail au CNRS, en annexe. Ces dispositions sont complétées par des instructions et des notes de service affichées sur les panneaux d'information prévus à cet effet dans l'Unité.

Conformément à l'article 47 du décret n°82-453 du 28 mai 1982, des registres d'hygiène et de sécurité destinés à recueillir les observations et suggestions relatives à la prévention et aux risques professionnels, ainsi qu'à l'amélioration des conditions de travail, sont ouverts.
Les ACMOS sont désignés par les procédures en vigueur au sein de l'ENST.

## 4 – Valorisation, publications

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### 4.1- Confidentialité

Chacun est tenu de respecter la confidentialité des travaux qui lui sont confiés ainsi que ceux de ses collègues. En particulier, en cas de présentation à l'extérieur de l'Unité, l'autorisation du directeur de l'Unité, du responsable d'OR ou de département est obligatoire.

### 4.2- Publications

Les publications des membres de l'unité doivent porter les mentions « GET/Télécom Paris » et « LTCI, UMR 5141 CNRS », conformément aux recommandations de l'accord d'UMR.
Toutes les publications de l'unité doivent être enregistrées sur le site afférent de l'unité dès leur parution.

## 5 – Formation

Le plan de formation des personnels CNRS de l'unité est soumis pour avis au conseil de laboratoire. Le directeur de Laboratoire informe et conseille les personnels CNRS pour leurs besoins et demandes de formation. Il élabore le plan de formation des personnels CNRS. Le plan de formation des personnels ENST est assuré par la Direction des Ressources Humaines.

## 6 – Utilisation des moyens communs

### 6.1- Moyens informatiques

L'utilisation des moyens informatiques est soumise au respect du règlement informatique du SG/SIAV joint en annexe.

### 6.2 – Bibliothèque

L'utilisation des ressources de la bibliothèque est soumise au respect du règlement de la bibliothèque, joint en annexe

**Liste des Annexes :**

- Règlement intérieur de l'ENST
- Décision du 07 février 2002 de création du conseil de laboratoire
- Décision n° 920368SOSI du 28 octobre 1992 relative au conseil de laboratoire

- Décret n° 2000-815 du 25 août 2000 relatif au temps de travail dans la fonction publique
- Arrêté du 31 août 2001 relatif au temps de travail dans les établissements publics à caractère scientifique
- Décret n° 278-54 du 30 novembre 2004 relatif au temps de travail
- Liste des autorisations spéciales d'absence de droit
- Liste des autorisations d'absences dites mesures de « bienveillance »

- Décret n° 2002-634 du 29 avril 2002 relatif au compte épargne-temps
- Circulaire CIR040001DRH relative au compte épargne-temps au CNRS

- Décret n° 82-453 du 28 mai 1982 relatif à l'hygiène et la sécurité dans la fonction publique
- Instruction générale n° 030039IGHS du 24 juin 2003 relative à l'Hygiène et la sécurité au CNRS

- Règlement intérieur du SG/SIAV, moyens informatiques
- Règlement intérieur du SG/DOC, bibliothèque.

Paris le 17 février 2006

Le Directeur du LTCI
Henri Maître

Le Délégué régional CNRS Paris A
Tony Roulot

Le Directeur de Télécom Paris
Marc Peyrade

## E.2 Conseil de laboratoire

Suite à la précédente évaluation du laboratoire (en 2010) il avait été décidé d'élargir la composition du conseil de laboratoire, ce qui a été fait pour le mandat en cours (2011–2014). Au 30 juin 2013 le conseil de laboratoire était composé de :

**Membre de droit**

- Olivier CAPPE, directeur du LTCI

**Membres élus**

**dans le collège des personnels techniques et administratifs**

- Christophe GOSSET

**dans le collège des professeurs et directeurs de recherche**

- Jean-Claude BELFIORE
- Isabelle BLOCH
- Gaël RICHARD

**dans le collège des maîtres de conférences et chargés de recherche**

- Talel ABDESSALEM
- Patricia DESGREYS
- Gersende FORT
- Hugues RANDRIAMBOLOLONA
- Ghaya REKAYA-BEN OTHMAN
- Isabelle ZAQUINE

**dans le collège des doctorants et autres personnels**

- Georges GOURITEN

**Membres nommés**

- Marc BOURREAU
- Yves GRENIER, responsable du département TSI
- Armand LEVY, directeur de l'innovation et du développement
- Christian LICOPPE, au titre du département SES
- Laurent PAUTET, au titre du département INFRES
- Dario ROSSI
- Alain SIBILLE, au titre du département COMELEC

**Invités permanents**

- Patrick DUVAUT, directeur de la recherche
- Laurent GILLE, responsable du département SES
- Gérard MEMMI, responsable du département INFRES
- Bruno THEDREZ, responsable du département COMELEC

# Chapitre F

# Listes des personnels

Liste des personnels chercheurs et enseignants-chercheurs de l'unité présents au 30 juin 2013 et qui le seront toujours au 1er janvier 2015.

*Note : Il n'a pas été possible pour le 15 octobre 2013 de faire circuler cette liste afin de recueillir l'ensemble des signatures des personnels concernés. La liste comportant les signatures sera fournie lors de la visite d'évaluation.*

| **1. Radiofréquences et microondes (RFM)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| BEGAUD | XAVIER | PR | |
| BERGEAULT | ERIC | PR | |
| COUSIN | JEAN-CHRISTOPHE | MCF | |
| HUYART | BERNARD | PR | |
| LEPAGE | ANNE-CLAIRE | MCF | |
| ROBLIN | CHRISTOPHE | MCF | |
| SIBILLE | ALAIN | PR | |

| **2. Télécommunications optiques (GTO)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| ERASME | DIDIER | PR | |
| GABET | LAURENT | MCF | |
| GALLION | PHILIPPE | PR | |
| GRILLOT | FREDERIC | MCF | |
| JAOUEN | YVES | PR | |
| WARE | CEDRIC | MCF | |

| **3. Circuits et systèmes de communications (C2S)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| DESGREYS | PATRICIA | MCF | |
| LOUMEAU | PATRICK | PR | |
| NGUYEN | VAN TAM | MCF | |
| PETIT | HERVE | MCF | |

| **4. Electronique des systèmes numériques complexes (SEN-LabSoC)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| AMEUR-BOULIFA | RABEA | MCF | |
| APVRILLE | LUDOVIC | MCF | |
| COUDERT | SOPHIE | MCF | |
| DANGER | JEAN-LUC | PR | |
| DUC | GUILLAUME | MCF | |
| GRABA | TARIK | MCF | |
| HOOGVORST | PHILIPPE | CR | |
| MATHERAT | PHILIPPE | CR | |
| MATHIEU | YVES | PR | |
| NAVINER | LIRIDA | PR | |
| PACALET | RENAUD | PR | |
| POLTI | ALEXIS | MCF | |

| **5. Communications numériques (ComNum)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| BELFIORE | JEAN-CLAUDE | PR | |
| CIBLAT | PHILIPPE | PR | |
| HACHEM | WALID | DR | |
| REKAYA | GHAYA | PR | |
| RIOUL | OLIVIER | MCF | |
| RODRIGUEZ | GEORGES | MCF | |
| SOLE | PATRICK | DR | |
| TCHAMKERTEN | ASLAN | MCF | |
| WIGGER | MICHELE | MCF | |

| **6. Réseaux, mobilité et services (RMS)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| BONALD | THOMAS | PR | |
| BOUKHATEM | NADIA | PR | |
| CHAUDET | CLAUDE | MCF | |
| COUPECHOUX | MARCEAU | MCF | |
| GAGNAIRE | MAURICE | PR | |
| IANNONE | LUIGI | MCF | |
| KOFMAN | DANIEL | PR | |
| MARTINS GONCALVES | PHILIPPE | PR | |
| ROSSI | DARIO | PR | |
| ROUGIER | JEAN LOUIS | MCF | |

| **7. Systèmes, logiciels et services (S3)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| BELLOT | PATRICK | PR | |
| BORDE | ETIENNE | MCF | |
| DEMEURE | ISABELLE | PR | |
| DIACONESCU | ADA | MCF | |
| KUZNETSOV | PETR | PR | |
| NAJM | ELIE | PR | |
| PAUTET | LAURENT | PR | |
| ROBERT | THOMAS | MCF | |
| SHARROCK | REMI | MCF | |
| TARDIEU | SAMUEL | MCF | |
| VIGNES | SYLVIE | MCF | |

| **8. Interaction, cognition et complexité (IC2)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| ABDESSALEM | TALEL | PR | |
| BURTSCHY | BERNARD | PR | |
| DESSALLES | JEAN-LOUIS | MCF | |
| EAGAN | JAMES | MCF | |
| LECOLINET | ERIC | MCF | |
| SENELLART | PIERRE | MCF | |
| SOZIO | MAURO | MCF | |

| **9. Sécurité et réseaux (SR)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| ALLEAUME | ROMAIN | MCF | |
| DIAMANTI | ELENI | CR | |
| LABIOD | HOUDA | MCF | |
| LENEUTRE | JEAN | MCF | |
| MARKHAM | DAMIAN | CR | |
| SERHROUCHNI | AHMED | PR | |
| URIEN | PASCAL | PR | |
| ZAQUINE GROBON | ISABELLE | MCF | |

| **10. Mathématiques de l'information, des communications et du calcul (MIC2)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| COHEN | GERARD | PR | |
| DECREUSEFOND | LAURENT | PR | |
| HUDRY | OLIVIER | PR | |
| LOBSTEIN | ANTOINE | CR | |
| MADORE | DAVID | MCF | |
| MEYER | BERTRAND | MCF | |
| RANDRIAMBOLOLONA | HUGUES | MCF | |
| USTUNEL | ALI SULEYMAN | PR | |

| **11. Audio acoustique et ondes (AAO)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| BADEAU | ROLAND | MCF | |
| DAVID | BERTRAND | MCF | |
| ESSID | SLIM | MCF | |
| GRAMFORT | ALEXANDRE | MCF | |
| GRENIER | YVES | PR | |
| RICHARD | GAEL | PR | |

| **12. Traitement et interprètation des images (TII)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| ALMANSA | ANDRES | CR | |
| ANGELINI | ELSA | MCF | |
| BLOCH | ISABELLE | PR | |
| BOUBEKEUR | TAMY | MCF | |
| BRETTEL | HANS | CR | |
| CAMPEDEL | MARINE | MCF | |
| GOUSSEAU | YANN | PR | |
| LADJAL | SAID | MCF | |
| MEMARI | POORAN | CR | |
| NICOLAS | JEAN-MARIE | PR | |
| ROUX | MICHEL | MCF | |
| SAHBI | HICHEM | CR | |
| TIERNY | JULIEN | CR | |
| TUPIN | FLORENCE | PR | |

| **13. Multimedia (MM)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| CAGNAZZO | MARCO | MCF | |
| CLAVEL | CHLOE | MCF | |
| CONCOLATO | CYRIL | MCF | |
| DUFAUX | FREDERIC | DR | |
| LE FEUVRE | JEAN | MCF | |
| LIKFORMAN SULEM | LAURENCE | MCF | |
| MOISSINAC | JEAN-CLAUDE | MCF | |
| PELACHAUD | CATHERINE | DR | |
| PESQUET-POPESCU | BEATRICE | PR | |
| SIGELLE | MARC | MCF | |
| VALENZISE | GIUSEPPE | CR | |

| **14. Statistiques et applications (STA)** | | | |
|---|---|---|---|
| **NOM** | **PRENOM** | **CORPS** | **SIGNATURE** |
| BIANCHI | PASCAL | MCF | |
| CAPPE | OLIVIER | DR | |
| CARDOSO | JEAN-FRANCOIS | DR | |
| CLEMENCON | STEPHAN | PR | |
| FORT | GERSENDE | DR | |
| MOULINES | ERIC | PR | |
| ROUEFF | FRANCOIS | PR | |
| SALMON | JOSEPH | MCF | |