



# Research Report 2009-2011

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## Télécom ParisTech / LTCI



février 2012

# commu- -nication



# Research Report 2009–2011

Laboratoire Traitement et Communication de l'Information  
Institut Télécom - Télécom ParisTech & CNRS

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# Chapter 1

## General Survey of Research Activities

This report covers the period from June 2009 to December 2011. It takes place in the continuity of the “Research Report 2005-2009” (dated July 2009) issued for the previous AERES evaluation (March 2010) which may be found on our web site<sup>1</sup>.

### 1.1 Organization

#### 1.1.1 Télécom ParisTech and Institut Télécom

Télécom ParisTech is a member of Institut Télécom<sup>2</sup>, which also includes Télécom Bretagne, Télécom SudParis and Télécom Ecole de Management. Institut Télécom animates, federates and coordinates its research activities in the separate schools.

Coordination is made by means of a “*Comité Directeur de la Recherche*”, with two Sections, one devoted to Research, the other to Innovation. Coordination also takes the form of joint representations: for instance a unique Institut Carnot (*Télécom & Société numérique*<sup>3</sup>) covers the partenarial research of all the four schools (along with several external partners). In a same way, Institut Télécom is representing all the schools in the KIC ICT Lab<sup>4</sup>.

Scientific animation at the Institute level is made by use of transversal communities of research (called RT as *Réseaux Thématiques*) which cover the main research domains of the schools. The 9 domains active in 2012 are:

- RT1: Communication & Information Physics & Technology
- RT2: Networking architecture
- RT3: Networking services
- RT4: Contents, Knowledge & Interaction
- RT5: Network & information System Security
- RT6: Digital Health
- RT7: Information Technologies & Environment

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<sup>1</sup> <http://www.ltcj.telecom-paristech.fr/overview/article/rapports-d-activite-depuis-2002?lang=fr>

<sup>2</sup> On March 1st 2012, Institut Telecom was absorbed by the newly created Institut Mines-Telecom.

<sup>3</sup> [http://www.institut-telecom.fr/p\\_fr\\_recherche\\_carnot\\_1553.html](http://www.institut-telecom.fr/p_fr_recherche_carnot_1553.html)

<sup>4</sup> <http://eit.ictlabs.eu/>

- RT8: Information Technologies & Society
- RT9: Applied Maths & Theoretical Computer Sciences

### 1.1.2 Télécom ParisTech and LTCl (Laboratory for Communication and Processing of Information)

All the research activities of Télécom ParisTech are made within a joint laboratory with CNRS called UMR 5141 or LTCl. LTCl is part of INS2I, "*Institut des sciences et technologies de l'information et de leurs interactions*". It is also associated with INSIS ("*Institut des Sciences de l'Ingénierie et des Systèmes*") and with INSMI ("*Institut des sciences mathématiques et de leurs interactions*").

Within Télécom ParisTech, research is basically within the purview of the Director of Research (Henri Maître) and the Director of Innovation and Development (Armand Lévy).

The Direction of Research is in charge of the academic relationships, with universities and research institutes (CNRS, INRIA, INSERM, . . .), the evaluation of research, and the animation of research. The Direction of Innovation and Development acts in defense of the IP, in valorizing research results, in weaving partnerships with industries, in fostering innovation and start-ups. Both directions follow the Telecom ParisTech research and Innovation strategy as elaborated by the Direction Committee (CoDir or *Comité de Direction*) and discussed in the Research Committee (*Comité de la Recherche*). The Research Committee brings together representatives of the faculties, external experts from the industry and the university, and Télécom ParisTech Direction. The Lab Council (*Conseil de Laboratoire*) follows up the execution of research on a monthly basis.

Research at Telecom ParisTech is evaluated by AERES<sup>5</sup>. The last evaluation took place on March 2010. Telecom ParisTech received the highest grade:  $A^+$ . The next evaluation will probably take place in 2015.

An important element of the research activity is the Ecole Doctorale (ED 130 Edite<sup>6</sup>), where all the Ph'D candidates of Telecom ParisTech are registered. Edite is a joint Ecole Doctorale between Université Pierre et Marie Curie (UPMC) and Télécom ParisTech. In 2011 CNAM (*Conservatoire National des Arts & Métiers*), joined Edite as a third partner. Télécom ParisTech is entitled to deliver its own doctoral diploma. Edite has been evaluated as an  $A^+$  doctoral school in the 2008 evaluation campaign.

### 1.1.3 Télécom ParisTech and ParisTech

Télécom ParisTech is a founding member of the PRES (*Pôle de Recherche et d'Enseignement Supérieur*) ParisTech<sup>7</sup>, which groups 12 prestigious Grandes Ecoles on 3 sites: Paris Centre, Palaiseau-Saclay and Marne La Vallée. As an institute of science, technology and management, ParisTech covers the whole spectrum of science and technology plus management, and constitutes a unique potential of education and research. The complementary nature of ParisTech's fields of excellence is of major interest for Télécom ParisTech which finds in these companion schools the qualifications which may be absent rue Barrault.

ParisTech is influential on Télécom ParisTech's research through the *Commission Recherche* which elaborates joint programs (as for instance "Sustainable Mobility" or "Robotics"), federates international actions (with TÜM in Munich, NTU in Singapore, Jiao Tong in Shanghai or the IITs in India) and fosters joint responses to European calls (ULAB project). The *Collège des Directeurs d'Ecole Doctorale* is also an exceptional tool to improve the quality of the PhD programs through an intensive exchange of best-practices, sharing doctoral lectures and associating industrial partners to the doctoral education (*Cercle Docteurs et Entreprise*).

<sup>5</sup>Agence d'Evaluation de la Recherche et de l'Enseignement Supérieur

<sup>6</sup><http://edite-de-paris.fr/>

<sup>7</sup><http://www.paristech.fr/>

### 1.1.4 Organization at LTCI

Research is carried out within the four departments of Télécom ParisTech. They are in charge of elaborating the strategy for research in their domain of expertise. They decide upon the academic and industrial partnerships, they have the capability to engage their strengths in projects, to recruit non permanent scientific staff, to allocate means to specific operations. The four departments are:

- department of Communications and Electronics (Comelec), headed by Bruno Thédrez (Part: I), with four teams devoted to Digital Communications (ComNum, Chapter 2), Complex Digital Electronics Systems (SENLabsoc, Chapter 3), Electronics & RF Systems (EleCRF, Chapter 4), Optical Telecommunications (GTO, Chapter 5);
- department of Computer Science and Networks (Infres), headed by Gérard Memmi (Part: II), with five teams: Interaction Cognition & Complexity (IC2, Chapter 6), Mathematics of Information & Computation (MIC<sup>2</sup>, Chapter 7), Network & Information Security (SR, Chapter 8), Networks, Mobility & Services (RMS, Chapter 9), Software, Systems & Services (S3, Chapter 10);
- department of Economics and Social Sciences (SES), headed up to end of 2011 by Christian Licoppe, then by Laurent Gille (Part: III), with only one team but three main research axes: Regulation & Innovation (RINNO, Chapter 11.1), Mutation of Cultural Industries in a Digital World (MICEN, Chapter 11.2), Interaction, Technology & Activity (INTERACT, Chapter 11.3);
- department of Signal and Image Processing (TSI), headed by Yves Grenier (Part: IV) with four teams: Audio Acoustics & Waves (AAO, Chapter 12), Multimedia (MM, Chapter 13), Statistics & Applications (STA, Chapter 14), Image Processing & Understanding (TII, Chapter 15).

### 1.1.5 Personnel in the Service of Research

The official status of those contributing to research at Télécom ParisTech can be very varied ; permanent employees of Institut Télécom or of the CNRS, teaching staff, researchers or research assistants, engineers. Among non-permanent staff can be found professors on sabbatical or on assignment, post-docs, thesis students, engineers on short-term contracts and trainees (cf. Table 1.1).

**Permanent personnel** In December 2011, contributing to research were the following permanent members of the staff:

- **142 Teachers** ("enseignants-chercheurs" or EC) of the Institut Télécom: 52 Professors, 78 Associate Professors, 6 Directors of Studies, 5 Assistant Directors of Studies, 6 Lecturers.
- **11 Engineers or technicians of the Institut Télécom:** permanent members of the staff (Directors of Studies, Assistant Directors of Studies, Lecturers) who have chosen to take part in the research activities of the LTCI within a department by contributing to the development or maintenance of scientific or technical platforms (including equipment and software).
- **30 Permanent researchers from the CNRS** (13 Research Directors, 17 Research Fellows), representing various sections of the CNRS' National Committee: 07 (19 researchers), 34 (4), 01 (2), 08 (2), 27 (2), 36 (1).
- **1 Engineer of the CNRS** assigned to functions on the computer and networking systems.
- **1 Researcher from INRIA** (Research Fellows, assigned to work on research in the social sciences;

- **5 Outside adjunct researchers:** these researchers belong neither to the Institut Télécom or the CNRS but nonetheless carry out most of their research with teams working within Télécom ParisTech. They often co-author articles with members of the permanent staff of the Institut Télécom and members of the CNRS working within our institution.

Télécom ParisTech				CNRS (+INRIA)		
Prof + Dir Studies	Ass. Prof + Ass. Dir. S.	lecturers	Engin.	DR	CR	Engin.
55	78	15	11	13	18	1

Table 1.1: Numbers of teachers and researchers as in January 2012

**Non permanent personnel: doctoral students** The doctoral students constitute an important part of Télécom ParisTech's research potential. The institution currently has 334 registered doctoral students (see Table 1.2). Some are supervised by professors outside Télécom ParisTech in some partner's labs: at Eurecom, at INRIA, at ISEP. Their results are not collected in this report. Among the 257 students which are supervised by a professor of Télécom ParisTech, some spend most of their time outside, often in the research lab of a partner company: Orange, Alcatel-Lucent, Thales, among others. Many of them do their research part time at Télécom ParisTech and part-time outside. Their work will be presented in this report only to the extent that there is a significant connection with the research programs of Télécom ParisTech. The number of PhD students present on site is around 220 as an average.

Télécom ParisTech				Partner's lab			Total
Comelec	Infres	Ses	Tsi	Eurecom	Isep	Inria	
69	75	30	84	62	4	10	334

Table 1.2: Doctoral students registered at Telecom ParisTech as in January 2012

Among the 257 doctoral students under our supervision, a relatively small number (53) receive institution funding (see Table 1.2). The other students are often engaged on contracted research projects and grants (110) or are directly financed by our various partners (94). The country of origin distribution of our doctoral students is quite varied: 39 % are French, 14 % come from another European country, 6 % from America, 18 % from Africa and 23 % from Asia.

**Non permanent personnel: engineers, post-doc.** Assigned to contracted research done by Telecom ParisTech, an average of 60 short term employees are strenghtening our teams as engineers (25) or post-doctoral fellows (35). Their term varies from 12 to 16 months.

## 1.2 Research at a glance

### 1.2.1 Positioning of Telecom ParisTech research

LTCI and Telecom ParisTech have a specific positioning in French research to be fully and only addressing the domain of Sciences and Technologies of Information and Communication

allowances from MESR	12
allowances for students from X or ENS	8
allowances from Foreign countries	24
allowances from Institut Telecom: Futur & Ruptures IT	9
allowances from CEA, INRA, CNRS or CNES	11
finite term contract from Telecom ParisTech	51
doctoral contract from Telecom ParisTech	59
salaried employee under a Cifre convention	70
other salaried employees of a company	12

Table 1.3: Origin of the doctoral students salaries as in January 2012 (MESR = Ministry of Higher Education and Research, Cifre convention = state supported contractual relations between a lab and a company)

(STIC). It shares this property with its two sister schools: Telecom Bretagne and Telecom Sud-Paris. These activities range from the hardware layer (microwaves, antennae, electronics, optoelectronics, SOC, . . . ), to the economic and social issues of new communication technologies. They cover protocol and standardisation aspects as well as mathematical ones (graph theory, optimization, probabilities). They encompass studies on audio, video and images as well as studies on user-centric services, or quantum communication issues.

### 1.2.2 Major orientations in the period

The period covered by this report has seen several new developments of great importance for our lab. Some are presented below. The other will be discovered in the core of the report.

**Modelling imagination, innovation and creation.** An academic Chair of Research and Training has been founded in 2010 for a 5 year period : **Modélisations des imaginaires, innovation et création**. Headed by Pierre Musso, Professor in the SES department, it makes a link between the "Technologies of the Mind" (video games, virtual realities, and 3D artificial worlds) with humanities, social and cultural sciences of imagination and imaginary (see Chapter 11.3.3). With four industrial (PSA Peugeot-Citroën, Ubisoft, Dassault Systems and Orange) as sponsors and two academic partners (Telecom ParisTech and University Rennes 2) and the additional partnership of Bell Labs - Alcatel Lucent and DATAR<sup>8</sup>, the Chair is federating efforts issued from the SES department and the TSI and Infres departments as well, in a multidisciplinary attempt to improve the innovation process in high technologies (see Chapter 11.2).

**Development of Signal processing for high rate coherent optical communications.** At the cross road of Optical Communications and Theory of Communications, a new scientific project appeared to develop very high rate optical communications, taking benefit of advanced coding theories, smart signal processing algorithms and high speed computation (see Chapter 5). This domain is jointly developed by Yves Jaouën and Ghaya Rekaya Ben Otthman with the help of their colleagues of the ComNum and the GTO teams. Their efforts transpose in the domain of coherent optical processing the technologies which were proven efficient for software radio. They take the best of our experience in the ComElec department.

**Development of Affective Computing: interaction and embodied conversational agents.** A group, devoted to emotional computing, is born with the venue of Catherine Pelachaud, as a CNRS senior scientist in October 2008 (see Chapter 13.2.4). A first step was to set up the

<sup>8</sup>Délégation à l'Aménagement du Territoire et à l'Attractivité Régionale

platform of the embodied agent GRETA which progressively received emotional behaviors, then social behaviors and is now enriched with interactive capabilities. The software has been rewritten to run independently of the technology and adapted to NAO robots. The Emotional Group team is now made of 4 postdocs, 2 engineers and 6 doctoral students and welcomed 3 senior scientists on sabbatical leave. It has been seminal in 6 European projects and 6 national projects (4 ANR and 2 FUI). As a testbed, GRETA is used by several PhD to experiment new theories on emotional behaviors when performing social links with embodied agents.

**Computer Graphics, Digital Geometry and Rendering.** A new research group arose with the arrival of Tamy Boubekeur in the TII group in 2009 (see Chapter 15.2.4). Fastly growing with the additional arrival of 3 young research scientists (2 from CNRS and 1 from Telecom ParisTech), this group also hosts 6 doctoral students and welcomes several visiting professors. It now covers a large range of domains as 3D geometric modeling, rendering, perception and visualization. Its scientific production has yet been fully appreciated in the main arenas of the computer graphics community: SIGGRAPH and EUROGRAPHICS for instance. One of its middle term goals is to bridge the gap with the image processing and computer vision fields covered by the other scientists of the TII group.

**Information Security and Network Team.** The extremely fast development of networking activities has fostered the creation of a Team on Network and Information Security. With security-oriented researchers issued from the various teams of the InfRes department, this team is in charge of research to improve the resilience and the security of modern IT infrastructures both from manageability (operator-centric view) and usability (user-centric) aspects (see Chapter 8).

**Identity & Security Alliance.** March 31, 2011, Morpho (Safran Group) and Telecom ParisTech (InfRes, Comelec and TSI departments) launched a common research laboratory, the IDentity & Security Alliance to address the technological challenges of identity protection and data security. The laboratory will focus on developing and enabling next-generation identity-based applications while guaranteeing security and privacy. It aims to cover research topics such as biometrics, IT security, cryptography, components security, and identity management systems.

**Ingénierie des Systèmes Complexes Chair.** Thales, Dassault Aviation, DGA (*Direction Générale de l'Armement*), DCNS, as well as three components of ParisTech, Ecole Polytechnique, ENSTA ParisTech et Telecom ParisTech signed on November 2011 an important extension of the chair *Ingénierie des Systèmes Complexes*. This chair settled in Saclay, is focusing on education and research on architecture, design, and development of systems. It will allow the Infres department to develop research on middleware of complex systems, in particular on ambient or autonomous architectures.

### 1.2.3 Highlights of research at Telecom ParisTech over the period

#### Main research events in 2009

- Telecom ParisTech, as part of the Institut Telecom, joins the **RTRA** (Advanced Research Thematic Network) **Digiteo**, the only Excellence cluster in information science and technology in France, situated in the Saclay Campus. Digiteo is supported by the Ministry of Higher Education and Research, it hosts 1800 researchers from the main research labs: CNRS, INRIA, Polytechnique, Université Paris Sud-Orsay, ENS Cachan, Supelec, Centrale, CEA-LIST.
- Telecom ParisTech participates in the founding of 2 GIS (*Groupements d'Intérêt Scientifique*) with his academic partners to develop his research:



1. **GIS PariStic** with the LIP6 Lab of Université Pierre et Marie Curie, in the domains of Computer Science, Data Management, Networking, etc.
  2. **GIS eSys** with 7 labs: Telecom ParisTech, SupElec, Universities Paris VI and XI, ES-IEE, ISEP and CNRS, in the domain of conception of analog and hybrid circuits (see Chapter 3).
- Aslan Tchamkerten, Associate Professor in the Comelec Department receives an **ANR Junior Excellence Chair** to develop asynchronous communications (see Chapter 2).
  - ENSTA ParisTech and Telecom ParisTech decide to coordinate their research in telecommunications. Research teams of ENSTA ParisTech and Telecom ParisTech working on propagation channels, antennae, and electromagnetic propagation, merged in a single team, in a laboratory based at LTCI, and the anechoic room of ENSTA ParisTech transported into the Telecom ParisTech Lab (see Chapter 4).
  - In 2009 finished the important **Infom@gic project**, one of the flagships of Cap Digital cluster in which almost 20 teams of many academic and private labs from the whole Ile-de-France region collaborated on the topic of data management. Telecom Paristech has been an important partner of Infom@gic, involved in speech and image indexing and retrieval, in video analysis and in machine learning (see Chapters 12 and 15).
  - a joint laboratory between Telecom ParisTech, Telecom Bretagne and Orange is created devoted to studying the effects of electromagnetic waves on the human body. The **WHIST lab** (Wave Human Interaction & Telecommunication Lab) is directed by Dr Jo Wiard from Orange and located in Telecom ParisTech (see Chapters 15 and 4).
  - The **LINC**, a joint Lab with INRIA, Telecom ParisTech, Université Pierre et Marie Curie and Technicolor is created, to foster the theoretical studies on Futur Networks. LINC is located in a building shared by the 3 academic partners, but in its own spaces, close to the main buildings of Telecom ParisTech (see Chapter 9).
  - ParisTech and Renault Foundation create the **Sustainable Mobility Lab**, of which Telecom ParisTech is a partner, involved in research and education as well (see Chapters 9 and 11.3).

### Main research events in 2010

- Eric Moulines, Professor in the TSI department, receives the **CNRS Silver Medal** for his career in signal processing and machine learning (see Chapter 14).
- Nancy Bertin, a PhD from TSI/AAO, receives the **SPECIF / GretsI / GdR Isis Theses Award** (see Chapter 12).
- Antony Leverrier, a PhD from INFRES/MIC2, receives one of the **ParisTech Theses Awards** (see Chapter:8).
- Hichem Sahbi, a CNRS research fellow at LTCI in TSI/TII, and Xi Li, a post-doc, receive the **best paper prize** from ACV2010 Conference at Queenstown (New Zealand) (see Chapter 15).
- Charles Antoine Deledalle (doctoral student at TSI/TII) supervised by F. Tupin (Prof), L. Denis (Ass. Prof in Lyon) receives the **best student paper award** from the IEEE ICIP 2010 in Hong Kong (see Chapter 15).
- Nicolas Widynski (doctoral student at TSI/TII and UPMC) receives the **best paper award** from RFIA 2010 Conference in Caen (see Chapter 15).

### Main research events in 2011

- Éric Moulines, professor at TSI/STA, receives the **Grand Prix 2011 France Télécom de l'Académie des Sciences** (see Chapter 14).
- Laura Draetta, associate professor at SES department in its Sophia-Antipolis premises, receives the **Prix 2011 de la Croissance Verte Numérique** for her work on the social acceptability of IT (see Chapter 11.1).
- Michèle Wigger, associate professor at ComElec/ComNum, is laureate of the **Emergence(s) Program** from the City of Paris for her project “ Pushing the Performance Limits of Wireless Networks by Exploiting Side-Channels ” (see Chapter 2).
- Julien Cornebise, doctoral student from University Pierre et Marie Curie, co-supervised by Éric Moulines, receives the **Savage Award** from the International Society for Bayesian Analysis (see Chapter 14).
- Results on modelling foetus and pregnant woman from medical imaging and using computer graphics modelling, within the joint Orange / Institut Telecom WHIST Lab, receive the **Eurographics Medical Prize Awards (Honorable Mention of the Dirk Bartz Prize for Visual Computing in Medicine)**(see Chapter 15).
- Elmar Eisemann, associate professor at TSI department receives the **Eurographics Young Researcher Award** from Eurographics Society (see Chapter 15).
- Quang Hien Chu, doctoral student under the supervision of Jean-Christophe Cousin, associate professor at ComElec department, receives the **VTC2011 Best Student Paper Award** at the IEEE-VTC2011-Fall Conference in San Francisco (see Chapter 4).
- Houssein Maghrebi (doctoral student), Sylvain Guilley (ass. prof.) and Jean-Luc Danger (prof) from ComElec Department receive the **WISTP'11 Best Paper Award** at the “WISTP'11 Security & Privacy of Mobile Devices in Wireless Communications ” Conference in Heraklion (Greece) (see Chapter 4).

## 1.2.4 International Research program

### Distinguished guest visitors

Telecom ParisTech used to host visiting scientists either to foster new collaborations or to strengthen existing ones. The list is presented in Table 1.4 with the hosting team of the visitor.

### Telecom ParisTech Professors abroad

Telecom ParisTech encourages also his staff to spend research periods in foreign universities. In Table 1.5 the sabbatical stays of our professors abroad are presented.

## 1.2.5 Scientific production

### Publications

A survey of the scientific publications in the last four years is presented in Table 1.6. We may notice that these publications are more or less steady, with a trend to decrease for communications in conferences and a trend to grow for peer reviewed journals. The objective to have an average of 1 publication in peer-reviewed journal per permanent researcher is constantly overtaken. An exact situation at the team level is provided in the following chapters. Notice the exceptional figure for PhD theses in 2010, the year were the new governmental recommendations to prevent long-during thesis were put in application. Notice also the constant flux of patents which started up in the early 2000.

Visiting guest	University	Period	Host lab
Murad Taqqu	Boston University, (USA)	5-09	STA
-	-	5-10	-
-	-	5-11	-
Naofumi Homma	Tohoku University, (Japan)	4-09 : 5-10	SEN
Hong Sun	Wuhan University, (China)	7-09 : 8-09	TII
-	-	5-10 : 6-10	-
-	-	6-11 : 9-11	-
Richard Lepage	ETS Montréal (Canada)	5-09 : 8-09	TII
Rod Watson	University of Manchester (GB)	5-09	INTERACT
-	-	6-10	-
-	-	6-11	-
Marat Burnashev	Academy of Sciences - Moscow (Russia)	3-10	COMNUM
-	-	10-10 : 1-11	-
Carlo Cambini	Politecnico di Torino (Italia)	10-10 : 12-10	RINNO
Dirk Heylen	University of Twente (Netherland)	6-10 : 10-10	MM
Charles Crook	University of Nottingham (GB)	3-10 : 6-10	INTERACT
Daniela Tuninetti	University of Illinois (USA)	9-09 : 8-12	COMNUM
Lorenzo Bruzzone	University of Trento (Italia)	6-11	TII
Michael Lindenbaum	Technion - Tel Aviv (Israel)	3-11 : 9-11	TII
Kari Kuuti	University of Limerick (GB)	6-11	MICEN
Christian Heath	Kings College London (GB)	6-11	INTERACT
Candy Sidner	Worcester Polytechnic Institute (GB)	8-11	MM
Mariano Tepper	University of Minnesota	10-11	TII
Janos Korner	La Sapienza - Roma (Italia)	6-11 : 7-11	MIC2
Valerio Pascucci	University of Utah - Salt Lake City (USA)	6-11 : 7-11	TII

Table 1.4: Foreign visiting scholars invited in the period July 2009 - Dec 2011

### HdR: Habilitations à Diriger des Recherches

This grade is an important step in the career of a French scientist. It allows him/her to officially supervise alone a doctoral student. HdR are granted by the universities after a public defense of the candidate. We present in Table 1.7 the list of the HdR which have been obtained by the Telecom ParisTech faculties in the reference period.

### Grants and financial supports

Table 1.8 presents a survey of the research funding for each department as a result of the applications to national grants (ANR or FUI), of European grants (STEP, NOE, ...) or as direct partnerships with companies or agencies. Notice the importance of the growth of these resources.

### 1.2.6 Participation to *Investissements d'Avenir*

The French government decided in 2009 to open a series of programs to stimulate the emergence of novel structures for research. Based on the model of competitive calls for participations, with international committees, these programs received an exceptional attention all over France.

Telecom ParisTech took part with various partners to the different calls. In February 2012, the following projects of which Telecom ParisTech is member have been laureates:

- **Initiatives d'Excellence (IDEX):** the Université Paris-Saclay IDEX built on a consortium of

Professor	University	Period	from Lab
Jean Louis Dessalles	Tokyo University (Japan)	9-09 : 3-10	IC2
François Roueff	Université de Louvain la Neuve (Belgium)	9-10 : 9-11	STA
Elsa Angelini	CSIRO Health Res. Center Brisbane (Australia)	2-10 : 9-10	TII
Cédric Ware	Columbia University - New York (USA)	10-10 : 9-11	GTO
Nadia Boukhatem	Univ. of California Los Angeles (USA)	1-11 : 7-11	RMS
Jean-Louis Rougier	Univ. of California Los Angeles (USA)	1-11 : 7-11	RMS
Annie Gentès	Oxford University (GB)	1-11 : 6-11	MICEN
-	Stanford University (USA)	6-11 : 12-11	-
Marceau Coupechoux	IIT of Bangalore (India)	9-11 : 9-12	RMS
Eric Bergeault	XLIM CNRS Lab, University of Limoges (France)	9-11 : 9-12	RF
David Bounie	Carnegie-Mellon, Pittsburg (USA)	9-11 : 9-12	RINNO

Table 1.5: Scholars from Telecom ParisTech on sabbatical leave in the period July 2009 - Dec 2011, with their hosting labs.

	2008	2009	2010	2011
peer reviewed journals	196	186	207	203
international peer reviewed conferences	423	395	438	416
articles in a collection	19	17	10	9
full proceedings of conferences	5	1	3	2
books	16	14	11	14
chapters of a book	29	45	28	32
patents	17	14	6	6
PhD theses	76	79	111	68

Table 1.6: Scientific production

18 partners<sup>9</sup> has been accepted as one of the 8 French Idex.

• **Laboratoires d'Excellence (LABEX):**

- Labex Digiworlds, in Saclay, focused on Computer Sciences and STIC, with 3 domains of specific interest:
  - \* Software development, Security and Model checking,
  - \* Networking and Information Theory,
  - \* Big data, Learning and Visualization.
- Labex LMH, in Saclay, on Mathematics, both theoretical and applied to Biology, Engineering, STICS and Physics
- Labex SMART, in Paris, on advanced Man-Machine Interaction in the society (modelling of human, human between real and virtual worlds, etc.)
- Labex UCN@SOPHIA, in Sophia-Antipolis, on user-centric networking.

• **Equipements d'Excellence (EQUIPEX):**

- Equipex Digiscope, in Saclay and Paris, on Man-Machine Interaction, Visualization and Interaction for very large data bases, with applications in medical imaging, satellite imagery and the Social Sciences

<sup>9</sup>Université Paris-Sud, Université Versailles Saint-Quentin, Polytechnique, Centrale, Sup-Elec, ENSTA ParisTech, Institut d'Optique Graduate School, Agro-ParisTech, HEC, ENSAE ParisTech, Institut Telecom, ENS Cachan, CEA, CNRS, INRIA, Inserm, Onera, INRA, IHES.

Name	Team	University delivering the grade	Date
Brigitte Munier-Temime	Micen	University Paris V	July 2009
Annie Gentès	Micen	University of Avignon	July 2009
Yann Gousseau	Tii	ENS Cachan	Oct. 2009
Jamal Najim	Sta	University of Marne-la-Vallée	Oct. 2009
Valérie Fernandez	Interact	University Panthéon Assas	Dec. 2009
Thomas Bonald	Rms	University Pierre & Marie Curie	Jan. 2010
Gersende Fort	Sta	University Paris-Dauphine	Feb. 2010
Patricia Desgreys	Sen	University Pierre & Marie Curie	Sept. 2010
Maya Baccache	Rinno	University Paris-Sorbonne	Sept. 2010
Ahmed Serhrouchni	Rms	University Pierre & Marie Curie	Oct. 2010
Roland Badeau	Aao	University Pierre & Marie Curie	Nov. 2010
Jean-Louis Rougier	Rms	University Pierre & Marie Curie	Dec. 2010
Jean-Claude Dufourd	Mm	University Pierre & Marie Curie	Dec. 2010
Dario Rossi	Rms	University Pierre & Marie Curie	Dec. 2010
Elsa Angelini	Tii	University of Nice Sophia-Antipolis	Jan. 2011
Hichem Sahbi	Tii	University Pierre & Marie Curie	June 2011
Aslan Tchamkerten	Comnum	University of Marne-la-Vallée	July 2011
Sylvain Guilley	Sen	University Paris Diderot	July 2011
David Bounie	Rinno	University of Strasbourg	Sept. 2011
Julie Delon	Tii	ENS Cachan	Oct. 2011
Pascal Blanchi	Sta	University of Marne-la-Vallée	Nov. 2011
Aurélien Garivier	Sta	University of Paris-Sud Orsay	Nov. 2011
Céline Lévy-Leduc	Sta	University of Paris-Sud Orsay	Dec. 2011

Table 1.7: *Habilitation à Diriger des Recherches* granted to LTCI members in the period July 2009 - Dec 2011

- Equipex FIT Future Internet of Things, in Paris, establishing testbeds on wireless and wired technologies for networked and embedded objects
- Equipex DIME-SHS, in Paris, collecting data on the web for the Social Sciences, developing qualitative data banks and tools and methods to process them.
- **Instituts de Recherche Technologique (IRT)**: IRT SystemX, in Saclay, Paris, and Bruyères-le-Chatel will focus on systems of systems applying technologies like embedded systems, high performance computing, cloud computing and network architecture, simulation and design environments to energy management, multimodal transportation, and digital security and trustworthiness.

	2007	2008	2009	2010	2011	Total
Comelec	1 979	1 745	1 686	1 975	2 473	9 858
Ses	1 464	1 574	1 555	2 102	2 405	9 100
Infres	4 181	3 020	3 152	2 945	2 634	15 932
Tsi	1 686	2 018	2 116	3 301	3 558	12 678
Total	9 310	8 356	8 509	10 329	11 072	38 258

Table 1.8: Grants and contracts in keuros by department.

**Part I**

**Communications and Electronics**





# Communications and Electronics Department (COMELEC)

The research led in the “ **Communications and Electronics** ” department is devoted to the physical layer of ICT (Information and Communication technology). A useful concept for depicting the department main research concern is that of “physical information”, where the information content is actually reached through some physical properties and manipulated using physical laws such as Maxwell electromagnetic equations or Quantum Hamiltonians. The department covers both the field of communication and that of information processing (electronics).

The department accounts for 39 permanent research staff and hosts over 100 non permanent researchers every year, including PhD students. The research activity is covered by four different teams. While fixed communications are dealt with by the **Optical communication team**, the **Electronics and RF systems team** concentrate on the transformation from analog to digital information and to its transmission through wireless means. The **Digital communications team** works on the digital coding of the information, and prepares for the future digital communication breakthrough in cooperative system, multi-hop communications or multi-users wireless communications. Processing information requires extremely sophisticated Silicon chips (processors, FPGAs, SOCs), the architecture of which is central to the **Complex Digital Electronics system team**. Transverse to all these activities, one may also find security as a main topic.

The department research policy claims for a research effort that spreads from fundamental physics to applied results. One may for example note our results in quantum communication (see the optical communication team) or that of metamaterials for advanced antennas (Electronics and RF Systems team). The balance between exploratory research and market oriented results is well expressed by the 1:5 ratio between our private partners funding and our total research contract income (4.7 M€ cumulated over the period). Because of an innovation minded research taking its roots in fundamental theories, the department was granted 16 patents while publishing over 450 papers in journals and conferences in the evaluation period.

The department is also strongly involved in educating students for research. This is reflected by the 51 defended PhD thesis over the period. A budget of about 40 k€ is also spent yearly for master student internships in the department research groups, with a total of about 80 man.month of internship generated every year. Besides its contribution to the “ingenieur courses” of Telecom ParisTech, the department researcher’s participate to master courses with Universities Pierre et Marie Curie and Paris-Sud Orsay, as well as with the University of Nice.

The past period has been an exciting and successful period for the department. The success of our research proposals is well expressed by steady 15% growth rate per year of our lab contractual budget. As an indication of the department growing international recognition, the amount of international contract has raised from 13% in 2009 to 39% in 2011. In terms of publication, this growth reflects in as much as 99 published peer reviewed journal papers and 349 conferences accepted in the last two and a half year.

The period has also been very active for our lab facility with the launching in January 2010 of a new 130  $m^2$  lab area, including a 40  $m^2$  anechoic chamber for our antenna tests. Another 300  $m^2$  of laboratory floor were entirely refurbished, giving rise to an environment entirely devoted to very high frequency experiments. These changes were strengthened by the purchase of nearly

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800 k€ of new scientific equipments.

Two other major events with long lasting consequence must also be pointed out.

- A research team from ENSTA ParisTech merged with the Telecom ParisTech RFM team in 2010, making Telecom ParisTech an internationally recognized environment for UWB antenna design and applications.
- The joint ParisTech Morpho Lab "Identity & Security Alliance" which was inaugurated in march 2011 was created from teams in the Infres and Comelec department , a recognition of the successful research in embedded electronics security which is led in the department.

The coming period should open new opportunities for the development of our research. Discussions for joint research labs have already been open with several companies. Novel research masters will be proposed in 2012 for accreditation. And overall, a number of exciting new research projects in all of our research segments are already under consideration for fixed and wireless high bit rate communications with terabit/s communications in mind, in opportunistic radio, in secured electronics, or sustainable ICTs.

Faculty [IT, CNRS]	[32.8, 4]
PhD students	65.5
Post-docs, engineers and sabbaticals	16.1
Defended PhD thesis	51
Defended HDR	3
Journal papers [published, in press]	[99, 15]
Papers in conference proceedings	349
Chapters and books	15
Patents and software	[16, 3]
Grants [public, private, european] (k€)	[2667, 876, 1207]

## Chapter 2

# Digital Communications

**Team leader** Philippe Ciblat (P).

### Faculty

Jean-Claude Belfiore (P), Philippe Ciblat (P),  
Walid Hachem (DR CNRS), Ghaya Rekaya-Ben Othman (MC),  
Olivier Rioul (MC), Georges Rodriguez (MC),  
Patrick Sole (DR CNRS), Aslan Tchamkerten (MC),  
Michele Wigger (MC,12/09–).

### PhD students

A. Le Poupon (09/02–09/09), Z. Zhao (10/05–09/10), C. Hucher (01/06–07/09),  
R. Ouertani (01/06–11/09), 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), C. Abgrall (02/08–10/10),  
A. Osmane (10/08–12/11), A. Charaf (11/08–), M. Plainchault (11/08–),  
P. Delesques (09/09–), M. Sefidgaran (10/09–), C. Mihoubi (11/09–),  
D. Serrano-velarde (11/09–), S. Marcille (01/10–), S.H. Mirghasemi (03/10–),  
F. Iutzeler (10/10–), M.M. Azeem (01/11–), L. Sok (01/11–),  
J. Vinogradova (09/11–), S. Belhadjamor (10/11–), Y. Wu (10/11–).

### Post-docs and engineers

L. Luzzi (10/07–05/10), M. Sarkiss (02/09–08/10), F. Chapon (11/10–10/11),  
M.R. Palattella (07/11–10/11).

### Sabbaticals

M. Burnashev (09/10–10/10), P. Saxena (12/10–12/10), M.C. Estela Zamora (03/11–04/11),  
L. Budaghyan (04/11–10/11), C.C. Trinca (04/11–), S. Jitman (09/11–09/11),  
D. Tuninetti (09/11–).

Faculty [IT, CNRS]	[6.8, 2]
PhD students	13
Post-docs, engineers and sabbaticals	1.8
Defended PhD thesis	15
Defended HDR	2
Journal papers [published, in press]	[25, 9]
Papers in conference proceedings	81
Chapters and books	1
Patents	6
Grants [public, private, european] (k€)	[322, 162, 163]

## 2.1 Objectives

For the last five years, the Digital Communication team has mainly been working on the physical layer of wireless networks. The most important results were 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), and finally multi-user cellular networks (when the communication is one-to-many or many-to-one). In such contexts, the team has focused on finding new:

- Coding techniques
- Resource allocation algorithms
- Estimation and synchronization methods

Nowadays, the most important topic is to design, analyze, and optimize many-to-many (wireless) communications where different flows of information are propagating through a common wireless network. Depending on the application, the network may be either centralized or ad hoc. The digital communications group has followed this important evolution by working on so-called Mobile Ad Hoc Networks (MANET). Our contributions cover different points of view: information theory, coding, resource allocation, distributed signal processing, and security (which is a major concern in such networks). Notice that the group has been enforced by hiring new Associate Professors in the area of Information Theory.

Even if our activities on wireless networking are central, we are also pursuing significant research activities on the (more traditional) physical layer of wireless or wired networks. Our main contributions here are new codes (asynchronous codes, etc.) and improved cross-layer designs (hybrid ARQ which takes into account the network layer) for wireless networks, and new signal processing algorithms and codes for next generation fiber-optical systems. This last project is a collaboration with the Optical Telecommunications team. In our research we typically present solutions on the three important facets of signal processing, coding, and information theory.

The team has important international editorial activities: we take part in the technical committee of the flagship conferences and in the editorial board of IEEE Transactions on Information Theory and IEEE Transactions on Signal Processing. All our research activities are supported by national, European, or industrial funding.

Our group is also very active in teaching for the Engineering school as well as for various Masters programmes. In particular, jointly with the Université Pierre et Marie Curie, we are leading the "Master Recherche" called ESCO/STN.

## 2.2 Main Results

The main research results obtained during the period July 2009 - December 2011 are presented below.

### 2.2.1 Wireless Network Optimization

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

**Main events** Philippe Ciblat has served as Associate Editor (resp. Area Editor) for IEEE Transactions on Signal Processing since 2008 (resp. 2010) as well as Track Chairman for the European flagship conference EUSIPCO'2001. Philippe Ciblat, Walid Hachem, and Michèle Wigger have been respectively invited professors at the International University of Rabat (Morrocco), the CTTC (Spain), and the Technion (Israel).

**Projects** ANR Chaire d'Excellence, "Futur & Ruptures" grants, DGA doctoral grant, Digiteo post-doctoral fellowship, ANR SESAME, Emergence Grant from the City of Paris, FP7 NoE NEW-COM++

**Wireless network coding** Wireless networks for high data rate transmissions are becoming more and more dominated by interference. Fundamental works in Information theory clearly shed a light by using lattices on this problem. But information theory states the fundamental limits but does not say anything about "how to achieve these fundamental limits". Thanks to our expertise concerning lattices for wireless communication, we obtained important results on lattice coding for interference channels. We are now able to propose new lattice coding schemes and analyze them. We are currently working on lattice network coding for which we were able to give a criterion of design for the lattice codes that are used. This work was a generalization of the so-called Compute-and-Forward protocol proposed by Nazer and Gastpar in 2009. In the same spirit, we started to work on the interference channel where we focus on the so-called lattice alignment for the interferers. This work had a big impact, theoretically and practically. We are developing some new tools to understand in a better way the behavior of lattices on such channels and relate it to the fundamental limits.

**Fundamental Limits** We studied the capacity of wireless networks where the transmitters or the receivers have some side-information, e.g., about other transmitters' messages or signals, or about the signals observed at some of the (other) receivers. Our contributions were twofold:

i) For the many-to-many interference network where the transmitters have side-information about the adjacent transmitters' messages (e.g., by prior communication over separate bluetooth links) and the receivers have side-information about the signals observed at adjacent receivers (e.g., by communication over a high-rate backhaul link) we studied the high-SNR behavior of the capacity. We mainly focused on Wyner's soft handoff model for cellular systems, for which we determined the degrees of freedom. Our result allowed us to establish a duality between the side-information at the transmitters and the side-information at the receivers in the sense that in terms of degrees of freedom they are equally valuable. We also determined the degrees of freedom when the transmitters only have partial knowledge of their adjacent transmitters' messages.

ii) For the one-to-two memoryless broadcast channels (BC) where the transmitter has feedback from both receivers (as is the case in most uplink-downlink scenarios) we studied the capacity region. This problem is unsolved for almost all memoryless BCs. In our works, we determined the capacity region of some BCs, and we proved that the capacity is increased even if the feedback is noisy. We also showed that for Gaussian broadcast channels in some cases the gain in capacity thanks to perfect feedback can be unbounded, and in most cases the high-SNR capacity is as if both receivers could perfectly cooperate. [5]

Motivated by practical communications systems, such as certain wireless sensor networks, the receiver of a communication system does not know perfectly the timing of information transmission and this leads to the so-called "asynchronous communication". This kind of communication has long been a neglected field in information theory. We have been investigating a new information theoretic model for asynchronous communication. Main results are the characterization of the minimum energy needed to transmit one bit of information asynchronously, and the proof of suboptimality of training in certain communication regimes. The second result says that the prevalent communication architecture where synchronization and information transmission are treated separately can be suboptimal; each transmitted bit should carry information while help the decoder locate the transmitted message [111].

**Distributed computation** In distributed computation/optimization/estimation communication is becoming a technological bottleneck. The problem arises both at the large and at the micro scales. Consider the task Google faces for search queries. After the query makes its way to a data center, the search task is handled to a number of servers working in cooperation. Yet, the minimum communication requirement to take advantage of multiple servers is not well understood. More traditionally in the field of wireless sensor networks, resource allocation without a fusion center has to operate and can only be done in a distributive way. Similar problems occur for target location, etc.

We have focused on two types of computation: the maximum values of the sensor measurements and the average ones. Concerning the maximum computation, we have developed new algorithms well suitable for wireless communications. The main task has consisted in analyzing theoretically its performance [65]; Concerning the average computation, new powerful algorithms outperforming existing ones have been introduced and analyzed also in depth. These computations are actually the first step of the distributed optimization issue which is a key point in the domain of the decentralized wireless networks. We also developed new algorithms for distributed estimation (one application could be the mobile location). These algorithms (based mainly on the so-called stochastic approximation approach) have been deeply analyzed in terms of convergence, asymptotic properties (such as asymptotic normality, asymptotic covariance). Moreover, we are moving the analysis of such algorithms in a non-stationary environment.

Finally, to better understand some of the communications tradeoffs in distributed computing, we have been investigating function computation of separate sources of information. For this setting, we provided bounds on the minimum number of bits needed to be transmitted by each source so that the receiver can reliably compute the function. For certain functions and sources these bounds are tight. [101].

**Detection theory for cognitive radio** The random matrix theory has received a lot of attention in probability, statistics and signal processing for communications. We have focused on the applications of this theory to the statistical estimation (direction of arrival, detection at the fusion center, Shannon capacity evaluation, etc). We have especially analyzed the extremal eigenvalues of large random matrices and the corresponding subspaces. [8]

## 2.2.2 Coding for single-user communication

**Faculty** J.-C. Belfiore, P. Ciblat, G. Rekaya-Ben Othman, P. Solé, A. Tchamkerten

**Main events** Jean-Claude Belfiore has served as Associate Editor for IEEE Transactions on Information Theory since 2010. Jean-Claude Belfiore and Patrick Solé are the recipient of the Best Paper Award in *IEEE Information Theory Workshop (ITW)* in 2009. Patrick Solé and Jean-Claude Belfiore organized the International Conference SETA 2010 at the school site. This conference was supported partly by Digiteo and dealt with all aspects of sequences over finite alphabets. Ghaya Rekaya-Ben Othman has been invited professor at Indian Institute of Technology in Bangalore in 2010. Daniela Tuninetti (Ass. Professor at Illinois Univ.

at Chicago) is in sabbatical stay in the lab in 2011. Finally Ghaya Rekaya-Ben Othman has been selected to contribute to the national event "1000 chercheurs parlent d'avenir".

**Projects** ANR ORIANA, CIFRE MITSUBISHI, CIFRES THALES, FP7 SMARTEN, "Futur & Ruptures" postdoctoral fellowship, Carnot Institute grant

**Synchronization codes** Our motivation was to study the performance of codes for joint coding and synchronization. A new class of codes intermediary between unrestricted binary codes and constant weight codes, namely bounded weight codes, and allied combinatorial functions, has been introduced. It turns out that the concept is also useful in list decoding, in bounding the list of candidate words at a given distance from the received word. In addition, but closely related, we worked on analytic number theory. We have especially connected the ideas of Alain Connes on a quantum mechanical approach to zeta functions with Jean-Louis Nicolas extremal view of arithmetic functions to derive an infinity of new criteria for Riemann Hypothesis.

**Space time codes** We still focused on the Space-Time codes design but in an original way. For the first time, codes over rings with non Hamming metrics are used to construct space time codes by a concatenation process similar to the so-called Construction A of lattices. We hope this work will attract the coding community attention to codes over *non commutative* rings an open territory in Coding Theory.

**Cooperative communication** The best known protocol for cooperative communication is the Dynamic Decode and Forward (DDF) protocol according to its Diversity-Multiplexing Tradeoff (DMT). We were interested on the practical implementation of this protocol for the relay channel with the assumption of relay unaware source. We have 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 have proposed patching techniques in order to maximize the achievable micro and macro diversity. This technique consists of creation at the relays linear combinations of symbols already sent by the source and symbols going to be send by the source. The destination realize the same linear combinations (patching) of the received signals to build an equivalent transmission system. We have proposed different schemes using patching : patched Monostream, Patched Alamouti, Patched Golden Code and Patched Silver Code. [27]

To achieve the cooperative diversity, a synchronous communication is actually assumed. This a priori synchronization condition could be quite costly in terms of signaling and hard to handle in a relay networks. To relax this constraint, we have constructed  $M \times M$  delay-tolerant codes based on cyclic division algebras of the  $M \times M$  perfect codes. For  $M = 2, 3, 4$  and  $5$ , the new codes maintain the same properties (full rate, full diversity and non-vanishing determinants) as perfect codes in synchronous case. These codes are useful in a network without a direct link between the source and the destination. We have also proposed "bounded delay-tolerant STBC" which ensures optimal performances when the cooperative nodes are synchronous an a full diversity and optimal rates for a certain set of delay profiles that depends on the code length.

**Hybrid ARQ schemes analysis** In modern wireless networks, the physical layer is combined with Automatic ReQuest (ARQ) technique to improve the reliability of the whole system. Moreover the ARQ (or more generally, the Hybrid-ARQ (HARQ) which "belongs" to the MAC layer) can be greatly improved by taking into account the upper Network layer. Our first contribution has consisted in analysing deeply the theoretical performance (packet error rate, delay, jitter and efficiency) of any HARQ scheme at any layer for any channel model (the Gaussian one, the Rayleigh one, ...). We have also taken into account imperfect feedback conditions. We have also proposed new HARQ techniques more robust to imperfect feedback.

### 2.2.3 Optical communications

**Faculty** P. Ciblat, G. Rekaya-Ben Othman, O. Rioul

**Projects** FUI 100GFLEX, "Futur & Ruptures" Grants, ANR TCHATER, CIFRE MITSUBISHI

Due to the new applications (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 communications tools have to be applied to the optical communications field. Indeed, the information (passing through the optical fiber) now relies on the wave intensity but also on the wave phase. Therefore standard wireless digital communications can be now advocated for optical communications.

In this new paradigm, we have focused on various facets:

i) Usually adaptive approaches have been carried out to mitigate the inter-symbol interference (generated by the dispersion of the fiber and also the polarization mixing) and the carrier frequency offset. but as the channel is very slowly time-varying, we have proposed to counter-act these impairments by using block-wise methods. Thanks to simulations and experimental measurements, we have proven that this block-wise approach enables us to speed up significantly the convergence by the expense of moderate extra computational load, and thus is well adapted to burst mode transmission [30]. In addition, we have studied some near maximum a posteriori probability low-complexity phase estimators under phase uncertain channel for BPSK and QAM signals and prove their convergence, via a conditional gradient descent algorithm, towards the Bayesian Cramer-Rao lower bound for which we also found simple expressions depending on the modulation used and other assumption (off line / online, data aided / non data aided scenarios). This in particular explained anatically why such low-complexity estimators perform so well over a wide range of SNRs.

ii) In order to evaluate the ultimate performance of optical communications, we have also considered a information-theoretic point-of-view. We especially derive Shannon-like channel capacities when nonlinear impairments occur.

iii) The polarization multiplexed optical systems can be seen as multi-input multi-output (MIMO) systems, and so space-time coding techniques could be applied in this case. The implementation of such codes requires the use of OFDM systems. We have showed that the space-time coding can efficiently mitigate polarization dependent loss (PDL) impairments, and that their performance are very different from those obtained in wireless communication. The Silver Code performs better than the Golden code. This results was explained by an analysis of the error probability. We have also showed that the gain provided by Space-time coding is added to the gain provided by error correcting codes.

### 2.2.4 Security issues

**Faculty** J.-C. Belfiore, O. Rioul

**Main events** Jean-Claude Belfiore has been invited professor at NTU (Singapore).

**Physical Layer Security** Due the broadcast nature of the wireless channel, the security has also to be takein into acount by the physical layer (and not only but the cryptographic point of view). The most famous example is the so-called wiretap channel where one eavedrooper can listen to the message too. Our contribution dealt with the analysis of the nested lattice codes for the Gaussian wiretap channel as well as for the MIMO wiretap channel. The proposed closed-form expressions for the system performance were related to the theta series of the lattice (Gaussian case) and to some zeta function (which can be Epstein or Solomon) in the MIMO case. These results gave a design criterion for the lattice codes which have to be used. We are continuing with the proposition of practical lattice codes now.



**Hidden channels for electronic devices** Side-channel analysis (SCA) aims at extracting cryptographic keys from a device by analyzing its leakage, knowing its input or output. The general formalisation of SCA models the leakage as well as the data that causes it (called the sensitive variable), from an information theoretic standpoint. The traditional approach consists in distinguishing the correct key from the bad key hypotheses by selecting the key guess that maximizes the mutual information between the leakage and the sensitive variable. Now, it is well known that this mutual information is equal to the Kullback- Leibler divergence between the leakage and the leakage conditioned by the sensitive variable. In this work, we have suggested another distinguisher consisting in the divergence between pairs of conditional leakage. Our goal were twofold: to compare it theoretically with the mutual information, and to study its efficiency for certain types of leakage (especially in the presence of countermeasures to SCA, like masking).

### 2.2.5 Tools for Information Theory and Statistics

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

**Projects** ANR Chaire d'Excellence

**About Fitt's law** Whether Fitts' law (a well-known model of human pointing movement in experimental psychology) is a logarithmic law or a power law has remained unclear so far. Papers have claimed that the power model they derived from their celebrated stochastic optimized-submovement theory encompasses the logarithmic model as a limiting case. We have shown that this claim is questionable mathematically. Our analysis revealed that these papers imply in fact a quasi-logarithmic (Shannon-like), rather than quasi-power model, the two models being not equivalent. Also, testing the prediction that throughput (TP) is conserved accross variations of speed/accuracy, we found it to be affected by the strategy, which pleads against a currently popular definition of TP which is incompatible with the Shannon equation. We also have shown that the statistical elaboration of the TP suffers from a problematic amount of random variability due to the inadvertent but multiple impact of Jensen's inequality.

**About entropy power inequalities** While most useful information theoretic inequalities can be deduced from the basic properties of entropy or mutual information, up to now Shannon's entropy power inequality (EPI) is an exception: Existing information theoretic proofs of the EPI hinge on representations of differential entropy using either Fisher information or minimum mean-square error (MMSE), which are derived from de Bruijn's identity. I have derived a unified view of these proofs, showing that they share two essential ingredients: 1) a data processing argument applied to a covariance-preserving linear transformation; 2) an integration over a path of a continuous Gaussian perturbation. Using these ingredients, I developed a new and brief proof of the EPI through a mutual information inequality. The result has the advantage of being very simple in that it relies only on the basic properties of mutual information.

**Theory of Optimal Stopping** Given sequential observations of a stochastic process, we consider the problem of estimating a stopping time defined with respect to an unobserved process which is correlated to the observation process. This problem, called the tracking stopping time (TST) problem, applies in a number of areas, including communications, monitoring, and forecasting. In spite of its simple formulation, the TST problem is hard as it also generalizes the well-known Bayesian change-point detection problem whose solutions have been reported only for specific (mostly asymptotic) settings. In spite of this apparent difficulty, we obtained interesting results for the natural settings where both the observed and unobserved processes are Gaussian random walks (possibly with drift), with the observed process being either a noisy version of the unobserved process, or a delayed version of the unobserved process. The stopping time to be estimated is some first-passage time of a given threshold. For this setting we characterized the best estimator with respect to arbitrary moment loss functions in the limit of large thresholds.

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## Chapter 3

# Complex Digital Electronic Systems

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Prof. Sorin A. Huss (Darmstadt U., Germany, 11/11).

Faculty [IT, CNRS]	[10 , 2]
PhD students	20.4
Post-docs, engineers and sabbaticals	5.5
Defended PhD thesis	10
Journal papers [published, in press]	[15, 1]
Papers in conference proceedings	113
Chapters and books	2
Patents and software	[3, 3]
Grants [public, private, european] (k€)	[1016, 359, 389]

### 3.1 Objectives

The “Complex Digital Electronic System” team research topics are about the architectures and methods to design efficiently digital electronic systems under harsh requirements. The objectives are closely linked to the study of cutting edge techniques which allow electronic designers to meet ever growing constraints of complexity management, reliability, power consumption, speed, security and flexibility. The team has research collaborations with well known companies of the area such as STMicroelectronics, NXP, Freescale, ST-Ericsson, CEA, Orange or TexasInstruments. Among the academic laboratories the most representative are the CNRS laboratories LIP6 (UMR7606), LIRMM (UMR5506), GIPSA-Lab (UMR5216) or TIMA (UMR51599). We are also highly involved in the CIM (Centre Intégré de Microélectronique) PACA regional framework and the SAME (Sophia Antipolis MicroElectronics) association, two very important academic-industrials French consortiums. In order to balance industrials concerns and advanced academic research, we increased during the two past years our effort for PhD supervision. We focused our research towards three main themes:

- Design methodologies are covered by the **Design Space exploration and assisted refinement of integrated systems** theme.
- Architectures with security constraints are dealt in the **Trusted computed hardware** theme.
- Architectures with a high constraint in Reliability 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 “Software defined radio” and multimedia applications are covered in this theme.

Team members, located in the sites of Paris and Sophia-Antipolis (LabSoC), have a strong teaching activity in the undergraduate and master level at Telecom ParisTech and at Eurecom. Lectures are in the fields of digital electronic design, embedded systems design, SoC (Systems-on-Chip) design and embedded systems security. An important part is given to practical aspects which are covered by supervisions of numerous student projects. The latest research results feed our teaching activity, for example, ANR SoCLib project methods are directly used in the “System-On-Chip Design” track of our master of engineering. Team members have teaching activities and responsibilities at master level in several others institutions such as Paris-6 University.

## 3.2 Main Results

The main research results obtained during the period mid-2009 - end-2011 are presented below for the research areas of the Complex Digital Electronic System team.

### 3.2.1 Design Space Exploration and Assisted Refinement of Integrated Systems

**Faculty** L. Aprville, R. Pacalet, S. Coudert, R. Boulifa

**Main events** Release of the free toolkit TTool<sup>1</sup>, 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

The increasing complexity of Systems-on-Chip requires new design and verification methodologies. The approach developed at LabSoC relies on modeling at a very high level and on early verifications in the design cycle. A strong separation between control and data processing is introduced. At the highest levels data processing is completely abstracted away. Control-oriented tasks exchange abstract and valueless samples, allowing ultra-fast simulations and static formal verification. This approach is supported by a dedicated UML profile (DIPLODOCUS) and a free software toolkit (TTool). For the period 2009–2011 the main achievements are:

**System-level Design Space Exploration (DSE):** definition of a four-step methodology, comprising requirement / property capture, application modeling, architecture modeling and mapping [152] [287]. Simulation and formal verification are used in the first and second steps [152]. The current focus is on the property modeling step that still needs to be enhanced [152], and the modeling of advanced communication schemes and hierarchical scheduling [287].

**Very fast simulation techniques:** Design of a new speculative and transaction-based simulator. [172]. The current focus is on adding power consumption estimation during simulation.

**Formal verification:** formal definition of the sets of primitives used in application and architecture modelling. Formal description and implementation of the mapping phase [219].

**Coverage-enhanced simulation:** To offer an intermediate scheme between a on-trace simulation, and an exhaustive computation of all system traces, definition of a coverage-enhanced simulation engine that can explore a given percentage of a mapping model [288]. To achieve this, definition and implementation of a new model-checker with possible variability in the system coverage.

**The TTool toolkit:** design and open-source release of a toolkit. This toolkit shares several features with related works of the team, on embedded systems modeling [168], embedded system dimensioning [276] and methodological assistant [275]. TTool is supported by Freescale. The whole framework is currently used in the context of the European project EVITA for security modelling and analysis on automotive security [245]. It has also been selected for the design of future aeronautics platforms (CORAC project).

**Automated and Proved Refinement** A new approach based on abstraction refinement [235, 283] intends to automate the refinement validation of high-level models into lower-level ones. That process shall as well guarantee the consistency between two abstraction levels.

**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 and security properties of component-based applications [146, 165].

<sup>1</sup> <http://labsoc.comelec.enst.fr/turtle/ttool.html>

### 3.2.2 Trusted Computing Hardware

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

**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).

**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.

Cryptoprocessor implementations can be attacked by taking advantage of the physical behaviour of the VLSI circuit. The passive attacks also called “Side Channel Attacks” are based on the analysis of the activity which can be made either by observing the power lines or the electromagnetic field radiation. The active attacks consist in injecting faults to modify the circuit’s behaviour. The attack goal is to recover the secret key of the known algorithm, or to modify the code stored in external memories. The Trusted Computing Activity of the “Complex Digital Electronic Systems” research group is to understand the attack mechanism and provide provable efficient countermeasures.

The attacks and therefore their protections are done at circuit level or board level. At circuit level they aim at recovering the ciphering key or even the algorithm. They can be performed on any circuit from the smartcard to bigger VLSI devices.

Board-level probing attacks use external memories and memory buses as natural targets.

**Protection at logical and physical level:** During the mid-2009 end-2011 period, the research about the **protection at logical and physical level** has advanced on many points:

The **Electromagnetic Analysis** has been investigated. It has been shown that the attack can be enhanced by using precharacterized models [230] or by performing a pre-stage of cartography which allows to locate accurately the spatial position of interests for the analysis [249, 291, 248, 250]. The observation traces represented in the frequency domain have also been studied and can greatly enhance the attack [231, 229, 233]. The **Template Attack**, a powerful attack which does not need any detail about the implementation but a profiling stage, has been investigated. It has been shown that it is possible to improve this attack by reducing the noise and by using good models [158]. Also the technique of Principal Component Analysis has been studied to find and combine the best points of interest [259]. The combination of different parameters of the attack, like the model and the points of interest has also been tried to enhance the attack [203]. The use of **digital signal processing** techniques, like the Kalman filtering, allowed to reduce the noise of the acquired traces and thus the power of the attack [256, 257]. These techniques can also be used to attack protected implementation where a jitter has been added on traces to avoid a synchronization operation [208]. The attack used for reverse engineering has started by using either the side-channels [207] or the fault injection technique [246]. Some protections have been proposed [184].

The **countermeasures with Dual Rail with Precharge Logic (DPL)** have been intensively used. It has been shown that the DPL logic which is a good protection against Side-Channel Attack has also good properties against fault attack [253, 178, 292]. Moreover techniques to show the impact and enhance the place and route stages of DPL implementations has been carried out [150, 247, 155]. A powerful DPL logic “BCDL” as Balanced Cell Differential Logic, has been devised to avoid the flaws of the traditional WDDL logic [193, 237, 179]. However special care has to be taken to implement a cryptoprocessor in BCDL, as explained in [181]. The technique of **countermeasures by masking** has been successfully analysed and formalized by using second order attacks [224, 225, 226]. Therefore powerful countermeasure by masking have been devised in order to thwart high-order attacks [227, 238, 271].

Protections at protocol level by using resilience properties have been studied [210]. They greatly reduce the needs to protect the implementations at physical level.

The randomness generation being a key operator for cryptographic systems, a True Random Number Generator has been studied to provide both speed and high level of robustness [148]. A study of Physically Unclonable Function (PUF) has started [186] to characterize the PUF at the design stage.

**Protection at board level:**

At board level, a complete architecture, called SecBus, has been proposed to protect the confidentiality and the integrity of code and data on the memory bus and on external memories [294]. This architecture has been combined with an internal protection mechanism to build a completely secure MPSoC [187].

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 [175, 176].

**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 requirement and attack tree captures, to the definition of the architecture [252] - including a hardware security module, and cryptographic protocols relying on this hardware security module - and the formal verification of this architecture [245] [244], and until its implementation and tests (on-going work). Future work will consist in applying techniques and architecture we have defined in EVITA for other kinds of systems, e.g. for future aeronautics platforms (CORAC project).

### 3.2.3 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, French/May 2010). Invited conference at the Schloss Dagstuhl for Informatik GmbH (Dagstuhl, Germany/September 2008).

**Projects** STIC-AmSud NanoRadio, CATRENE Rely, ANR RobustFPGA, CIFRE STMicroelectronics, 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. On these cases, 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 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 bilateral contracts.

**Reliability Assessment:** Our initial studies focused on estimating the reliability of logic circuits and we proposed two new approaches (Probabilistic Binomial Reliability-PBR- and Signal

Probability Reliability- SPR-) as mentioned in previous report. Both proposed approaches deal with different fault models and allow several trade-offs between accuracy and computation complexity for reliability assessment that outcome 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 [223] and progressive analysis [198]. Our search for even more effective approaches lead to two new methods (CPA and H-CPA) [284, 157, 270] 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[191]. 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 as well as multiple faults are supported [142]. Furthermore, we studied the problem of defining appropriate metrics for reliability assessment taking into account the processor target application [190] and in order to compare some fault tolerance approaches [265]. Work in progress include reliability analysis of probabilistic circuits and bottom-up reliability prediction of SoCs.

**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 schemas [173], a tool for automatic reliability improvement based on TMR [147], a progressive module redundancy approach [145]. 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 [159]. This powerful approach allows to guide efficient redundancy insertion and constitutes the basis of our actual work on selective hardening. Work in progress include design of defect-tolerant FPGA, design of cost-effective self-controlled digital arithmetic operators, hardening/test of embedded processors.

### 3.2.4 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 [153, 228, 289]. This work was carried out in collaboration with the Gipsa-Lab laboratory with the support of the ANR project TELMA. This work will continue in the framework of a new collaboration with the TIMA labs and control theory specialists from LAAS.

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

We continue the study of the origin of the dissipation of digital circuits, by focusing on the logical origins rather than the technological ones of this dissipation. The thesis beign carried 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 [255, 254]. 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 [154, 282]. Regarding education, we published a book on the history of microelectronics [272].

### 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), require new digital signal processing capabilities (sensing, etc.) This gives rise to the need of a flexible hardware platform that would be capable of supporting the baseband 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 a generic baseband prototype architecture for SDR applications[215, 240]. 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[242], sample rate conversion[151, 251] or channel decoding[285, 144, 143]. 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 hardwired 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 8 bits 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 open source licenses, both for hardware models and embedded software.

The baseband processor is complemented by an open source 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.

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## Chapter 4

# Electronics and RF systems (ELECRF)

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### Sabbaticals

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Faculty IT	10
PhD students	18.4
Post-docs, engineers and sabbaticals	4.1
Defended PhD thesis	11
Defended HDR	1
Journal papers [published, in press]	[30, 3]
Papers in conference proceedings	77
Chapters and books	9
Patents	6
Grants [public, private, european] (k€)	[674, 244, 498]

## 4.1 Objectives

Future “ambient intelligence” systems strongly depends on the emergence of a new type of embedded and mobile wireless RF systems that can sense their local environment and react to it by switching to some environment tailored configuration. The primary bottlenecks to address before the widespread use of ambient intelligence are related to communication requirements, energy sobriety, and security. Our research has developed along these lines innovating concepts at several levels of the physical layer: components (antenna), characterization and modeling (Power Amplifier, radio channel), system architectures (cognitive radio) and communication schemes (modulation) for wireless communication systems.

The need for terminals that provide their users ubiquitous access to a multitude of services calls for frequency-agile, multi-standard and multi-band terminals integrating the cellular standards GSM/EDGE, UMTS, LTE, LTE-Advanced as well as any additional wireless communication standards. Driven by these future wireless communications systems, our micro-electronics research has focused on agile deep-submicron CMOS circuit designs and architecture, and on the associated signal processing to correct errors, non-linearity and mismatch calibration. Our work on microwave technology concentrates on the so-called “RF front-end” which is one of the most sensitive parts of communicating objects. It involves improved RF modulation/demodulations schemes as well as the study of novel antenna technologies applied to several wireless communication standards from 450 MHz to 40 GHz. Another research topic has focused on wideband and low-profile antennas and arrays using artificial materials for the antenna’s reflector.

Other relevant challenges to the ELEF RF group are designing ultra-low power solutions for future generation ICs. We have targetted circuits with the largest energy consumption, such as PAs in the RF transmitters. To enhance the performances of RF power amplifiers, nonlinear power components operating in the Q band (33-50 GHz) have been characterized with advanced RF metrology. For integrated components, we have developed optimized low voltage micro-architectures.

Electronics and RF Systems designers have also to face many challenges to handle nanoscale technology: variability, new CMOS technology for the AMS parts, integration of novel technologies for the RF parts. In this context, our main research objectives were to design reliable and robust mixed-signal circuits in response to limited technological accuracy and repeatability, and to use design techniques impervious to technology suited to performance, cost and reliability compromises.

Finally, there is a great benefit in considering radio channel physical properties in conjunction with RF transceivers design. In this context, the sounding of RF propagation channels using relay between transmitter and receiver in a LTE communications scenario has been performed, in order



to provide an adequate propagation model with well matched parameters. The radio channel has been modeled by taking into account jointly the local propagation environment and the antennas. The method is based on a new statistical approach which has been applied to various use cases such as BAN networks, multiple antennas on terminals and UWB RFID tags. In particular, parametric models of UWB antennas have been developed, allowing a strong compression rate of the radiation data and lending themselves to statistical modeling of the antenna electromagnetic behavior.

## 4.2 Main Results

The main research results obtained during the period mid 2009 to end 2011 are presented below for the research areas of the “Electronics and RF systems” team.

### 4.2.1 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

**Main events** Coordinator of the TEROPP project between 6 Carnot Institutes and 3 Fraunhofer institutes, 3 new European projects, leader of the task on multi-standard and multiband transceiver for cellular applications in ENIAC ARTEMOS project.

**Projects** FP7 SACRA, ENIAC ARTEMOS, CATRENE PANAMA, ANR-07-P2IC TEROPP, ANR-06-TCOM HyperSCAN.

**Frequency-agile and reconfigurable receiver:** The focus is on frequency agile high dynamic range digital friendly RF architectures suitable for nanoscale CMOS. The properties such as the RF carrier frequency, channel bandwidth, noise figure, linearity and selectivity characteristics can be adapted to the requirements of the communication standard. This work which is a close collaboration with ST-Ericsson, is a part from European ENIAC ARTEMOS project starting on April 2011 where we are the leader of the task on multi-standard and multiband transceiver for cellular applications.

**High performances, reconfigurable ADCs:** One of our main research topics for years is high performances, reconfigurable ADCs for various applications. It is one of the key building components of the receiver. Our main expertise is on innovative delta sigma modulator architecture and the design in advanced CMOS technology. We has proposed innovative architecture for high-pass delta sigma modulator [309, 310], reconfigurability with high-pass and low-pass [366], unity signal transfer function with global feedback loop [381] and high performance ADC designed in 65nm CMOS technology [348]. We have been also working on continuous-time modulator in order to improve the performance in terms of low power consumption and 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 is recently sent to foundry. This work is a part of FP7 SACRA project and ENIAC ARTEMOS project. This ADC will be part of a demonstrator on cognitive radio systems in FP7 SACRA project.

The development of the software radio is still very much limited by the available resolution and speed of the ADC stage. Parallel ADCs seem to be the best suited way of increasing analog-to-digital conversion rates. After the study of time-interleaved (TI) Sigma Delta ADC with a four-channel [331, 297, 298], we studying TI architecture employing Nyquist pipeline ADCs. The objective is to compensate the frequency response error between the different channels. This work is ongoing in a bilateral project with an industry. An alternative solution for parallel architecture is to employ hybrid filter banks. The advantage of this approach compared to TI architecture is the robustness against channel mismatch at the cost of more complex analog and

digital parts. An innovative solution has been proposed [356, 357] using time multiplexing and frequency multiplexing at the same time in order to retain the advantages of both architectures (TI and hybrid filter banks). This work is a part of ANR-07-P2IC TEROPP focusing on opportunistic and cognitive radio, but this approach can be used for other applications as well.

**Non-uniform sampling:** To deal with the suppression of RF anti-alias filtering, Non Uniform Sampling (NUS) based receiver architectures have 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 appropriate NUS architecture. The results have been published recently [296]

**Disruptive technologies** Disruptive technologies offer new ways to accomplish breakthroughs in cognitive and opportunistic radio. Based on superconductivity physics, the RSFQ (Rapid Single Flux Quantum) logic is a very low power consumption and ultra-fast electronic logic which is considered as the best alternative to CMOS in the ITRS for ultra high frequency applications. The team has proposed an RFSQ Analog to Digital architecture in a work conducted within the ANR Hyperscan project. The goal is a 2x8 bits and 500 MHz BW Sigma-Delta analog-to-digital converter (ADC or CAN) circuit with performance specifications to achieve space telecoms at 30 GHz carrier frequency. To verify the project feasibility, we have developed a model that implements superconductivity physics into the RFSQ ADC circuit simulation [350].

**ADC design in the non linearity correction path of base station PA** Power amplifiers (PA) are inherently non-linear and even more if we aim to reduce its power consumption, therefore they introduce unbearable distortions for new modes of communication. The digital predistortion (DPD) is a very effective linearization technique due to the increasing use of digital modulations and progress in digital signal processing. This technique requires digitizing at least five times the input PA signal bandwidth as the distorted output PA is spectrally made up of a high power signal band and of lower power adjacent signal bands resulting from intermodulation. To digitize this signal we need an Analog to Digital Converter (ADC). The design of one single ADC meeting the requirements of high dynamic range (>60 dB) and wide bandwidth (>75 MHz) would produce an oversized solution consuming much power than using several parallel converters with adapted specifications. We suggest using 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. The problem is that the secondary converters may be saturated by high power signal band so this band has to be attenuated. We propose to use the inherent signal shaping achieved in Delta Sigma modulators to do this attenuation. A patent is pending for this innovative solution.

**Cognitive Radio Systems:** CRS is a disruptive technology targeting very high spectral efficiency. In CRS, cognition and intelligence are introduced in the terminal and cognitive network to take benefit of the high number of interacting devices to increase the spectral efficiency. Even interference is considered as an opportunity rather than a drawback by exploiting intelligently the degrees of freedom in CRS. CRS covers multidisciplinary areas attracting a large number of researches with many interesting obtained results. The challenges remain numerous, namely intelligence distribution and implementation, security, delay/protocol overhead, cross-layer design, flexible hardware design, etc. In this topic, we are working on high level concept of CRS [384], convincing use cases, RF receiver for spectrum sensing [356, 357, 418] and sensing algorithms talking into account the implementation constraints. We will study also cognitive radio resource management and smart spectrum management, all these taking into account the implementation constraints and perspectives. The work on CRS is part of ANR-07-P2IC TEROPP, FP7 SACRA project and ENIAC ARTEMOS project.

## 4.2.2 Nanoelectronics architectures and circuits

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

**Projects** CATRENE RELY

**Reliability of mixed-signal architectures and circuits:** Works on reliability of analog or mixed-signal architectures were initiated in Oct. 2008 with a PhD thesis. Considering that many circuits are today Systems-on-Chip (SoC), that they include often various analog or mixed-signal sub-circuits and that the reliability level 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 an abstracted behavioural level,
- to compare basic functions circuitries and architectures on both performance and reliability criteria,
- to define methods of architecture/circuit design that includes the reliability in the design criteria.

The present work is focusing on the reliability of A/D converters [299]. After studying the causes of degradation and failures in nanoscale integrated circuits with ageing [313], we are working on the prediction (early in the design process) of circuit lifetime facing process variability and devices aging (European project: RELY). This prediction will be based on physical models provided by physical design kits.

### 4.2.3 RF metrology

**Faculty** X.Begaud, E.Bergeault, J.C. Cousin, B.Huyart

**Projects** Bilateral project with LNE and Orange Labs, French ANR Smartvision (Système multi senseur de détection d'objets cachés)

**Power probes and PAs:** Our research in fundamental metrology with the LNE have yielded significant results on the RF power sensors (1-18 GHz) [307, 324, 368, 420] and the probe measurements of MMIC components (Monolithic Microwave Integrated circuits) over a wide frequency band (few kHz-40 GHz) [327, 326, 413]. Our efforts have focused since 2009 on the design and implementation of a load & source Pull measurement setup in the Q-band. The nonlinearities of the components of the RF front-end (PAs) causes spectral spreading over adjacent channels and distort the base band data. Numerical predistortion techniques have been used to fight the degradation of the RF signal [295]. The originality of our setup is that the excitation signals of the device under test have modulation bandwidths of gigabits/s [379].

**Radio communications channel sounding:** 2 sounders have been designed and realized for non stationary MIMO channel in the Wifi & UWB frequency bands. Our studies have been focused on the simultaneous determination of the angles of departure and arrival of transmitted and received signals [314] and the measurement of arrival time [345, 346]. Comparisons between measurement and models were made from a 3D ray tracing [378]. 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. These have allowed to assess the relaying aspects and to focus on the path loss models developed for the 4G systems [337], the shadow fading correlation [339, 338] and the impact of the relay antenna height [335]. A particular attention has been paid for the Base station-Relay Station link which had not been studied yet.

**Smart vision project:** An ANR project with Thales Service as the main leader has been developed since two years. This project has dealt with the realization of a smart corridor dedicated to an electronic body scanner to check people without a body search in airports for example. In this project, we have participated in the realization of the active body scanner based on a 77 GHz radar structure initially developed for the help drivers [385].

#### 4.2.4 Wireless communication systems technology

**Faculty** X.Begaud, B. Huyart, A.C.Lepage

**Main events** Publication of the book "UWB antennas" (Wiley), co-edited by X. Begaud, GDR ONDES, CNRS (X.Begaud)

**Projects** European projects FP7 SACRA (Spectrum and Energy Efficiency through multi-band Cognitive Radio) and Celtic SPECTRA (Spectrum and energy efficiency in 4G and beyond communication systems), EDA project MIMICRA (Metamaterial Inspired Microwave Conformal Radar Antenna), projects from the French Cluster SYSTEM@TIC PARIS-REGION : CONRAHD/OPTIMUM (CONnexion Radio sans fil Haut Débit) and PUMA (Produit Ultra haut débit sur bande millimétrique), bilateral projects with Thales Airborne Systems (2), Thales Air Systems (1), CNES, Innovation project "DEMODU" from Institut Telecom

**MMIC design for RF "front-end"**: Our research activity has been focused on the design of demodulator dedicated to software defined radio applications. 2 three-phase demodulators using MMIC technology have been designed in the 1-24 GHz bandwidth [369] and Q band (33- 45 GHz). This demodulator architecture shows a better rejection of adjacent channels [312].

**Metamaterial inspired wideband antennas**: The RF team's research is devoted to the design of wideband antennas and arrays. We initially focused our work on UWB (UltraWideBand) applications [323, 322, 408, 403] and add today the design of novel artificial materials to reduce the size/thickness of wideband antennas [406]. On one hand, the developed materials use periodic structures in order to exhibit the behaviour of an Artificial Magnetic Conductor (AMC) as well as that of an electromagnetic band-gap (EBG) structure [427, 426]. On the other hand, the extraordinary properties of Left Handed materials are exploited to develop miniaturized filters and directive antennas [423, 332] and Leaky-wave antennas [399]. We are developing a new methodology that takes into account the interaction between the radiating element and its artificial ground plane [304, 354, 347, 302]. We are also considering refined characterizations of the artificial material itself, a necessary step for improving our control on the phenomena occurring in these metamaterials [305, 343]. Finally, we are applying our artificial materials to the problem of reducing the coupling between elements in a wideband antennas array, with a focus on analytical models [426].

**Antennas for cognitive radio**: One of the main challenge of cognitive radio is to improve the efficiency of the system, ie. energy efficiency, spectrum efficiency and also reduction of the number of components. The following topics aim to propose solutions to these needs. 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 and having also cognitive radio capabilities in the TVWS band (TeleVision White Space) [380]. Diversity performances studies 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. In the framework of the European project SPECTRA, we propose to design a compact wideband antenna associated with an automatic matching circuit. In fact, over a wide band, the input impedance of the antenna varies due to intrinsic properties, but also due to the environment.

#### 4.2.5 Antennas and radio channel modelling

**Faculty** (from September 2009) C. Roblin, A. Sibille

**Main events** Publication of the book "MIMO: From Theory to Implementation" (Elsevier), co-edited by A. Sibille.

**Projects** European FP7 SELECT project on UWB RFID system, French FUI URC project on urban planning for radiocommunications, French ANR BANET on body area networks, French

FUI RECOSS project on high data rate communications for security services, European COST 2100 Action and COST IC 1004 Action on mobile networks.

**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) modeling 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 [408]. 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 modeling has been applied to full 3D measurements of omni-directional or moderately directive UWB antennas with a good accuracy and high data compression rates of more than 97% (and up to more than 99.9% for some cases) [391, 391]. These models can be efficiently used in simulations of the physical or link layers, or in deterministic propagation simulators based on asymptotic methods (UTD/GTD "ray tracing", etc.).

**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 multiantennas, multifrequency and where the behaviour of terminals in a use context is highly variable. The group has initiated and developed since a few years a statistical approach of this behaviour [321], 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 at 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 [395, 316] and to multiple antenna systems [392]. 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 [390, 318, 319]. Joint space and frequency correlated path loss data have also been modelled through a simple semi-Kronecker approximation [320]. The latest works address the statistical analysis and modelling of UWB tag antennas employed in a backscattering based RFID system [396, 300, 301, 377]. A patent has been issued on non regenerative relays [414].

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## Chapter 5

# Optical Telecommunications (GTO)

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Faculty IT	6
PhD students	13.75
Post-docs, engineers and sabbaticals	4.7
Defended PhD thesis	15
Journal papers [published, in press]	[32, 2]
Papers in conference proceedings	91
Chapters and books	3
Patents	2
Grants [public, private, european] (k€)	[654, 111, 157]

## 5.1 Objectives

The evolution of optical communication systems represents a particularly challenging guideline for the research activities taking place in the Optical Communications group of Télécom Paris-Tech. In addition to the topics directly relevant to the upgrading of optical networking techniques, architectures, devices, components, etc., our field of activity expands both to subjects that use similar methods and technologies and to characterization systems for telecommunication devices.

Following a meditated focus on access network technical solutions (FTTx) bridging the “last mile” by means of optical support, the new evolution step in the field of optical communications is related to a merging with digital communications and fast digital electronics and affects all the levels of the optical network. Technical forecasts predict a constant increase of bit-rate demand for networks with a steady rising factor of 40 to 60% per year (according the Systematic Paris-region Telecom roadmap). This tendency is supported presently by video-related application associated with new terminal facilities. Presently, the three traditional fixed-network segments are all going through a strong evolution process:

- with the deployment of FTTH (Fibre-to-the-home), the optical access network has relied first on rather traditional solutions while advanced optical technologies are still under strong competitive development (WDM PON, OCDMA, ...). New generation PON (NG-PON) investigating 10Gbit/s solutions are being normalized. A strong requirement on components able to fit the constraint of access network (technical specification, cost, consumption, foot-print) leads to some renewed question on sources and receivers;
- the metropolitan network has to cope with an enhanced connectivity and some constraints related to equipment cost which requires new technical solutions. New end-to-end network architecture are investigated;
- in the core network, traditional individual channel bit-rates enhancement up to 40 Gbit/s is progressively replaced by new paradigms making use of the digital communication knowledge that was the development key of RF mobile communication. Multi-levels or multi-carriers modulations associated with digital signal processing thanks to high rate digital circuits, brings the required spectral efficiency enhancement.

In this wide panorama, the GTO group relies on its theoretical competence and its modelling and experimental know-how for developing new concepts and for participating in advanced collaborative research on optical systems.

A first research axis concerns the development of new optical signal processing techniques and functional analysis of new components for communication systems. This field covers several related studies concerning light emission, light amplification, light transmission and new reception

techniques. Although a number of applications lie in the field of telecommunication, the activity expands to other application areas such as energy, industrial process and defense.

The second research axis lies closer to the actual networks and transmission systems structures, approaching multiplexing techniques, high bit rate communication, new optical network architectural topics.

Finally, a specific research axis is related to quantum communications in particular to quantum key distribution for cryptography systems.

These research axes usually associate theoretical investigation and modelling activities, simulation using internal or commercial software and experimental activities. The latter rely on a rather well-equipped optical laboratory which includes a 4\*10Gbit/s transmission platform, pico-second optical facilities allowing some 40Gbit/s experiments, very high sample rate arbitrary waveform generator associated to a real time oscilloscope and dedicated characterisation and sensor set-ups. The equipment for the assessment of coherent transmission systems and algorithm experimental testing, internally named "plateforme Penser 100Giga" has received a Region Ile-de-France SESAME-programme sponsorship.

The reporting period has been characterized by many national initiative interactions, (ANR, Cifre) and a strong activity on the European landscape. Through FP7-BONE and FP7-EUROFOS Networks of Excellence our international activity has been pushed to a high level. In addition to project review papers involving many teams, we can count journal publications with laboratories representing many different countries (Denmark, Japan, USA, Germany, Mexico, China, Greece, Tunisia, China, Sweden).

## 5.2 Main Results

The main research results obtained during the period mid-2009 to 2011 are presented below for the research areas of the GTO team.

### 5.2.1 Optical functionalities and novel devices for communication systems and networks

**Faculty** G. Debarge, D. Erasme, R. Gabet, P. Gallion, Y. Jaouën, C. Ware, F. Grillot (CNRS-Photon)

**Projects** PôleSystem@tic-CARRIOCAS(10/06—09/09), ANR AROME (01/07—12/09), ANR L2CP, ANR MODULE (11/09-11/12), FUI TRILOB(09/09-09-12), FP7-EUROFOS (05/08—04/12), trilateral projet with EDF and LCPC, Bilateral project with ONERA and with CEA, 3 cifre Thesis, collaboration with Shanghai Jiao Tong and Tondji universities.

The widespread introduction of broadband at all levels of communication networks, the ubiquity of data exchange, the wired network infrastructure increasingly using the optical medium, and its being extended over the last mile all the way to the end-users, are changing the deal on signal processing functions implemented directly in the optical domain, giving them a foremost place in system design. These optical functionalities aim at keeping, as best can be done, the optical signal's integrity, avoiding optical-to-electrical conversions. The intrinsically high speed of the physical phenomena to be used allows them to take over processes, which were traditionally implemented in the electrical domain, and the development of devices adapted to these applications.

#### Clock recovery

After yielding record results during the previous reporting period, our clock recovery activity was rewarded by an invited paper in the Journal of Lightwave Technology. It was built upon,

mostly through collaborations with international partners, especially in the framework of FP7-EUROFOS<sup>1</sup>. Bit rate was pushed up to 0.87 Tbit/s [536], 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.

### **Integrated semiconductor optical sources and receivers**

The recent evolution of the optical communication network led to a large demand for new low-cost and high-performance components. Following a proposal and some initial results obtained at the end of the CARRIOCAS project [524], the concept of “dual modulation”, consisting in modulating simultaneously the laser and the modulator of an EML source leads to the proposal of the new ANR project MODULE<sup>2</sup>, which we are leading. Condition for optimum modulation procedure for access—type distance range up to over 140km and rates up to 20Gbit/s. Single sideband modulation dedicated to radio-over-fibre and OFDM transmission have been demonstrated also [544, 504]. Simulation software has been used to confirm and explore transmission effect in dispersive fibres with dual-modulation. We also participated in the design of new “colourless” (wavelength-independent) devices for WDM-PONs and RoF applications, notably through a Cifre Thesis with Alcatel-Lucent III-V Lab, which more than doubled the state of the art for systems based on RSOAs (Reflective Semiconductor Optical Amplifiers) both in distance (100 km over standard fibre) and (separately) in bit rate (10 Gbps without any electronic processing). [433, 480, 562]. Additionally, another project FUI-TRILOB<sup>3</sup> studies the integration of ELM with a SOA in order to enhanced the budget of downstream access transmission in PONs. We have recently demonstrated the effect of chirp compression induced by the SOA, which allows the transmission distance to be augmented strongly [521, 522]. The group has been involved in other devices development through 2 more Cifre theses with III-V lab (on 100G receivers and reflective SOA modules for access networks). The former resulted in the development of state-of-the-art integrated very-high rate SOA-PIN receivers [560]. Modelling of semiconductor lasers have been push forward; Some new understanding on chirping effect and reduction in various configuration, especially in the case of feedback has been accessed [447],[503].

### **Optical Code-division access coders-decoders**

For OCDMA implementation (see next chapter), the most commonly used optical component is fiber Bragg grating (FBG). Part of the ANR-SUPERCODE<sup>4</sup> project was focused on FBGs both for direct-sequence codes (DS-OCDMA) and spectral phase encoding (SPE-OCDMA).

The FBG-based coding method has the disadvantage that each FBG-based component can only generate one code word while as much as 64 may be required. We have proposed to realize the coding devices by using the Hadamard transform on a 2 dimensional multimode interference couplers (2DMMIC). The approach demonstrates the possibility to achieve the higher order Hadamard transform using simple 2D structures and provides a possible solution for all optical CDMA systems. It is worth mentioning that although the discussion is based on the MMI structure, the method of extension of 1D structure to 2D can be generalized for other devices, such as the LPFGs based Hadamard transform devices. The simulation results match the theoretical prediction precisely. [463]. In addition, we have analyzed the optical switch based on the MMI couplers and proposed the operation principles for this device based on an analytical transfer matrix theory. The device can be controlled by proportionally adjusting the inter-stage variable phase

<sup>1</sup>FP7-EUROFOS (: Institute of Communication & Computer Systems/ National Technical University of Athens (leader), Heinrich-Hertz Institute, University of Essex, Universitat Politècnica de Catalunya, ACREO AB, Technical University of Eindhoven, Research and Educational Laboratory in Information Technology, Chalmers University of Technology, University of Karlsruhe, Politecnico di Torino, University College Cork, Scuola Superiore Sant’Anna, Universidad Polytecnica de Valencia, Interuniversitair Micro-Elektronica Centrum IMEC, Instituto de Telecomunicações, Technical University of Denmark

<sup>2</sup>Partners: GIE Alcatel-Thalès III-V lab, CNRS-LPN, IRCOM, Orange labs

<sup>3</sup>Partners: 3S-Photobics (leader), GIE Alcatel-Thalès III-V lab, Egide, ESPCI, Orange labs

<sup>4</sup>Partners: Institut Carnot de Bourgogne (leader), CNRS PhLAM, XLIM



shifter array. An 8\*8 MMI coupler based switch is analyzed in detail, which demonstrates the feasibility of the proposed operation principles. The theoretical prediction is verified by the numerical simulations. Fabrication error tolerance analysis is provided afterwards. The design principles presented here can be used for the design of the integrated MMI coupler based switches with either thermal-optical or electro-optical index tuning. [464]

### **Distributed Raman amplification**

The distributed amplification based on the Raman effect, appears as an alternative or an additional technique to the doped fiber amplifier (EDFA) widely used in today optical communications systems. It offers the benefits of low noise due to gain distribution over large span and of the potentiality of pump polarization attraction. However noise transfer from the pump noise to the signal, the pump polarization fluctuations and the double Rayleigh scattering (DRB) strongly impact the noise figure and the single pump configuration is bandwidth limited.

Raman amplifiers (RAs) with time-division-multiplexed (TDM) pumps have been analyzed using a computational cost-effective Fourier series approach. It gives deeper insight into the pump modulation induced noise (PMIN) in TDM pumped RAs. Moreover, the approach allows the analytical analysis of the TDM pumped RAs with multiple pumps. By optimizing the pumping order of the multiple pumps, more than 3-dB reduction of the PMIN can be achieved. For short fibres, by properly choosing the modulation frequency, more than 3-dB reduction of the PMIN can be realized. [465]

We have analyzed the Raman amplifiers (RAs) with time division multiplexed (TDM) pumps via analytical approaches for the forward and backward propagating configurations. The gain and the optimal analytical formulas of the pump power configuration have been derived, by using the least mean square (LMS) method. Explicit analytical formulas have been derived for double Rayleigh scattering (DRB) and ASE noises as well as the impact of the pump modulation. They provide a performing tool for the design, the analysis and the optimization of multi pump amplification. [462]

### **Brillouin-based optical sensors**

Given its low required power threshold, the Brillouin effect in optical fibre is one of the most promising nonlinear effect to design new all-optical processing or optical sensors. A self-referenced technique for measuring the Brillouin gain in an optical fibre has been recently proposed, and the importance of acousto-optic effective area in place of optical effective area on the Brillouin efficiency has been confirmed for the first time [446]. The analysis of optical and acoustic properties of optical fibers is required for accurate Brillouin gain spectrum (BGS) determination. Under collaboration with EDF, a 2 D FEM model has been proposed for BGS calculation in acoustic guiding and anti-guiding singlemode optical fibres [533, 532]. The intrinsic residual draw-induced stresses during the cooling from fusion to temperature to room temperature can impact significantly optical and acoustic mechanical properties, and should be taken into account in the calculation of BGS. Different fibres all coming from a same perform but with different conditions have been realized by Draka. The predicted theoretical BGS show very good agreement with corresponding measurement [534]. The following step in the EDF collaboration should be the analysis of Brillouin frequency shift dependence with strain and temperature and finally propose a fibre design specially devoted to optical sensing.

### **High-power fiber lasers**

The technology of rare-earth doped optical fibres - Ytterbium (Yb<sup>3+</sup>) for amplification at 1 $\mu$ m and Erbium/Ytterbium (Er<sup>3+</sup>/Yb<sup>3+</sup>) at 1.55 $\mu$ m - represents a strong contender for applications requiring high optical power. Our contribution is carried out mainly through collaborations with external laboratories (ONERA, CEA) and Keopsys Company. With ONERA we have participated in the

design of LMA fibre amplifiers, in the analysis of Brillouin spectrum of doped fibres in connection with doping, and more recently the combination of coherent fibre amplifiers in continuous regime [471, 466] and pulsed regime respectively [448, 508, 509, 473]. Spectral broadening is required on high power lasers to avoid Brillouin scattering in high power laser chains such as Laser Mégajoule. The collaboration with CEA concerns the spectral broadening properties on FM-AM conversion induced by non-sinusoidal phase modulation in comparison to the sinusoidal phase modulation case [442, 441, 523]. Taking into account recent developments in Thulium and Holmium fibres technology, more than 100W output powers with very good beam quality have been achieved at  $2\mu\text{m}$  and are an alternative to actual laser solutions. In collaboration with Keopsys Company and ONERA, we develop currently advanced architectures of pulsed fibre Thulium laser for LIDAR or remote sensing.

### Optical Low Coherence reflectometry

The optical low-coherence reflectometer (OLCR) developed in our laboratory has been upgraded over the years and has proven to be a unique investigation tool for the study and the characterization of new photonic components. Through collaboration with component makers, we have been able to measure some otherwise inaccessible parameters in optical wavelength mux-demux, speciality optical fibers, fiber Bragg gratings, semiconductor devices, including semiconductor optical amplifiers... Our state-of-the-art phase-sensitive OLCR spatially resolves internal reflections of the device under test, and allows measurement of different polynomial terms of dispersion, birefringence, loss / gain material coefficient, phase/amplitude coupling coefficients. It has attracted many national and international collaborations, industrial and academic. The latest results concern the study of photonic bandgap semiconductor waveguides under the ANR-L2CP<sup>5</sup> project [477, 478, 482, 535, 458, 439] in collaboration with Thalès R&T and specialty fibers characterization [468, 469] for which the OLCR provides incomparable elements of analysis.

## 5.2.2 Optical network evolutions

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

**Projects** ANR-SUPERCODE (11/06—11/09), ANR ECOFRAME (-12/09), ANR-TCHATER (10/07—12/10), ANR OCELOT(01/11-01/14)<sup>6</sup>, FUI 100G-Flex(06/10-05/13), FP7-BONE (1/08—12/10), FP7-EUROFOS (05/08—04/12), research project Orange labs, 3 Cifre PhD.

Fast development of bandwidth consuming services like high-definition/on-demand television, network gaming, cloud computing, makes stringent the need to further network capacity. The objective to provide broadband to a maximum of users (“broadband-for-all”) has been leading research and development in the field of fibre-to-the-home (FTTH) technology for the deployment of high bit-rate access networks. Deployment of FTTH, on one hand, of Cloud-computing on the other, will significantly impact the capacity requirement carried by metro and core transport networks in a medium-term future. The fibre capacity must also be maximized through the deployment of new techniques such as new multi-level modulation formats eventually combined with coherent detection, new techniques for multiplexing and routing (packet switching). Finally, a strong driver concerning the design of the physical layer or optical networks today is energy consumption.

### Optical access (PON) and code-division multiple access

Today, passive optical network (PON) have been largely accepted as a robust technique for the last mile bottleneck. TDM PON is the commonly accepted technique for resource sharing. For

<sup>5</sup>Partners: Thalès R&T (leader), CNRS-LPN, IEMN, Télécom SudParis, Télécom ParisTech

<sup>6</sup>Partners:Apex(Leader),Université de Rennes, GIE Alcatel-Thalès III-V lab

the next generation PON, hybrid-multiplexing solutions (WDM/TDM, WDM/OCDMA...), will be considered as well as source-less or color-less ONUs, long reach PON, and private networking. Our research in PON architecture and components is facilitated through collaboration and 2 successive Thesis with FT-Orange labs on new generation PON including extended PON, WDM PON, etc [570, 467]. The former thesis presents a complete study of extended PON solution and established design rules for such networks. Although large amount of the research field of WDM-PON is presently concerned with the matching of proper components or devices structure for obtaining the performance in terms of budget and splitting ratio, distance (see previous part)... specific techniques can be accessed embracing the overall architecture.

The ANR-SUPERCODE<sup>7</sup> project started off combining WDM and OCDMA by designing a supercontinuum pulsed source which can be shared among many users by being sliced into WDM channels, each of which supports multiple users through all-optical encoding and decoding. It also demonstrated the use of spectral phase encoding (SPE-OCDMA), which makes a better use of the bandwidth of the optical fiber, as in the long-haul context, by using the phase of the optical field instead of just the amplitude. Enhanced FBG-based encoders developed for this project were shown in a proof-of-concept SPE-OCDMA demonstration [539], which also used an all-optical power threshold at the receiver. The latter is the last non-cost-effective piece of the puzzle, which will require higher-nonlinearity materials to fully enable this technique in the access network.

In addition we propose a novel decentralized scheme supporting multiple optical private networking (PNs) over ring-based PON taking benefit of asynchronous OCDMA technique. This technique leads to interconnect optical network units (ONUs) in the same PN sharing the same codeword while other PNs benefiting from different code words. We have experimentally demonstrated the feasibility of 2-active PNs over ring at 625 Mbps. [494].

The network scalability and throughput performance of the proposed scheme have been analyzed and its bit error rate (BER) performance have been experimentally demonstrated. Finally, the network scalability and throughput performance of the proposed scheme are analyzed. Impact of time and wavelength domain crosstalk on capacity performance of a WDM/Optical CDMA have been investigated [436]

### **Optical Digital communications techniques for next generations of Metropolitan and Core networks**

Today's processing capability allows performing digital signal processing for optical communication systems at high bit rates. In close collaboration with the Digital Communications group, the potential and future trends of electrical signal processing techniques to mitigate e.g. noise accumulation, linear and nonlinear distortions are beginning to be investigated.

Under the project ANR-ECOFAME<sup>8</sup> we have modelled and simulated the physical channel of an optical ring WDM network architecture. We provide the parameters of the statistical distribution  $\chi^2$  and estimate the performance in collaboration with XLIM working on FEC implementation. An extension of the concept to mesh networks has been proposed.

Optical signal propagation simulations performed in the case of a new concept of packet ring network reveals that the Gaussian model is not sufficiently accurate to constitute a valuable model of noise-corrupted optical systems. We have proposed an alternative Chi-square model, which is more accurate and corrects deficiencies of the Gaussian model. In such specific channel, we design a FEC scheme based on Low Density Parity Check (LDPC) codes in the case of soft decoding. The performance of a Chi-square-based LDPC soft decoder and a Gaussian-based one are compared, both applied to a real Chi-square optical channel. We point out that the design can be done assuming an AWGN statistic but that considering the real channel statistics is essential to achieve optimal performance. [456, 563]

<sup>7</sup>Partners: Institut Carnot de Bourgogne (leader), CNRS PhLAM, XLIM

<sup>8</sup>Partners: ALU (leader), Orange, Prism Laboratories, XLIM

The convergence of digital communications and optical transmission is a key enabling factor to increase the capacity and flexibility of optical networks. Progresses 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.

The project ANR-TCHATER<sup>9</sup> concerns the design of a real-time coherent receiver at 40Gbit/s using a FPGA implementation. Our contribution concerns the design of hard and soft FEC solutions adapted to optical coherent systems. We have proposed an original construction of low-density parity-check (LDPC) code suitable for high bit-rate implementations and that have good performance compared to the codes proposed in the literature [517]. To improve the performances of the FEC, it is very important to consider the specificities of the channel. In particular, coherent and direct detection systems both require differential modulation and this degrades the performance. We have proposed a new structured interleaving of the FEC codewords with a corresponding decoding scheme, in order to reduce the penalties introduced by differential modulation [513]. Moreover, the proposed scheme allows decoding complexity reduction and redundancy decrease without any performance loss [454].

We have investigated the interest of space-time codes for optical transmission systems. They have been developed for MIMO wireless channels but can be employed in polarization multiplexed optical systems. However their implementation requires the use of optical orthogonal frequency multiplexing (OFDM). For the first time, we have shown that space-time coding can efficiently mitigate polarization dependent loss impairments. We have also shown that their performance is very different than in wireless transmission and explained the reason [515, 514]. In collaboration with Karlsruhe Institute of Technology, we have proposed for the first time an experimental implementation of Polarization-Time code for optical communications [518, 516]. The performance of Silver, Golden and Alamouti PT codes for PDL mitigation are compared to the uncoded case.

Taking into account recent advances in ADC and DSP circuits, real-time implementation of polarization multiplexing coherent receiver is currently available at 40Gb/s and 100Gb/s. The implemented algorithms in circuits running are well adapted for QPSK formats. As higher modulation formats are more sensitive to signal distortions, accurate estimators and more robust equalizers are still required for QAM formats. Our contribution concerns the development of robust Digital Signal Processing (DSP) tools specific to the optical channel. A new adaptive blind and decision-directed equalizers based on Pseudo-Newton gradient-descent algorithm that are well adapted to QAM and that offers a better convergence speed with only a little extra computational load has been introduced [529]. According to the fact that the channel is very slowly time varying (compared to the data rate), we have proposed block-wise implementation of the blind-time CMA equalizers [528]. We have shown that block-wise version outperform the sample-per-sample adaptive CMA approach in term of convergence speed only at a moderate expense of computational load [531]. Moreover, a new CFO estimator very adapted to QAM modulation yields remarkable performance and enables the system to work without penalty [527]. Our proposed algorithms should be tested using a simulation setup of an optical transmission system using coherent detection and validated with off-line processing of real measurements in collaboration with HHI in the framework of the European NoE EURO-FOS and Orange Labs respectively. We are currently investigated in the project FUI9 100GFlex<sup>10</sup>, dedicated to metropolitan and core transmissions systems based on multi-band OFDM approach for 100Gb/s in 50GHz. Particularly, the concept of optical sub-band switching can be use advantageously to realize a multi-band OFDM-based reconfigurable optical add-drop multiplexer (ROADM). A very high-baud transmission platform is currently in developing, including a 100Gb/s transmitter/receiver and a 400 km recirculating loop. This versatility and upgradability will enable us to investigate different aspects of digital optical communications: Tx/Rx characterization, propagation techniques, new detection schemes, digital processing and coding techniques dedicated to the optical channel.

<sup>9</sup>Partners: ALU (leader), E2V semiconductors, INRIA Lyon, ENS Lyon

<sup>10</sup>Partners: Mitsubishi Electric(leader), ENSAAT, Orange Labs, Télécom-Bretagne, Ekinops, Yenista

### **Analysis of High Bit Rate Optical Signals in amplitude and phase**

The asynchronous optical linear sampling of very high rate ( $>100\text{Gbps}$ ) optical signals with advanced modulation formats, especially in phase (x-PSK), by short laser pulses source ( $<1\text{ps}$ ) is a low cost technique, very competitive constellation oscilloscope market. It allows extracting amplitude and phasing information and displaying it in a constellation diagram, for system design characterization and survey. In the frame of the OCELOT project, aiming the development and the technology the transfer from a research industry, we have start to perform the identifications of the basics limit and the utilization range for this technique, as well as the associated signal processing. [487]. Classical real time phase and frequency signal measurement schemes have been revisited [455] following renew demand for signal assessment in new specific application in particular access networking components in collaborative project ( MODULE, TRILOB)

### **Optical switching**

The evolution of optical networks toward more efficient and more flexible architectures leads to tasking optical systems with more work than just what the physical layer requires, tending towards a "cross-layer" approach. The prime research axis in this direction is to route data packets or bursts directly on the optical layer.

In collaboration with Columbia University, we demonstrated a fast-failure-recovery-enabled architecture in an optical packet switching matrix based on a bandwidth-flexible wavelength-stripping packet format and semiconductor optical amplifiers used as gates [445]. Other avenues for cutting across the classical network layers are being pursued.

Also, following previous work on packet switching architecture, a whole addressing architecture based on the OCDMA technique and a flip-flop operation has been proposed and has been tested within a co-tutelle thesis in collaboration with Sup'Com Tunis. Within the frame of FP7-EUROFOS full scale experiments have been performed] leading to a demonstration of the feasibility of the architecture including flip-flop operation [474] and OCDMA addressing [476, 475].

## **5.2.3 Quantum Optics and application in Communications and Cryptography**

**Faculty** P. Gallion.

**Project** ANR-HQNet (12/06—11/09)<sup>11</sup>, collaboration CICISE-Mexico-BC

### **Balanced homodyne detection (BHD) system implementation**

We have implemented an all fiber one-way QPSK quantum key distribution system at 1550nm using both photon counting and balanced homodyne detection (BHD) configurations. It includes an automatic optoelectronic feedback loop for the interferometric phase drift compensation and a dual-threshold decision scheme for the BHD signal post-detection. Experimental comparison points out that BHD is potentially more effective in terms of quantum key generation rate and system flexibility.

We have also investigated the security issues of the BHD QKD system under two main individual attacks: intercept-resend attack and intermediate-base attacks. A mixed attack strategy of signal power modification has also been analyzed [460]. As the use of decoy states improves the security, facing the photon number splitting (PNS) attacks, we have generalized the standard QKD security analysis to the proposed systems based on coherent detection [453].

<sup>11</sup>Partners: GEORGIA TECH, FEMTO, PHOTLINE

### Optical carrier recovery for weak optical signals (WCS)

Access to the optical carrier phase is important in a diversity of applications, not only in coherent telecommunications but also in other fields such as a coherent optical sensor and instrumentation, coherent Lidar, etc., that require the measurement of the two field quadratures. Costas loops or decision driven loops that detect both field quadratures simultaneously, require 2 BHD receivers at the expense of additional measurement uncertainty which is introduced due to the vacuum fields that leak through the unused ports.

We implemented a receiver structure in which a sequential measurement scheme alternatively switches the local oscillator phase between  $0^\circ$  and  $90^\circ$  to sequentially beat with the signal. We implemented our digital Costas loop in the signal processor block, and we obtained good long-term stability. The measurements on the post-detection statistics were close to the uncertainty limit, especially for small values of the photon number. Similarly our measurements of BER were close to the standard quantum limit for low photon numbers [459, 461, 511].

### Space quantum communications

Optical communications with in low photon number for each transmitted symbol constitutes an expanding field in a diversity of applications. Beyond cryptography, many applications requiring power economy frequently deal with these quantum level signals, such as quantum communications for airborne, space to ground and inter satellite scenarios.

By using the quantum coherent state model of the radiation field, we have compared the 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 [542]. 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 compare with corresponding quantum limit [543].

### Holistic quantum security approach

The security of quantum communications is traditionally considered as limited only by the basic principles of physics and not, as in merely conventional safety, in terms of resources that Eve could realistically have. However the needs of a time independent truly unconditional security will be very limited and it is not proven that its cost will be finite, making the widely used unconditional security limitation discussion under risk of confining into academics or thought experiments, with weak economics or societal interest. Furthermore an unconditional security of the quantum layer is not sufficient to achieve an end-to-end security up to the application layer. The only way for quantum security to keep a credible role and to create a wide industrial application range is a progressive infiltration into the classically secured system technologies and culture, including an end-to-end security approach and to clarify its compatibility with optical fiber technologies and systems. In collaboration with local Electronics group and the Computer Science Department we have developed a holistic approach of quantum security [512, 490].

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**Part II**

**Networks and Computer Science**





# Networks and Computer Science Department (INFRES)

## Research Themes

The Network and Computer Science Department scientific work has been evolving around three main research themes: mobility, security, and complexity (where complex systems must be understood as encompassing large, complicated, distributed, exposed, dynamic, and possibly embedded systems). Energy efficiency is a relatively recent theme for the department, and new projects were defined and developed across different research groups during the period of evaluation.

Very large distributed systems are of particular interest with three particular instantiations: the Web, CloudComputing, and SmartGrid. The department recognizes the strategic importance of this kind of systems in our society of today and tomorrow and is organizing and applying its research to these particular use cases. In parallel, attention has to be paid to "smart" and communicating objects as they regroup into networks called "internet of things" which in turn can communicate to one another, access to the Web or to a cloud and globally form an instance of a complex distributed system that was described few lines sooner. These "things" may dynamically appear or disappear from their environment, often, they are mobile, they may be exposed to many users which enables many novel consumer applications but by the same token raises questions of security and privacy. Their interfaces are highly heterogeneous and it is a challenge to be overcome when compounding them. At last, interacting with them (as a machine or as a user) poses a set of new challenges.

Designing and verifying such systems or networks requires investigating multiple topics: visualization, fragmentation, ambient/auto-organizing systems, very large graphs, resilience, green it, probabilistic modelization just to name a few addressed in the department.

It also requires to partner, develop oneself a key and well-chosen set of disciplines.

## Partnership

In order to participate to the unprecedented string of proposals *investissements d'avenir* in France such as: IRT, IEED, labex, Equipex called by ANR or ADEME, the department had to minimize its usually important involvement in European projects in 2010 and 2011. It shows on Table 2 where it can be seen that the percentage of European contract moves down from 27-35% range to 22% in 2011. The department has devoted a lot of time of its very best members to this endeavor with a noticeable success: two Equipex were selected Digiscope to design and build collaborative applications; FIT to prototype and study internet of things. It is now time to refocus our partnership outside of France and the department will prioritize three geographic areas: Europe, USA, and China. This does not mean that no other cooperation will be undertaken elsewhere, this rather means that a particular effort will be put to create and foster cooperation in these areas.

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## Infres staff evolution

Our faculty staff is usually extremely stable, however, in this period, an important portion of our staff reached their retirement age. We succeeded to replace them with high potential young associated professors. Also, we were at the same time able to keep a strong relationship with members of our staff who departed: three former professors are today emeritus.

We have three visiting faculty members.

We also consolidated the quantum information activity by welcoming Isabelle Zaquine in the NIS group coming from the TSI department.

Four new HDR have been defended in 2010. Four professors have been promoted from associated professors. Teaching workload remains very important in the department: faculty members spend on average 35-40% of their time in research 65-60% of his time in education activities.

## Infres in few numbers

### Academic indicators

The number of defended thesis continues to vary between 15 and 25 theses each year with a low every other 3-4 years. This often matches with a pick amount of students defending their thesis in December the precedent year. This is what has happened in 2011 with only 11 theses against a high score of 26 in 2010 (Table 5.1).

The total number of publications is fairly stable approaching 200 publications in 2010 or 2011.

	2009	2010	2011	Total
PhD	13	26	11	50
Journal papers	25	59	61	145
Papers in conference proceedings	57	121	110	288
Chapters and books	10	8	19	37
Patents and software	2	5	1	8
Software		3		3

Table 5.1: Academic indicators

The total amount of receivables is relatively stable since three years. The unusual percentage of industrial contracts in 2011 due to an important cooperation with Citelum on optimization and forecast for charging electric cars (Table 5.2).

	2009		2010		2011	
European contracts	716,424	27,5 %	967,776	34,4 %	620,295	22,1 %
Industrial contracts	547,310	21 %	381,657	13,6 %	903,266	32,1 %
Public contracts	770,443	29,5 %	795,208	28,3 %	791,200	28,1 %
Contracts with Clusters ( <i>Pôles</i> )	573,087	22 %	666,857	23,7 %	496,301	17,7 %
Total	2,607,254		2,811,498		2,811,062	

Table 5.2: Contractual yearly receivables along four categories of contracts (in €).

The department has experienced a string of various important events which are a very good omen for the future of its endeavor.

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### **Few selected accomplishments**

As said earlier, the department is laureate of two Equipex: FIT and Digiscope. This will allow to partner with Paris11 U. and the TSI department in the case of Digiscope; with Paris6 and TSP in the case of FIT. End of 2011, the department joined the chair "Complex Systems" funded by Thales, this will allow to develop our research on ambient systems and partner with Ecole Polytechnique.

Two common labs were created: the LINCS with Paris 6U., Inria, and Alcatel Lucent; and ISA which a cross department lab involving not only INFRES but Comelec and TSI.

The IRT SystemX has been selected in December 2011, the department has had an important involvement in the proposal and G. Memmi became member of the board representing Institut Telecom.

Last but not least, for the first time since 8 years TPT earned the *prix de these ParisTech* with A. Leverrier highlighting the excellence of the department research on quantum information.



## Chapter 6

# Interaction, Cognition and Complexity (IC2)

**Team leader** T. Abdessalem (MC).

**Faculty** T. Abdessalem (MC), P. Bellot (P), B. Burtschy (P), B. Cautis (MC), A. Danzart (MC), J.L. Dessalles (MC), J. Eagan (MC, 04/11–), Y. Guiard (DR CNRS), G. Hebrail (P, –01/11), E. Lecolinet (MC), C. Potier (MC, –11/10), F. Rossi (P, –08/11), P. Senellart (MC), M. Vazirgiannis (Chair Professor, 05/11–).

**PhD students** K.-M. Adjanor (11/09–10/10), M. Baglioni (11/08–), L. Baud (01/07–04/10), I. Ben Dhia (10/10–), N. Derouiche (10/08–), A. Dimulescu (10/08–11/10), M. Durut (03/09–), M.-K. El-Mahrssi (07/09–), N. Gabsi (11/07–05/11), R. Guigoures (10/10–), S. Malacria (10/07–05/11), S. Maniu (10/09–), D. Munch (10/09–), T.-L. Nguyen (03/08–08/10), M. Oita (11/09–), S. Perrault (10/09–), A. Roudaut (11/06–02/10), N. Sokolovska (01/07–02/10), A. Souihli (10/09–), D.-B. Vo (12/09–), Y. Wang (12/09–).

**Post-docs, engineers and sabbaticals** 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 (12/10–11/11), H. Olafsdottir (10/08–), T. Pietrzak (09/09–12/10), A. Tabard (03/09–09/09).

**Hosted external collaborators** Y. Amsterdamer (PhD Student, Tel Aviv University & INRIA Saclay, 02/11–09/11), M. Gueye (PhD student, Cheikh Anta Diop University at Dakar, 02/10–), 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).

## 6.1 Objectives

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, business intelligence, and complex systems and protocols. The research activity of the team is organized in four institutional projects: two main projects in the fields of data and knowledge management (DBWeb) and human computer interactions (VIA), a former joint project with EDF company on business intelligence (BiLab), and a new project on complex systems and protocols (CSP). The objectives of these projects are presented in the following.

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

In this 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.

### Advanced Interaction and Visualization (VIA Project)

This 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 small, mobile 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;
- Information visualization, and more specifically interactive visualization, which aims at allowing users to explore and manipulate the data actively;
- Fundamental HCI research on simple reaching movements, overwhelmingly frequent in HCI, 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.

## Business Intelligence (BILAB Project)

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. As a matter of fact, one of the main challenges today is the burst of the volume of available data that feed BI systems. One solution which has been studied recently is to process data *on the fly* as they arrive instead of storing them beforehand in a data warehouse. This approach is referred as Data Stream Querying (if the goal is to query data) or Data Stream Mining (if the goal is to mine data).

Within this context, the BILab Project has acquired skills in this research domain and developed an activity on summarizing the history of data streams. Indeed, all existing data stream processing approaches can only provide results from the part of the stream posterior to the definition of queries or mining tasks.

Since 2007, the main activity of the project was within a joint research laboratory (the BILab, see <http://bilab.enst.fr>) with the research center of EDF (Electricité de France). This work was completed in late December 2011.

## Complex Systems and Protocols (CSP Project)

In this project, we study systems and communication protocols that can be described as complex, which means that their global behavior cannot be easily deduced from the properties of their components. The main goals are:

- to develop complex systems and protocols which emerging properties can be used to enhance computing and communication;
- to study complex systems and to build mathematical models for them.

Our research works focus on overlay protocols to ensure routing resilience, on the development of a novel method based on Complex System theories to define and measure the capacity of Air Transport Management (ATM) resources, and, finally, on the study of the World Wide Web properties. Our experimental studies are taken from the industrial collaborations we developed with EDF Research & Innovation, Eurocontrol Experimental Centre and with Hadopi Research.

## 6.2 Main Results

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

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

**Main events and external collaborations** J.-L. Dessalles visited the Tokyo University of Foreign Studies (6 months) in 2009–2010.

P. Senellart organized the ACM SIGMOD programming contest in 2010 [716]; he chaired the Industrial track of EDBT 2011 and the tutorials of ICDE 2011.

Ongoing collaborations with the database groups of the University of California San Diego (B. Cautis and A. Deutsch), Renmin University (T. Abdessalem, B. Cautis, P. Senellart and J. Lu), and the University of Oxford (P. Senellart, M. Benedikt, G. Gottlob and D. Olteanu).

**Projects** FP7 IP ARCOMEM (2011–), COOPOL VMS3D (2010–), ANR DataRing (2009–), ANR ISICIL (2009–), MODIM Chair (2010–), ANR LPOD (2008–2010), ANR PANIC (2010–2012), Advanced ERC Project DIADEM (2010–), Advanced ERC Project Webdam (2009–).

**Relational and semi-structured databases.** We study the problem of querying data sources that accept a limited set of queries, such as sources accessible by Web services which can implement very large (potentially infinite) families of queries. For the relational data model, we revisit in [574] a classical setting in which the application queries are conjunctive queries and the source accepts families of (possibly parameterized) conjunctive queries specified as the expansions of a (potentially recursive) Datalog program with parameters, under the assumption that sources satisfy integrity constraints. For semi-structured databases, we study in [593, 575] the problem of querying XML data sources that accept only a limited set of queries, such as sources accessible by Web services which can implement very large (potentially infinite) families of XPath queries. We also consider the problem of answering queries under access pattern restrictions (deep Web), in [604] where we characterize the complexity of determining if a given source is relevant to a query.

We have done extensive research on the management of probabilistic databases, and probabilistic XML in particular. In [572], we present a common model for and compare the expressiveness of different ways of organizing probabilistic information in trees. We also investigated the complexity of aggregate queries over probabilistic XML [688, 585, 573], introducing in the process the possibility of representing continuous distributions of data values. We proposed an alternative model for probabilistic XML based on recursive Markov chains [592] that allow for trees of arbitrary depth and width, which is akin to XML schemas [689, 586]. We researched the complexity of a number of other probabilistic XML data management problems: updates [663], join queries [664], mining [710]. We study in [690] the complexity of query answering using views in a probabilistic XML setting, identifying large classes of XPath queries – with child and descendant navigation and predicates – for which there are efficient (PTime) algorithms. Finally, we looked at practical aspects of implementing a probabilistic XML database engine, in particular with the help of approximation algorithms [698, 613].

**Web data.** We propose in [583, 596] 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). It illustrates a two-phase querying of the Web, in which an intentional description of the data that is targeted is first provided, in a flexible and widely applicable manner. The extraction process leverages then both the input description and the source structure. Our approach is domain-independent, in the sense that it applies to any relation, either flat or nested, describing real-world items. Extensive experiments on five different domains and comparison with the main state of the art extraction systems from literature illustrate its flexibility and precision.

We study in [667, 609] 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 their interactions. Our study sheds light into principles underlying a signed network that is captured by social interaction. We look into whether this network over Wikipedia contributors represents indeed a plausible configuration of link signs. We assess connections to social theories such as structural balance and status, which have already been considered in online communities. We also evaluate on this network the accuracy of a learned predictor for edge signs, obtaining strong evidence that our network does reveal an implicit signed configuration and that it has similar characteristics to the explicit ones, even though it is inferred from 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 [584, 634].

Similar graph mining algorithms are also applied to determining truth values of facts stated by independent sources [692, 603] and to a probabilistic approach to the matching of very large ontologies [699, 614].

We propose in [632] 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. The main idea is the specification of the target



audience of each access rule in terms of a reachability constraint, which is expressed as a path expression over the social network graph. Thus, the enforcement of an access rule consists in the evaluation of a path, which should be computed on the fly when the resource is requested by the seeker.

We propose in [693] a matrix factorization technique that aims at improving the accuracy of recommender systems. Matrix factorization models allow a high quality of rating prediction. However, a major drawback of the existing techniques is their static nature that results in a progressive declining of the accuracy of the predictions after each factorization. Matrix factorization can not be done very often because of its high computational cost. The goal of our work was to enable online integration of new ratings, in order to maintain a good quality of the predictions between two factorizations. We proposed a solution that combines clustering and users' biases in order to limit the computational cost.

Finally, we have conducted a number of research works in the field of Web archiving. One line of work considers using semantic clues from RSS feeds to extract and archive the main content of a Web page [695, 671]. We have also surveyed the methods used for estimating the dynamics and freshness of Web pages [672], which is of great importance in Web crawling. We are currently investigating the introduction of intelligent, adaptive, behavior, in archival Web crawler, in particular in the context of the archiving of the social Web.

**Cognitive computing.** We propose in [577, 706, 624, 623, 655, 622, 704, 705, 707, 578, 625] a consistent model of social communication. Altruistic communicative acts are possible when agents maximize their own benefit (in contrast with cooperative models), if they provide reliable clues about some quality that is socially in demand. In this model, relevant communication is profitable to the emitter because it advertises definite qualities (relevance) that are appraised by listeners. This model crucially relies on the role played by communication in building and preserving of social networks.

We focus in [621, 597, 598, 599] on the simplicity theory (see <http://www.simplicitytheory.org/>) and we show that the interesting events are unexpected. Unexpectedness is formally defined as cognitive complexity drop. This law correctly predicts that events close in time and space are more likely to raise interest. It also explains in detail why coincidences are experienced as fascinating; it predicts story rounds, and several other spectacular aspects of spontaneous communication.

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

## 6.2.2 Advanced Interaction and Visualization (VIA)

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

**Main events and external collaborations** Official launching of the DIGISCOPE Equipex project (2011); Ongoing collaborations to the UBIMEDIA joint lab. with Bell Labs ; various research collaborations (1 PhD, several scientific papers) with LIG IJHM (Grenoble) and INRIA/Aviz & INRIA/InSitu (Orsay) ; Industrial collaborations with Technicolor, Movea and Archos.

**Projects** NIU project with Alcatel-Lucent Bell Labs (2008–), OSEO Quaero/PVAA (2008–), ANR TennisServer (2006-09), Cap Digital ENEIDE (2006-2010) and QUATRO 2 (2010–).

Our work on novel interaction techniques have led us to develop new kinds of Marking menus, such as LeafMenus [611], Wavelet Menus [602] and Finger-Count and Radial-Stroke Shortcuts [588]. These techniques, based on gestural interaction, allow users to easily learn in novice (i.e., closed-loop) mode and later quickly execute in expert (i.e., open-loop) mode fairly large sets of commands. Recently we have extended this work by considering 3D gestures for increasing the interaction bandwidth with mobile devices [610] [587] and gesture-aware remote controls [589].

In the context of Interactive TV, we have also investigated free-hand interaction techniques [590] using the Kinect.

Our work on gestural interaction includes the leveraging of input dimensions that have been overlooked so far, such as pseudo-pressure for improving navigation in long lists [635]. We have also proposed several techniques that exploit the shape and the kinematics of gestures to enrich the input vocabulary of tactile surfaces. Thanks to rolling gestures, MicroRolls [612] make it possible to interact very efficiently with the thumb. Motion-Pointing [601] and CycloStar [607] rely on elliptical oscillatory gestures: Motion-Pointing allows selecting targets without pointing, CycloStar is a powerful approach for improving navigation tasks such as panning and zooming. Interestingly, most of these techniques are very well adapted for facilitating the interaction with mobile devices.

During this period we have also worked on augmented classrooms by developing the U-Note system [673] [608]. By using digital pen and capturing events that occurs during the class, U-Note allows to leverage the advantages of paper while letting teachers and pupils benefit from the richness that digital media can bring to a lecture.

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 [600], having received a notable paper award at UIST 2011.

Finally, we have started casting some new light on Fitts' law, a famous empirical regularity of experimental psychology. In particular, we have clarified in what sense Fitts' law constitutes an instance of a speed-accuracy tradeoff [715]. We have also shown that the traditional definition of the independent variables involved in the law suffers a high degree of indeterminacy, and suggested a novel way of defining the basic dimensions of the problem [605].

For working on these subjects, we have developed long-term collaborations with several industrial and academic partners: Alcatel Lucent Bell Labs (and the UBIMEDIA joint research laboratory), LIG / IJHM (Grenoble), INRIA InSitu and Aviz projects (Orsay), etc.

Finally we are also part of the DIGISCOPE EquipeX which is a high-performance visualization infrastructure for collaborative interaction with extremely large data sets. DIGISCOPE involves 10 academic partners (CNRS LRI and LIMSI, INRIA, CEA, ECP...) and will foster lasting collaborations between them and the industrial partners that are associated to the project.

### 6.2.3 Business Intelligence (BILab)

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

**Main events and external collaborations** A joint research laboratory with EDF R&D was created in 2007 for four years (2007-2011). The BiLab was headed by G. Hebrail until 2010, and by F. Rossi in 2011.

Industrial collaborations with Orange Labs (1 CIFRE PhD student), with Lokad (1 CIFRE PhD student).

**Projects** ANR MDCO MIDAS (2008-2010).

**Data stream management.** Our main activity related to data stream processing focuses on summarizing structured data streams: this requires the summaries to be built incrementally with little computation for each record and bounded or slowly growing disk space for storage [681]. We have developed several new approaches to summarize one or several structured data streams [708, 652],[683, 658, 651] and designed solutions to query the summaries both on the history of the stream and on the current stream [684, 594, 659]. We have extended the temporal sampling approach called 'Master' developed in 2008. Master 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). Clusmaster applies a clustering method to the SSE (Sum of Square Errors) matrix in order to identify similar sensors before the execution of the optimized summarization phase. Experiments with time series from electric power meters were carried out and are described in [595, 576].

Also, we have analyzed data streams describing the working phases of a nuclear power plant [711]. 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 [702]. The main novelty in this approach concerns the change detection strategy which is based on the clustering extension, i.e., individual memberships reflecting the current system state.

Most of the work on data stream management has been done within the MIDAS ANR Project from 2008 to mid 2011. The BILab team was the leader of this project. The main result of the project is a demonstration platform which has been designed and integrated by the BILab team (see <http://midas.enst.fr>).

Finally, a new approach has been designed for forecasting the generation of photo-voltaic (PV) electric power. The goal is to forecast local production at a very short term (a few hours). The approach uses the history of the local production and is enhanced by a collaboration between neighbor sites [661, 694].

**Time series and functional data mining.** BI deals frequently with time varying objects. Such objects are not standard data described by a fixed set of numerical and/or nominal values. They are better understood as functional data: each object is described by some functions that map time to appropriate values describing the object on a given dimension at the specified date.

We provide exploratory analysis of functional datasets via a combined clustering and segmentation approach. Functions are clustered into homogeneous clusters with the specific property that each cluster is represented by a simple functional prototype, for instance a piecewise constant function. The complexity of the prototype set is globally optimized by an efficient dynamic programming scheme [662, 713, 579]. Related work include [665] in which a piecewise constant approximation of functional data is built in a supervised manner: one finds a simplified representation optimized according to an external criterion (such as the ability to separate efficiently two classes of functions). We have also continued our work on supervised modelling of functional data, in particular on the use of derivatives to capture some shape aspects of functional data [631, 582].

In [703], we handle time varying data in a quite different manner: in this case, the evolution through time of an unique system (a web server) is studied. A time aware clustering algorithm is used to track the evolution of the web server usage patterns.

**Graph exploratory analysis.** We have been developing graph/network exploratory analysis techniques, with a focus on social networks. We have proposed in [674, 630, 581] a new topological quality measure for graph clustering, inspired by the self organizing map algorithm. Our deterministic annealing based algorithm optimizes this way a tradeoff between a graph clustering quality measure (Girvan and Newman's Modularity measure) and a visualization quality measure. The method results in a coarse grained graph that is both a faithful simplification of the original graph and easy to draw. We have used this method and similar graph clustering techniques to analyze successfully real world networks in the genetic domain [666], in the epidemic domain [654, 653] and in the historical domain [697]. We have also modelled information propagation in social networks and used similar visualization technique to display local propagation in important clusters [712].

**Large scale data analysis.** Large scale data analysis has recently gained interest in database and data mining communities, and in the information industry. Processing and analyzing large volumes of data provides both opportunities and challenges. In France, the forthcoming deployment of new communication power meter (Linky) in 35 million households until 2020 will generate

massive load curves in real time. New approaches are needed in order to deal with such a voluminous and dynamic data. A proactive work has been initiated in collaboration with EDF R&D in order to look for solutions to storage and manage massive time-changing data series. A prototype solution based on HDFS (Hadoop distributed file system) for distributed storage and Hadoop ecosystem (Pig, Hive, Hbase) for massive data analysis 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 [656, 691].

#### 6.2.4 Complex Systems and Protocols (CSP)

**Faculty** P. Bellot

**Main events and external collaborations** Conference organizations (IEEE RIVF 2009 and 2010). Best research paper award at WebTech 2010.

Ongoing collaboration with EDF Research (Chatou, STEP departement), Eurocontrol Experimental Centre (Brétigny sur Orge), and Hadopi Research (Paris).

**Projects** ANR HQNET (2006–2010), EUROCONTROL (2009).

One of our main results is the design and implementation of ROSA (Robust Overlay with Self-Adaptive topology) [618, 642, 640, 641, 639, 638, 636, 646, 637]. Overlay networks offer a way to bypass the routing characteristics of the underlying network. ROSA used this property to offer a resilient routing to critical applications. Unlike other overlay networks dealing with the routing resilience issue, we oriented our research towards building a locally robust overlay network topology instead of a robust routing function. Resilience is an emerging property of the system. ROSA is basically an unstructured overlay network. We proposed a structure, called Chain of Lumps (CoL) which provides the advantage of structuring ROSA. Once ROSA endowed with the structure, we proposed a reliable storage system deployed over ROSA. We showed using simulations and the Watts and Strogatz model, that the routing algorithm of ROSA, based on a DHT, is a case of small-world phenomenon. This is interesting from a routing point of view. Indeed, a routing algorithm with the small-world property is not influenced anymore by the size of the network. That means that the number of virtual hops to route a message is nearly constant and does not depend on the size of the network. In the post Fukushima context, we have set up a collaboration with EDF Research & Innovation to study the possibility of using ROSA as an emergency routing algorithm for an intelligent and autonomous middleware for the orchestration of contextual services of the nuclear plant control command.

In collaboration with Eurocontrol, the European Organisation for the Safety of Air Navigation, we develop a new method, based on Complex Systems theories, to define and evaluate the capacity in terms of ATM resources availability [591, 677, 616]. Measurements and analysis of traffic flow characteristics and controllers activities provide meaningful indicators to evaluate the intrinsic difficulty of the ATM tasks as well as the methodologies to quantify these indicators impact on the system performance. An hybrid model of the availability of system resources is currently built embedding a macroscopic level of controller cognition. Mechanisms that are used to balance cognitive complexity and desired system performance will be described. We hope that the proposed model and mechanisms not only can estimate the available capacity but will also provide an effective way to allocate traffic to traffic management.

Complementary to the previous works, we have developed a toolkit named SAW-SDK (Stand Alone Web application SDK) [645, 620, 644, 643, 619] for an easy Java development of efficient Web and Mobile applications. Available at <http://www.infres.enst.fr/saw>, it has been used for the IEEE RIVF 2010 conference that can be seen at <http://www.infres.enst.fr/rivf2010>. It is used internally to provide a Web and a mobile Android application for students evaluation. One of its avatar will probably be incorporated in the middleware we are currently developing with EDF Research & Innovation for services implementation.

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## Chapter 7

# Mathematics of Information, Communications and Computation (MIC<sup>2</sup>)

**Team leader** L. Decreasefond (P) (01/09–11/11), O. Hudry (P) (11/11–)

**Faculty** I. Charon (P) (–06/11; Emeritus Professor since 06/11), G. Cohen (P), L. Decreasefond (P), O. Hudry (P), A. Lobstein (CR CNRS), D. Madore (MC), B. Meyer (MC) (09/11–), H. Randriambololona (MC), J. Sakarovitch (DR CNRS), A.S. Üstünel (P).

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

**Post-docs, engineers and sabbaticals** J. Körner (05/09–07/09, 04/11-05/11)

**External collaborators** H. Chabanne, N. Puech, G. Zémor.

## 7.1 Objectives

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.

## 7.2 Main Results

The main research results obtained during the period 2009-2011 are presented below for the research areas of the MIC<sup>2</sup> team.

### 7.2.1 Probability, Stochastic Modeling

**Faculty :** I. Camilier, **L. Decreusefond**, E. Ferraz, I. Flint, R. Lassalle, **A.S. Üstünel**, J. Valentin, A. Vergne, T. Vu.

**Projects:** *Projet structurant* : MONGE

- MASTERIE, ANR blanc (10/10–10/13)
- CRE Orange Labs (01/11 – 12/13)

Historically, the team was interested in analysis in infinite dimension, mainly Malliavin calculus and nuclear spaces, and its applications to telecommunications networks.

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 [768], 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. At least, three papers are in the course of publication. 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 [767]. 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 9th Workshop on stochastic analysis and related fields was organized in honor of A.S. Üstünel for his 60th birthday.

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 [744], 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 [780] for an introduction to this formula in the context of point processes), we developed robust dimensioning formulas for LTE radio-systems like OFDMA [776] 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  $[x_1, \dots, x_n]$  belongs to this list if and only if the intersection of the balls centered on the  $n$  points  $(x_1, \dots, x_n)$ , 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 to be defended soon, computed some characteristics of such random complexes using Malliavin calculus formulas [745] 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. The mathematical analysis of this algorithm is our current work.

## 7.2.2 Discrete Mathematics, Communication, Information

**Faculty :** P.-Y. Angrand, D. Auger, **I. Charon** (Emeritus Professor since June 2011), **G. Cohen**, J.-P. Flori, T. Fuhr, **O. Hudry**, B. Kindarji, J. Körner, **A. Lobstein**, **D. Madore**, A. Patey, **H. Randriambololona**, **J. Sakarovich**, R. de Souza, G. Zémor.

**Projects :** *Projet structurant* : COOPT

- European grant VIPBOB
- ANR project Computational Social Choice n° ANR-09-BLAN-0305-03

## 7.2.3 Algebraic Geometry, Number Theory and Cryptography

One research direction is the approach to problems of arithmetic nature (transcendence, Diophantine equations) by geometric methods (algebraic geometry, Arakelov geometry, Hermitian lattices). But of equal importance is also the application of these same geometric methods to concrete problems in combinatorics, coding theory, cryptography, analog and digital modulations, quantum information theory, etc. And indeed, during the last two years we made important contributions in a variety of domains such as number theory, algebraic geometry, combinatorics, algebraic complexity, cryptography, and perhaps more marginally also in probability theory, and algebraic topology. Of the most notable interest are the following four:

1. We gave new proofs, and then improvements, of some results about the number of solutions of systems of polynomial equations over finite fields. We then gave applications of these new results to problems in coding theory.

2. We constructed a space-time code for  $2 \times 2$  MIMO channels that is optimal both for maximum likelihood decoding and for iterative decoding. This construction was made possible by the use of objects from various branches of mathematics: matrix groups, quadratic forms, algebraic number theory, generalized quaternions.
3. We explained how to hash (efficiently) into elliptic curves. The proof that the hash function thus constructed satisfies cryptographic resistance criteria relies on the careful analysis of the geometry of an algebraic surface.
4. We studied a combinatorial conjecture on the number of carries in a modular addition, that was motivated by applications in cryptography.

The results of these works can be found in [733], [771], [764], [? ], [777].

Besides these works, in [? ] we started a whole new field of research by explaining how to use deep methods from number theory and algebraic geometry to construct  $(2, 1)$ -separating systems of asymptotic rate beating the probabilistic bound. We also explain how the very same methods lead to results on the bilinear complexity of multiplication in finite fields, and on the construction of secured multi-party computation schemes.

Also, in public-key cryptography, we began to explore the possibilities of finding cryptosystem not relying on the hardness of the discrete logarithm or the factorization, and if possible, efficient. That is why we are studying the potentialities of objects stemming from algebraic geometry such as algebraic tori, semi-abelian varieties, cubic hypersurfaces, in existing cryptosystems (especially on elliptic or hyperelliptic curves, e.g., pairings). We also study links with coding theory (e.g. toric codes) and information theory (secret sharing) and the possibility of applying combinatorial game theory to cryptographic protocols (so as to formalize them).

Last, the activities of the team during this period include the following PhD supervisions: Thomas Fuhr (Conception, proof, and analysis of cryptographic hash functions), Jean-Pierre Flori (Boolean functions, algebraic curves and complex multiplication), Eduardo Ferraz (Topology of random simplicial complexes and applications to sensor networks).

### Combinatorics and Optimization

The external co-authors are L. Belgacem (FuturMaster), Y. Ben-Haim (University of Tel-Aviv, Israel), S. Gravier (CNRS, Institut Fourier, Grenoble), I. Honkala (University of Turku, Finland), B. Leclerc (École des hautes études en sciences sociales, J. Moncel (University Toulouse 1), B. Monjardet (University Paris 1))

Once we realize that any technological system will eventually suffer errors or failures, 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 [720, 723, 739], generalization to watching systems, study of special graphs [737, 730], complexity and algorithmic issues [722, 719].

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 [724, 727, 787].

Another direction of research deals with mathematical aspects of the aggregation of preferences, through the linear ordering problem for tournaments and consensus procedures [760, 735, 784]. More specifically, this includes complexity issues [755, 756, 782] and comparisons between different methods [736].

A last topic is about combinatorial optimization and more generally operations research [783]. This includes works on the design of exact methods [779, 774] or of some metaheuristics [734] in order to solve NP-hard problems [759]. An application can be found in [770? , 729] for the resolution of the so-called Routing and Wavelength Assignment Problem.



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 (numbers 187 and 190 of Mathematics and Social Sciences, 2009 and 2010).

### Information Theory

Our contribution to the field can be divided into 3 main themes:

#### 1. Combinatorial coding

Our work on identifying codes as continued [737]; a new notion of identification has been put forward: that of witness, where we want a code such that its codewords can be recognized by inspecting a small window acting as a "witness" [775? ]. From a more graph-oriented perspective, we have been interested in zero-error capacity issues in various spaces [731, 742]. Finally, in a more classical coding concern, we have studied thresholds in one of the most used classes of codes, the Reed-Solomon codes [772] and cardinalities of codes under weight constraints [728].

#### 2. Cryptography and biometry

This application of coding theory to biometrical identification is potent. However, a number of questions needed to be addressed. In practice, the distribution of biometric traits is far from uniform and the scheme is liable to leak undesirable partial knowledge to an unauthorized third party. It was thus desirable to have a protocol for which zero information leakage to potential eavesdroppers is guaranteed. We dealt with this issue by considering the information leakage as a wire-tap channel problem [? ].

Then, we explored the possible applications of this approach to devise biometric identification techniques, in the framework of cooperation programs and joint PhD students with SAGEM/Morpho [773, 732]. Indeed, Morpho and Telecom ParisTech launched a collaborative research center, the IDentity & Security Alliance, to address the technological challenges of identity protection and data security, in March 2011. The IDentity & Security Alliance will have an international scope and will focus on developing and enabling next-generation identity-based applications while guaranteeing security and privacy. It aims to build a scientific knowledge base covering research topics such as biometrics, IT security, cryptography, components security and identity management systems. Projects will be based on a mutual exchange of research and technology expertise, involving researchers from both Morpho and Telecom ParisTech. The IDentity & Security Alliance is co-directed by Vincent Bouatou, Deputy Director of Research and Technology at Morpho and Gérard Memmi, Head of the Networks and Computer Science Department at Telecom ParisTech, while Gérard Cohen is a scientific adviser of the IDentity & Security Alliance.

#### 3. Codes and cryptography

The intersection of these two fields was for us bent functions, related to Reed-Muller codes, and of use in symmetric cryptography. Our approach was arithmetical and combinatorial [777? ].

In addition to the publications, the results include invited talks, invited session in a conference (ITW 2010 Dublin), contribution to technical program committees (SETA 2010, ISIT 2011), SAGEM/Morpho contracts (CIFRE grant Sagem Bruno Kindarji 2007-2010, CIFRE grant Morpho Alain Patey 2011-2014, ANR COCQ "domaines émergents" 2008-2011), PhD thesis supervision (Bruno Kindarji [788]; Jean-Pierre Flori: Méthodes algébriques, combinatoires et géométriques en sûreté de l'information, 2008-2011; Zizhu Wang: Novel protocols for quantum networks, 2009-2012, Multi-party quantum cryptographic primitives in realistic environments; Alain Patey: Distributed secure biometric matching, 2011-2014).

### Automata Theory

The activity in this domain is conducted by J. Sakarovitch, his PhD student (P.-Y. Angrand) and several external collaborators, mainly S. Lombardy. It may be described under three themes: synthesis, research, and construction of software for handling finite automata.

Two chapters ([781, 786]) in collaborative books have been published, in addition to the English corrected version of the monography on automata ([785]). The research activity may be illustrated by a work on weighted transducers ([778]) that allowed to answer a problem that was stated 30 years ago and by the study of a variant of the derivation of expressions ([718]) that may reverse the construction of expressions from automata ([762]).

As for the software activity, 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 and will serve both as a test suite and a milestone for future versions. The bases for a completely new design of the core have been defined. The realisation of a new version following these new specification will be conducted in the framework of an ANR project attributed in October 2010 (starting March 2011).

The features of the contract ANR Vaucanson 2 on the “programme Blanc inter SIMI 2” are the following:

- Object: New architecture of the core of the platform Vaucanson 1, stronger specification of the programming interface of automata, and modular graphical user interface.
- Partners: IGM at Univ. Paris-Est (coordinator), LRDE at EPITA, LTCI at CNRS/TPT, EE Dept. at National Taiwan Univ.

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Below is the full list of articles published, since January 2009, in international journals, in books, or in proceedings of international conferences by current members of the team). The full list of publications of the team is available at the following URL:

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## Chapter 8

# Network and Information Security (NIS)

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**Permanents** R. Alléaume (MC), E. Diamanti (CR CNRS), A. Hecker (MC), H. Labiod (MC), J. Leneutre (MC), D. Markham (CR CNRS), A. Serhrouchni (P), P. Urien (P), I. Zaquine (MC).

**Doctorants** A. Al Mamou (02/06 - 01/10), M. Aljnidi (10/05 - 12/09), L. Aranda (11/07 - -), A. Bocquet (07/08 - 12/11), H. Dau (11/09 - 08/11), S. Delamare (10/06 - 06/10), A. Famulari (03/11 - -), M. Faycal (04/05 - 05/10), D. Fotue (10/10 - -), J. Ghalbouni (10/10 - -), H. Guerid (11/10 - -), T. Guillet (12/06 - 09/10), R. He (11/07 - 10/10), P. Jouguet (09/10 - -), M. Kasraoui (05/11 - -), C. Kiennert (01/10 - -), A. Marin (10/09 - -), R. Moalla (04/11 - -), S. Natouri (11/10 - -), D. Ngueguia Nyamy (11/07 - -), T. Nguyen (12/11 - -), A. Pappa (11/10 - -), H. Qin (11/11 - -), B. Rodier (01/09 - 09/09), R. Saad (11/06 - 09/10), M. Sokhn (11/07 - 09/11), C. Thibaud (01/09 - -), Z. Wang (10/09 - -), G. Zhioua (04/11 - -).

**Postdocs, ingénieurs contractuels, sabbatiques** N. Ababneh (04/09 - 06/11), I. Agha (10/10 - -), A. Ahmad (03/10 - 08/10), J. Aranda Buenos (10/10 - 12/11), Y. Benchaib (07/07 - -), A. Boukerche (11/09 - 12/09), X. Chen (09/10 - 12/11), P. Desfonds (10/11 - -), S. Elrharbi (11/07 - 01/11), S. Felloni (04/10 - 04/11), S. Haddad (01/09 - 03/11), K. Haddadou (03/10 - 04/10), P. Jouguet (03/09 - 02/10), C. Kiennert (08/08 - 12/09), S. Ktari (01/10 - 7/11), P. Laurier (06/08 - 04/10), T. Lawson (10/11 - -), P. Marie (02/09 - 12/09), R. Moalla (01/11 - -), N. Nogueira Lima (10/09 - 11/09), N. Oualha (09/09 - 08/10), B. Rai (09/10 - 06/11), T. Rätý (01/09 - 07/10), J. Victor (10/10 - 10/10).

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

## 8.1 Objectives

Modern ICT technologies are increasingly software-driven. Software components in networks and infrastructures account for more flexibility in operations, but also render the infrastructures more complex in their behavior and, in fine, more vulnerable. In current systems, the fragility of the software predominates even in high-availability infrastructures. The proliferation of the generalized connectivity (locally, through short range radios and xDSL technologies, and globally through the democratization of the Internet) on the one hand, and the abundance of personal digital devices on the other hand (smartphones, netbooks, tablets, portable PCs) are responsible for the ongoing opening of previously closed and often isolated, private, ICT infrastructures. It becomes increasingly more and more difficult to address the cyber-security through the classical security methodology, which studies the impacts of events on an asset from its environment, since, in practice, both the environment and the actual ICT system per se are not fixed, but rather react and adapt in mutual interdependency.

The current situation is rather worrisome. Since software has found its way in almost all activities of the modern society, no industry sector can ignore IT security problems. Furthermore, since the ongoing trend to the generalized networking and continuous connectivity is rendering all these installations generally accessible through different means, no industry player can feel secure and has to face the challenges of cyber-security. Indeed, alone for 2011, the press has reported major cyber-security breaches in such branches as electronics, gaming, commerce, banking, defense, energy production, water supply and traffic control. States increasingly feel the pressure of the cyber-security risk and start programs spanning from protective measures and additional regulatory obligations over emergency trainings to the troubling notion of “cyber warfare”, i.e. of a coordinated big-scale counter-attack.

Needless to say, ordinary citizens have long been lost in the maze of security settings and security warnings of all kinds. Ignoring both what is on stake and how to mitigate it, they often make fatal decisions with regard to their privacy, reputation and their civil or financial responsibilities. Often they serve as ignorant middlemen whose systems are used to mount large-scale attacks. The same is in principle true for small and middle enterprises. Networking is at the heart of all these developments. For systems to be secure, system architectures - i.e. today, including networks - have to address some security questions at the earliest stages. The problem is further amplified by the inherently multi-tenant nature of networking, which often involves external partners and third-party authorities with different security policies or traversal of public networks or systems with unclear security properties.

That is why, 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. As of December 2012, members of this group include 2 full professors, 6 associated professors, 2 CNRS researchers, about 20 faculty (post-docs, engineers, PhD students) and 1 professor emeritus.

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, starting from the security of links and individual components and mechanisms and going 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.

## 8.2 Main Results

The results of the group are presented along the following research activities:

1. Security of Internetworking and of Its Typical Applications



- Internet infrastructure security
  - Internet Applications security
2. Internet of Things, M2M and Identity Management with Trustworthy Devices
    - Internet of Things and M2M communications
    - Smartcards and smart tokens
  3. Infrastructureless, Wireless and Autonomous Networking
    - Vehicular networks
    - Autonomous networks
    - New security models, self-protections for autonomous networking
  4. Quantum Information
    - Quantum key distribution, and experimental platform
    - Quantum cryptography, entanglement and quantum information theory
    - Entangled-photon sources and quantum repeater
  5. Resilience, quantitative security and trust in open and critical infrastructures
    - Critical infrastructures and processes security
    - Operational security evaluation
  6. International Cooperation on Security Research

In the following, we present the main results of the research group for the period June 2009 - December 2011 by these research activities.

### 8.2.1 Security of Internetworking and Its Typical Applications

**Permanents** A. Serhrouchni, H. Labiod, A. Hecker

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

The objective of this activity is dedicated to the improvement of the security of internetworking and of its typical protocols. Consequently, the body of work in this domain is of a tremendous thematic span, going from specific provisions in the authentication phases of the protocols as required by the corresponding services and to the architectural decisions regarding service overlay levels and Internet infrastructure security.

I. We have defined and elaborated a new approach to communication protocol security based on the addition of new semantics to the protocol runs [950][944][943][942][911][885][857][856]. By relying on a semantic interpretation of the available data elements of standard protocol executions, our approach remains fully interoperable with the existing implementations - a non-negligible fact when facing a broad industry acceptance and deployment. Moreover, such an interpretation is not required from all entities. However, the supporting entities can benefit from the new properties provided by our method at the service level. Concretely, we use the random data, so called nonces, used e.g. in SIP (Session Initiation Protocole) or HTTP (HyperText Transfert Protocol). Our research has concentrated on a secure way to give a meaning to this opaque blocks in order to improve the security level and to offer new security services, e.g. 1) capability for a user to verify communication billing by the service providers 2) capability to counter BYE and CANCEL attacks on the SIP protocol, 3) capability to optimize the authentication phase of SIP

resulting in a gain of one RTT (round trip time) for an equal security level. We formally verified all results using AVISPA. Besides, we implemented and tested our proposals in open source platforms, e.g. for SIP using modifications in the Jain API or in the widely deployed Asterisk server. The perspective is to add these capabilities to SSL/TLS. These contributions have been published academically [911][885][857][856][859][883][883][858], and have resulted in three patent applications [944][943][942] and the PhD thesis of Thomas Guillet [950].

II. To improve the Internet infrastructure resilience, we continued our work on IP traceback, necessary to stop distributed denial of service attacks. We concentrated on a specific Internet traffic using the ICMP protocol, and notably its ping service (echo-request/echo-reply). We have proposed a probabilistic marking solution to efficiently trace this kind of traffic in-band. To validate our approach, real-scale experiments have been conducted and a simulator using real traffic data has been implemented [880].

III. We continued working on P2P control, optimization and security. Our objectives here are twofold: we would like to make some overlay parts private, while improving the transport characteristics over the typical multi-AS system like the Internet without any central authority. The most prominent P2P protocols right now are DHT-based approaches (used for data organization and search) and Bittorrent (used for an efficient data retrieval). DHTs are hash tables projecting a common identification space; the latter is distributed, according to the used algorithm, over all participating nodes. To obtain an ID of a node responsible for an object, classically, a usual hash function is calculated over the object identifier to determine the identifier of the researched object in the DHT. Then, the mechanisms permit to route to such an identity. In such a way, every object remains essentially universally searchable and universally accessible. Our objective was to make some objects private: to do that, we needed to cut the ID space in virtual slices, the access to which needed to be controlled. Our solution relies on the usage of a keyed HMAC function instead of the normal hash function. In the resulting proposal, only a group knowing the secret key can locate the objects in the virtual space. Yet, our method does not affect other principles of the DHT (routing, retrieval, etc.) and therefore remains transparent. We have validated this proposal through large-scale simulations, and we could show the advantages namely for peering between different AS in the Internet [926][924][925]. In another effort, dedicated to structure-aware routing in current DHTs, we have developed a rewiring method for current overlays [951]. We reuse the existing structure and the existing signaling to significantly improve routing performance at practically no additional cost: as described in [813], we use graph theory to find topologically important nodes, which we then use to shorten network diameter and improve general resilience to (untargeted) errors. Note that despite the apparent promise of balanced structure, we always observed strongly skewed node degrees in all current DHTs [902]. Interestingly, in our approach, the topologically important elements emerge from the existing operational structure, and do not need to be chosen in advance. We conceived, implemented and evaluated our PowerDHT approach [903][902], which exploits the available knowledge at nodes such that the typical DHT routing profits from the partly scale free properties of the graph. Then, owing to the heterogeneous nature of nodes participating in most overlay networks, we also proposed an algorithm to transform an existing, deployed overlay in a real scale free network [900]. Our algorithm can be used with practically any existing DHT (Chord, Pastry, Kademlia, etc.) and remains backwards compatible in the sense that PowerDHT nodes can participate in a normal DHT network without changes - which allows progressive deployments. In another effort, to improve the actual data retrieval, we have adapted an FEC (Forward Error Correction) mechanism for bittorrent by using it on data segments in order to reduce the latency in data access. We have validated our approach in [924].

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

**Permanents** P. Urien

**Faits marquants** Best Demonstration award at the IEEE CCNC conference 2010; CARTES

2009 Best Software Award; Best Paper award at the ICSDT 2010 conference; OSEO Award attribution to EtherTrust spinoff.

**Projets** FP7 SecFuNet, Systematic FEDER ONDEMAND, ANR T2TIT.

The goal of this activity is to tackle practical security issues in the networks, the Internet, the Internet Of Things (IoT) and 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 a Secure Element (SE).

Three PhD students are currently working on these subjects, another thesis ended in 2010 and deals with the security in SIP [914]. Other doctoral works target privacy for the IoT and Identity for the Cloud Computing and Mobile Services.

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. The HIP-RFID protocol [916] issued from the T2TIT project is currently a working item group [960] at the IRTF (Internet Research Task Force), which should be finalized by the end of 2012, and whose editor is P. Urien. The T2TIT team also published two books in 2010 [935] and 2011 [937], targeting RFIDs and the IoT.

In January 2010, the demonstration detailed in the paper [913] received the Best Demonstration award from the IEEE CCNC conference, and demonstrated the first OPENID infrastructure based on smartcards.

A paper [915] co-written with Christophe Kiennert, a CIFRE student funded by EtherTrust Company (Spinoff of Télécom ParisTech, <http://www.ethertrust.com/>), won a Best Paper award at the ICSDT 2010 conference. A new prepayment architecture was designed for a big player and is detailed in [917]. Secure channels are managed between secure elements located in bearers' cards and merchants' terminals. This platform was successfully tested with a set of beta-test users, and is a step towards trusted computing for M2M networks.

In 2011, two new research contracts were won, OnDemand and Secfunet. Ondemand is a French FEDER project addressing security for on demand virtual networks. SecFuNet (<http://www.gta.ufrj.br/secfunet/>) is an international European-Brazilian FP7 project targeting Identity for virtual networks.

The EtherTrust spinoff, created in 2007, won the OSEO award in fall 2009 (<http://www.ethertrust.com/?p=71>). It engaged three employees in 2010 (among them one CIFRE, linked to INFRES department), and two others in 2011. Main industrial achievements are prepayment system designed for a big player, and mobile identity model (SIMply Me!) developed in a partnership with Morpho company.

### 8.2.3 Infrastructureless, Wireless and Autonomous Networking

**Permanents** H. Labiod, J. Leneutre

**Faits marquants** H. Labiod is one of the main organizers of the NTMS conference series; co-organized in April 2010 the 3rd IEEE International Conference on Software Testing, Verification and Validation (ICST); co-organized in September 2010 the 3rd International Workshop on Autonomous and Spontaneous Security (SETOP2010) co-located with the ESORICS Symposium, J. Leneutre co-editor of the corresponding proceedings published in the Lecture Notes in Computer Science series (Springer); Ruan He received the honorific mention of the CONET AWARD 2011 for his PhD work (see below); the paper [887] receives the Best Paper Award.

**Projets** ANR TRAFIC, ANR VELCRI

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).

This research can be presented along three axis:

- Vehicular Networks
- Autonomous networks;
- The modelling of wireless security based on non cooperative game theory.

#### **Vehicular networks :**

Regarding the routing in vehicular networks, we have proposed new routing mechanisms based on trajectories of nodes. Our trajectory-based routing shows good results compared to position-based routing, geographic protocols and opportunistic mechanisms [866][851][904][862]. This work has been conducted in the French national project ANR TRAFIC. We currently work on the security of these routing mechanisms, notably in cases of cooperative mobility.

Beyond this work, we studied a dedicated architecture for intelligent transportation systems (ITS). Our current proposal is a hybrid fixed/wireless/sensor/VANET architecture that supports group mobility management and end-to-end routing mechanisms so as to enable ITS services in an efficient manner [904][862]. In a related effort, we proposed a global security architecture for hybrid ad hoc networks [847].

We conceived an Adaptive Traffic Signal control system based on inter-vehicular communication (V2V). This system permits to diminish risks of traffic jams, limit crossroads waiting times and increase the fluidity of the transportation traffic [831][910][934].

In the ongoing ANR project VELCRI, we currently conduct research on secure electrical vehicle charging. This will become part of an innovative, end-to-end security architecture, currently under development in cooperation with Renault.

#### **Autonomous networking :**

Regarding data sensing and retrieval in wireless and autonomic environments, we worked on the combination of data aggregation with routing, specifically in wireless sensor networks [875][878][877]. In order to tackle a related problem of resource allocation in NEMO, we proposed an optimization of the resource reservation in these kinds of networks [907]. We conducted an analytical research of the intra-domain handover mechanism in multi-homed NEMO [815].

Accounting for specific needs of such systems, we specifically addressed the security needs of these systems. As a result, we defined models and mechanism for self-protection in autonomous networks. The goal of this axis of research is to propose security models and their associated mechanisms for self-protection of e.g. wireless autonomous networks. Our approach introduces context-awareness into the security mechanisms themselves in order to make them autonomic. We mainly focussed on the access control function.

Adopting a policy-based management approach, we presented in [807, 888] ASPF (Autonomic Security Policy Framework), a policy-driven security framework which realizes several feedback loops. Enforced authorization policies in a device are adapted according to the security context both at the network and device levels.

In [886, 887], we proposed VSK (Virtual Security Kernel), a lightweight adaptable OS authorization architecture suitable for self-protection of pervasive devices. A virtual management plane, separate from execution resources, is defined for full run-time control by applications of

their execution environment. This plane also performs non-invasive and yet effective authorization thanks to optimized access request checking. The VSK component-based architecture provides flexibility both in the execution plane (for resource customization) and in the management plane (for run-time reconfiguration of authorization policies). The paper [887] receives the Best Paper Award.

In complement to previous work, we defined in [889] a domain specific language to describe security adaptation policies. The DSL is based on the condition-action approach and on a taxonomy of threats and applicable reactions. The DSL also allows to capture trade-offs between security and other concerns such as energy efficiency during the decision making phase.

These previous results have been obtained in the context of the CIFRE PhD thesis of Ruan He, co-supervised by Marc Lacoste from Orange Lab. Ruan He received the honorific mention of the CONET AWARD 2011 for his PhD work.

### **Modelling of wireless security based on non cooperative game theory :**

During recent years, we applied non cooperative game theory to model and analyze selfish and malicious behaviors in wireless networks. Through this approach, we are able to characterize some quantitative aspects in the design of security mechanisms.

We proposed in [798] a distributed pricing framework for cooperative relaying in wireless networks: sources pay relay nodes to forward their packets, and the payment is shared equally whenever a packet is successfully relayed by several nodes at once. This scenario is modelled as a Stackelberg (leader-follower) game, in which sources set the payment rates they offer, and relay nodes respond by choosing the flows to cooperate with. A systematic analysis of the fundamental structural properties of this generic model has been provided: multiple follower equilibria exist in general due to the non concave nature of the game, yet only one equilibrium possesses certain continuity properties that further lead to a unique system equilibrium among the leaders. This work has been done in collaboration with Lin Chen from University of Orsay and Lavy Libman from University of Sydney.

We considered in [797] the problem of jamming attacks in a wireless context performed by attackers with a limited energy amount. We proposed a defense strategy to defeat the jammer by draining its energy as fast as possible. The interaction between the jammer and the victim network is modelled as a non-cooperative game which is proven to admit two equilibria. As a result, the proposed defense strategy can eliminate the undesirable equilibrium from the network perspective and increase the jammer's energy consumption at the remaining equilibrium without degrading the performance of the victim network. We also investigate the game dynamics by developing the update mechanism for the players to adjust their strategies just based on observable channel information. This work has been done in collaboration with Lin Chen from University of Orsay.

Finally we provided a general methodology for designing efficient MAC protocols for autonomous wireless networks in [864].

## **8.2.4 Quantum Information**

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

**Faits marquants** Organization of QuPa workshop series (8 workshops so far); organization of workshop on Post-Quantum Security Models; creation of a unique experimental platform on security of quantum communications in Europe.

**Projets** ANR-EU CHIST-ERA Project HIPERCOM, EU FP7 Marie-Curie IAAP QCERT, IdF C'nano GENEPHY, ANR Blanc International France-Canada FREQUENCY, ANR Blanc EQUANET, ANR Jeunes Chercheurs CRYQ, ANR SEQUIRE

A team of researchers 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 above) 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).

### **Quantum key distribution (QKD) :**

Our team has a recognized expertise in the field of QKD, illustrated by several important publications [789][872][803][836], as well as a network of collaborators (French-Canadian collaboration in ANR FREQUENCY, European collaboration in FP7 IAAP Q-CERT, French-European collaboration in ANR-EU CHIST ERA project HIPERCPM) that are key players in the European and international QKD community. These collaborations date back from the beginning of the FP6 European project SECOQC [2004-2008] and have fruitfully developed into new projects and research themes, ranging from the experimental development of continuous-variable QKD systems, to theoretical studies on QKD security models [795] or QKD networks [790][841], as well as a theme of growing importance: the practical security of QKD systems.

#### 1. Practical security of QKD systems: side-channels, attacks, counter-measures

QKD is the first technology emerging from quantum information science that reaches a level of maturity that is sufficient to target industrial development and commercial applications. However, this transition is far from easy, as QKD has mainly been thought and developed as an exciting and stimulating playground for the development of quantum communication techniques, with a (too) distant eye on cryptography and security questions. The challenge for QKD, in order to become a recognized security technology is twofold.

- One has to better understand how QKD compares to other crypto technologies and this was the purpose of our review paper [789], studying how QKD could be used, in combination with other cryptographic primitives, to achieve different security functions, while comparing it with classical cryptographic alternatives.
- More importantly, one has to study not only the theoretical security of QKD, but also the practical security of QKD implementations. As a matter of fact, while several QKD protocols are proven to be unconditionally secure, if the practical implementation differs from the ideal model used in the proof, this can open the door for effective attacks on the systems, as this has been demonstrated in the last years.

The ambition of the project Q-CERT, in which we collaborate with world leaders in QKD (University of Geneva and IdQuantique) is precisely to study, on our experimental platform (financed by IdF SESAME "Sécurité Quantique" as a platform for quantum security experiments) some family of vulnerabilities of QKD systems in order to develop counter-measures and thus move forward towards the security certification of QKD.

#### 2. Continuous-Variable QKD (CVQKD)

The research on CVQKD has been initiated at the Institut d'Optique in collaboration with Thales Research and Technologies, teams with which we have a history of close collaborations and joint work [803][802][836]. The goal we are now pursuing is to study the material security of CVQKD, but also to improve the systems in order to reach higher performances. Following ideas developed earlier in the group and in collaboration with SeQureNet, the expected performance of the systems in terms of maximal key distribution distance, which was up to now strongly limited by the error correction efficiency, has been considerably increased, from 30 km to 150 km [808].

### 3. Valorization: intensive collaboration with a spin-off company

The start-up SeQureNet (<http://www.sequenet.fr/>) was founded in 2008 and has considerably developed its activities during the period 2009-2011 following the recent recruitment of two full-time employees: S. Kunz-Jacques, technical director, and P. Jouguet, R&D engineer. SeQureNet develops and commercializes quantum cryptography systems, specializing in particular in the technology of continuous variable quantum key distribution. It exploits a patent held by CNRS/Thales, for which it has signed a licensing agreement, and is in the process of negotiating a licensing agreement for a second patent, held by CNRS/Institut Télécom. SeQureNet is in close collaboration with the quantum information research activities within NIS, in particular via joint participation in several projects: FP7 Q-CERT, ANR Frequency, and ANR-EU Hipercom. SeQureNet is planning to produce in 2012 its first quantum cryptography product, which will be of interest to research laboratories.

### 4. Experimental platform

An experimental platform "Sécurité Quantique" is currently under development with funding from Region Ile-de-France, Institut Télécom and CNRS. It serves the purpose of examining the practical security of quantum key distribution systems (FP7 Q-CERT, ANR-EU HIPERCOM) and testing new quantum cryptographic protocols in two and multi-partite settings (ANR FREQUENCY, ANR CRYQ). It is worth noting that this experimental platform is one of only 5 of this type in the world.

## Quantum cryptography and entanglement :

There is great subtlety and great potential in the use of multipartite quantum states for information processing. Almost all of the known applications of quantum information to date either involve two parties (for example Quantum Key Distribution), or a large number of systems (quantum computing - currently well beyond the best technologies). In fact there is a wealth of unexplored variation in the behavior of quantum systems between these two extremes.

Our goal is to understand and exploit multipartite quantum states for information processing in a distributed network setting. There are two parts to this; one is to understand the great subtleties of the quantum mechanics of multiparty entangled states. The other part is to understand how we may apply this in a useful manner. Indeed these parts are often much intertwined and both necessitate and support the other.

We have studied how two broad classes of entangled states can be used for quantum information processing: graph states and symmetric states. Both these classes are at the forefront of experimental implementation, and we are working closely with the top experimental groups around the world to implement our findings. For graph states we have developed the theory of quantum secret sharing to a high degree [810][811][956], so that we are now working at how we can both implement proof of principle experiments, and theoretically how these protocols can be integrated into more involved many party schemes (such as multiparty secure function evaluation [908]). For symmetric states we are still at an earlier stage of understanding what the key quantum features of use are. We have shown how these states exhibit a full range of entanglement features, with deep relationship to the symmetries involved [826][854][793]. We then went on to explore how this entanglement can be used to perform non-local tasks in the forms of extended Bell inequalities [961]. Currently we are working on both implementing first proof of principle experiments and also how these protocols can be understood deeper in an information theoretic

sense, for example their ability to reduce communication complexity and their power as quantum games. Much of this work has contributed to the project ANR FREQUENCY (ANR blanc international France-Canada).

As multipartite quantum states are of great importance in multiple applications in a network setting, a fundamental question is whether the users can trust the source that generates the states or whether they can efficiently verify that the right state is produced and distributed. We have studied this problem for the so-called GHZ states, and we have shown these can be efficiently verified in the adversarial model, even in the presence of multiple malicious players [835].

For all the above protocols, the role of entanglement is crucial. Exploring the exact role of entanglement in the performance of quantum computation and cryptographic protocols is in fact very interesting. Some tasks do not require entangled resources; we have developed for example a practical quantum coin flipping protocol with security guarantees strictly better than any classical protocol can achieve [834]. This protocol can be implemented with standard technology, using for example attenuated laser pulses, over up to 20 km of optical fiber and work is currently underway in our experimental platform [88] for the practical implementation of the proposed protocol in a two and multi-partite setting (projects ANR CRYQ, ANR FREQUENCY).

#### **Entangled-photon sources and quantum repeaters :**

The quantum repeater is one of the major challenges towards long distance quantum communications. It requires entangled photon pairs and the possibility of storage of the photonic qubits in a quantum memory. Our goal is to build a source of entangled photon pairs based on spontaneous parametric down conversion (SPDC) that is suitable for long distance propagation in telecom optical fibers and also compatible with the quantum memory. This objective is pursued in collaboration with experimental groups in Nice and Orsay (ANR project EQUANET). In order for the quality of entanglement to be conserved, in spite of the necessary filtering, fiber coupling and various causes of losses, the design of the source must be optimized. We have calculated the respective weights of these various possible contributions to source quality degradation, and shown how to find the best compromise, providing a "users guide" to the design of narrowband pulsed SPDC sources [844]. We have also shown a simple way to evaluate the quality of entanglement that can be obtained with a given source, using very simple measurements [845]. We are also investigating the possibility of multi-user distribution of entangled photon pairs, with only one source. Using commercial telecom DWDM filters, we can take advantage of the natural wide band of SPDC sources, to improve the photon rate and prepare the way to cheap quantum communication networks.

### **8.2.5 Resilience, quantitative security and trust in open and critical infrastructures**

**Permanents** A. Hecker, M. Riguidel, C. Chaudet (RMS)

**Faits marquants** Creation of industry special group (ISG) on information security indicators (ISI); A. Hecker is vice-chairman of the ISG ISI at ETSI; acceptance for publication of an ETSI standard [955] reflecting our work on operational security assurance.

**Projets** CELTIC BUGYO BEYOND, ANR SINARI

This research activity is dedicated to a vision of a rational and quantifiable security, i.e. to reasoning about the conformity, cohesion, quality and efficiency of the security mechanisms deployed in an operational networked IT environment. The goal is to provide network and security administrators with a set of tools for a better handling of security mechanisms of their systems. We believe that current tools are rather inadequate and often very specific; they do not permit security management at the system level. Instead, system administrators have to tinker with specialized tools for device-level configurations to achieve system-wide results at the service level. Given the inextricability of the existing real-life IT installations, we currently advocate an empirical



approach to this problem, as opposed to the “security by design” approach based on a formal transformation process. Contrary to formal methods, usable for new designs, we would like to render more resilient the existing, deployed systems. In IT security, a lack of knowledge of the local administration with regard to the security posture of the managed system is well-established. The main idea is therefore to render the existing security resiliently manageable and, through this provision, to ultimately render the overall system more resilient, in spite of the undeniable presence of faults and attacks in modern networked IT systems.

It is difficult to evaluate conformity in an operational, distributed environment. Even more difficult is the evaluation of cohesion (i.e. the mutual non-disturbance) and of the efficiency of the deployed security mechanisms. Testing, pentesting, fuzzing and other approaches need to be used from different topological points without disturbing the control traffic required to launch the tests and to gather results. We studied and elucidated the related problems in the European research project Celtic Bugyo Beyond [83], which the team has successfully finished in October 2011, and through publications on the distributing monitoring and evaluation framework. We studied the fundamental problems related in our early work [892]. They can be roughly subdivided in “how to measure resiliently” i.e. in spite of faults, reconfigurations and attacks, and “how to make sense of the gathered data”, i.e. how to evaluate such data. More specifically:

1. The first part of the problem has been extensively studied: we have formulated functional requirements and a layered model for an operational measurement framework in this context [809][895]. One of the crucial requirements on such frameworks is resiliency with respect to node and path failures of all kinds. To address these issues, we have developed a dedicated P2P-based overlay for simple, server-less, resilient communications [809].
2. The latter problem is mainly related to the information model. For security to make sense, such models require profound understanding of both the objectives and the realizations. Since both vary a lot, this does not have an easy solution. We proposed a viable mid-way through the use of patterns called Assurance Profiles [884]. This approach has found a strong echo within the standardization community: ETSI TISPAN WG7 is about to standardize the format of the proposed profile as TR 187 023 [955].
3. To fulfill partly contradictory requirements on P2P structures in this context (resiliency, efficiency, furtiveness), we can use the work developed in the thesis of S. Ktari [951]. With a simple parameterization, the proposal [813] yields a generalized P2P overlay capable of dynamically adjusting its structure from equally distributed over decentralized, hub-based to fully centralized networks. We use the same algorithm to adapt the structure to the perceived criticality level. Such adaptability permits to use the same implementation in changing environmental security conditions (threat level).
4. To study incident propagation effects and impacts on the behavior of our proposals, we have designed and implemented a network virtualization tool, VIRCONEL [794][861], capable of deploying real software (OS, servers, clients, etc.) in a given network topology; it also enables us to alter any link, any node and any defined service element as of a scenario definition. This permits us to evaluate different IT service realizations under attacks and fault scenarios. VIRCONEL is available as an open-source (LGPL) software under <http://virconel.enst.fr>.
5. Incidents, which hit the network and disturb communications delivery to users, cannot be always prevented. Network recovery mechanisms are used to redirect communications to a non-failing part of the network. We have studied a new kind of recovery mechanism based on peer-to-peer routing (also called overlay routing) in [947]. The proposed mechanism relies on a virtual network, made of a network nodes set performing routing operations. Its advantages are that it can be used to recover any kind of IP communications, and does not depend on the network infrastructure. It also allows an end-to-end protection of communications. This is contrary to usual recovery mechanisms, such as typical routing protocols, which only operate inside the various networks used to forward a communication and do

not cooperate between themselves. Finally, this mechanism is deployed by network users, and thus can be adapted to the dependability needs for each of their communications. Our system can improve communications dependability when incidents hit the network, particularly if recovery mechanisms deployed by network operators cannot bring the dependability level pursued by a user.

6. In order to enhance the dependability, survivability and resilience of EU ICT-based critical infrastructures by introducing appropriate Middleware Improved Technology components, suitable for preventing and limiting cascading effects and supporting automated recovery and service continuity in critical situations, the security models and crisis management for metasystem need to be revised [919]. The electrical power infrastructure and its supporting telecommunication infrastructure have been chosen as first priority example test case that has been extensively studied in [948].

## 8.2.6 International Cooperation on Security Research

**Permanents** M. Riguidel, A. Hecker, D. Markham

**Faits marquants** M. Riguidel is FIA caretaker of trust and security; security related policy-making in Europe through the authorship of the RISEPTIS report; co-organization of a workshop in the French Senate on the security of critical infrastructures in June 2009; creation of a joint lab on security and trust with Jiao Tong University in Shanghai; signature of a MoU with School of Informatics of the University of Edinburgh.

**Projets** FP7 ThinkTrust, FP7 IncoTrust, FP7 BIC, FP7 Panorama

There is significant investment and worldwide research activity aimed at creating complex networked systems that can be justifiably trusted to perform as expected: to be resilient; to remain dependable and secure, in spite of problems that they may experience; to be adaptable; and to be able to evolve in response to changed requirements and environments. Therefore, within FP7, the European Commission has a requirement to develop global partnerships with their international peers in these areas.

Besides, owing to the inherently international nature of modern networking, security solutions call for international coordination in terms of identification, reporting and taxonomy of security incidents, security data sharing, enforcement of common policies, objectives, functions and distributed mechanisms and the like.

To answer these challenges, our group actively participates in the international cooperation and coordination of security research activities. Such coordination includes research agencies from partnering countries as described in more details in the following.

### ThinkTrust :

ThinkTrust (<http://www.think-trust.eu/>) was a Coordination Action project (Jan 2008 - Dec 2010) of the European Commission FP7 work program. The objective was to formulate recommendations on policy environments and future research agenda, addressing security, dependability, privacy and related ethical issues across different challenges [838] and objectives of this work program. Think-Trust has produced a list of research challenges, which need to be addressed to work towards a trustworthy ICT environment [936]. The Think-Trust project included the support of an Advisory Board (RISEPTIS for "Research and Innovation for SEcurity, Privacy and Trustworthiness in the Information Society") in ICT research on security and trust formulating recommendations on:

- Policy environment - The development of coherent legal and administrative frameworks, operational environments, and human behavior relating to security, privacy and confidence, in view of the technological changes leading to and arising from the future Information Society,

- Research Agenda - Future European research and development that can facilitate the creation of an Information Society that will be secure, whilst respecting freedom and privacy of its citizens, with due attention given to the ICT infrastructures, networks, services and applications.

RISEPTIS made six recommendations for action, covering both technical and supportive regulatory measures, presented by V Reding at the European Parliament [959].

**INCOTrust :**

IncoTrust (<http://www.inco-trust.eu/>) was a Coordination Action project (Jan 2008 - Dec 2010) of the European Commission FP7 work program, specifically targeting international cooperation in the area of Trustworthy, Secure and Dependable ICT infrastructures:

- To promote collaboration and partnerships between researchers from the developed countries (European Commission, US-National Science Foundation NSF, US-Department of Homeland Security DHS, Japan Science and Technology Agency JST and Australian National ICT Australia NICTA) with the goal of coordinating the multiple research efforts underway in the areas of ICT Trust, Security and Dependability.
- To leverage and harmonize efforts on the respective sides related to the building and maintenance of large-scale trustworthy ICT systems and infrastructures and the services they deliver with a long term visions and research roadmaps.

The INCO-Trust project identified the following two groups of recommendations [957] that are labeled under the categories Strategic and Tactical which are road-mapped for FP7/FP8 calls. The Strategic group are meant to be the pre-requisite enablers for international cooperation, setting out the frameworks, common understandings and motivations, and overall landscape to ensure the possibility and effectiveness of the more concrete Tactical group recommendations. In the frame of this project, we also have tackled the global governance [839] and the security of the Internet of Things [918].

**BIC :**

Starting on 1st January 2011, the Coordination Action BIC project - Building International Cooperation for Trustworthy ICT: Security, Privacy and Trust in Global Networks & Services, <http://www.bic-trust.eu/> - will expand the co-operation models of EU researchers and program management with their peers in new ICT high-growth countries, specifically Brazil, India and South Africa, who represent emergent world-impacting information economies through the scale and sophistication of their growing ICT sectors [865]. In addition, the project will provide continuity and bring together a truly global collaboration with the participation of the already established connections from the INCO-TRUST project between the EU and the United States, Japan, Australia, South Korea and Canada.

**Panorama :**

PANORAMA is a FP7 FET project to coordinate the pervasive adaptation (Perada) network for the organization of the research agenda and the management of activities. The goal of the PANORAMA coordination action is to bring together the wide range of researchers in the field covered by the PERADA proactive initiative, and to build a new community of researchers who can work together on common goals, so ensuring that the research carried out by members of that community is integrated, coordinated and informed. We produced a vision paper [837].

**FIA (Future Internet Assembly) :**

The European Future Internet Assembly, also known as FIA ([http://www.future-internet.eu/fileadmin/documents/misc/What\\_is\\_FIA.pdf](http://www.future-internet.eu/fileadmin/documents/misc/What_is_FIA.pdf)), is a collaboration between projects that have

recognized the need to strengthen European activities on the Future Internet to maintain European competitiveness in the global marketplace. Currently FIA brings together around 150 research projects that are part of Challenge 1 of the ICT program of FP7. We are member of the FIA caretakers of the Working Group Trust and Security ([http://security.future-internet.eu/index.php/Main\\_Page](http://security.future-internet.eu/index.php/Main_Page)).

#### **Joint Lab between Jiao Tong University and Telecom ParisTech :**

A joint Lab in Security research was launched on July, 2011. The Lab is addressing the need of creating a research environment for investigating and experimentally validating innovative ideas in security and trust for new networking and service paradigms: , new models, new cryptographic protocols, new architectures for the Future Internet. The academic research and a wide-scale experimentation that is required for industry (such as Huawei) aim to provide a framework in which security and trust paradigms can be integrated in the design of the Future Internet.

#### **MoU with School of Informatics of the University of Edinburgh :**

Based on ongoing and future collaborations, we initiated and saw to fruition a memorandum of understanding between the School of Informatics in the University of Edinburgh and Télécom ParisTech, cementing our relationships and facilitating many activities such as student exchanges. The School of Informatics in the University of Edinburgh is the biggest and best computer science department in the UK (top in the last RAE) and one of the top centres in the world. The project with the quantum information team in NIS focuses on the future of networked quantum information, beyond the limited focus of much of the current field on two party protocols (QKD) and a quantum computer, to explore the wealth of possibilities in between. This includes blind quantum computation, distributed computation and the exploration of many new multiparty quantum protocols.

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## Chapter 9

# Networks, Mobility & Services (NMS)

[NMS]

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Faculty [IT, CNRS]	[11, 0]
PhD students	30.4
Post-docs, engineers and sabbaticals	16
Defended PhD theses	19
Defended HDR	3
Journal papers	33
Papers in conference proceedings	84
Chapters and books	6
Patents and software	2
Grants [public, private, european] (k€)	[1229, 831, 1103]

### 9.1 Scientific Environment, Positioning and Objectives

Services have evolved very quickly during the last years. In particular, we have assisted to a fast development of virtualization and the outsourcing of services 'in the cloud'. In this new environment, the global service that are offered to customer need to be composed from unitary services involving a whole chain of stakeholders (Content provider, Software providers, Data Center provider, Network providers etc.) — a composition that has been extensively studied in our team. Market-oriented parameters inherent to the multi-tenant environment of Cloud have a close interaction with the resource allocation procedure. For confidentiality purposes, network operators do not provide the Cloud Service Provider (CSP) a real view of their infrastructure. We

have evaluated these two aspects of Cloud computing. Finally, the legacy fixed client/server model is no longer valid in this new environment and more flexible service and network architectures (like overlay networks) need to be designed. The activities of the group related to cloud, service architectures and service applications are summarized in section 9.2.1 below.

At the same time, the fast development of mobile applications (in particular with the advent of sophisticated smart-phones) has led to the saturation of wireless access networks. The demand for capacity is particularly challenging and new access methods and radio network architectures had to be designed. Our group has a strong expertise in the modeling and dimensioning of wireless network and has thus contributed to these network evolutions from this point of view. As frequency bands are limited by nature, the concept of cognitive radio has also arisen as a means to better use these scarce radio resources. We have made several contributions in this area. Finally, the services need to be ubiquitous in heterogeneous network environments (3G, 3.5G, 4G, Wimax, Wifi, ...). In particular, the handover and simultaneous access management in this heterogeneous network environment has been deeply investigated. All these contributions related to wireless networks and mobility are outlined in section 9.2.2.

With its extraordinary success and growth, the Internet is confronted with difficult scalability and limitation issues. In particular, the Internet needs to be rethought with the advent of the so-called 'Internet of things', where an extremely large number of objects, in particular sensors, are expected to be connected to the Internet. Furthermore, the TCP/IP stack is not adapted to such 'things' with very limited resources and need to be adapted. Our group has started to investigate these issues and to propose solutions. Furthermore, carriers seem to have difficulties in offering advanced added-value services on top of the global Internet. One of the reasons is that the current Internet business model offers little incentives for ISPs to collaborate in order to offer end-to-end services. On a technical point of view, one of the main issues is related to Internet routing architecture (based on BGP) where end points are offered a single, best effort route. It is acknowledged that the addition of multi-path capabilities would bring more robustness and traffic engineering features. We have several contributions in this area (towards a multi-path internet) at both the routing and transport layers. Once offered, the route diversity can be exploited using multi-path transport protocols and Dynamic load balancing (DLB) mechanisms, that were also studied extensively. Finally, there is a growing need in IP networks for 'on the fly' flow identification in order to dynamically allocate resources in the network (in particular for value-added services). All these contributions are presented in section 9.2.3.

Ever increasing Internet traffic demand challenges the use of electronic switching in today's networks. The routing bottleneck can be alleviated by means of transparent optical switching, which enables payload to be carried exclusively in the optical domain. The activities of the team on optical networks are focused on failure monitoring, quality of transmission-aware routing, wavelength assignment and Optical Burst Switching — they are briefly presented in section 9.2.4.

Finally, The NMS group has a transversal activity concentrated on energy efficiency (also nicknamed as 'green networking' activity), on both IP, cellular/wireless and optical networks. Our main results are summarized in section 9.2.5.

The team is greatly involved in national and international collaborative research projects (financed by the FP7, the ANR and national competitiveness clusters). Our group was the initiator of the FP7's European Network of Excellence Euro-NF and has chaired this NoE's Steering Committee (in particular responsible for coordination of all research activities) since it was created.

Moreover, by way of an example, during this period the team participated in several European projects (FP7 BONES, DICONET, EuroNF, ETICS, NapaWine, TIGER2, TRANS) and in the ANR (3MING, DIAFORUS, ECOFRAME, SUN, TEROPP, UBIS) among others. The team is actively involved in the System@tic (trust platform) and CapDigital (wireless high-speed Internet) competitiveness clusters. It is also involved in numerous bilateral research contracts with industrials, and particularly with Orange, SFR, Alcatel-Lucent and Thales.

The NMS group also maintains close links (joint works, double Ph.D. program, co-advisorship, sabbaticals and visits) with various international laboratories, including UCLA (USA), University of Waterloo (Canada), UPC (Barcelona, Spain), Politecnico of Turino and Politecnico of Milano (Italy), Université Catholique de Louvain and University of Ghent (Belgium), NCRL (National

Mobile Communications Research Laboratory, Nanjing , China), NTU (Singapore).

The team is also one of the cofounder 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).

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.

## 9.2 Main Results

### 9.2.1 Cloud and Services Architecture, Applications Services

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

**Projects** FP7 NAPAWINE; ANR UBIS; Systematic CompatibleOne, CARIOCAS, TIOSAFE; CapDigital Sebastian 2.

**Service Architectures.** Integration of new usages in the field of mobility and ubiquity has led to the redefinition of the means of how content should be delivered. In this concept, our work have concentrated on the design and engineering of service-oriented architectures that allows to offer a seamless continuity of services.

Our main outcome is the definition of an 'autonomous service', insuring a 'user centric' approach and that represents an excellent candidate for the 'Cloud' architectures. More precisely, our system is designed as a self-managed composition of services (application, network, hardware and presentation services) in order to meet the expectations of users that evolve in a mobile environment (encompassing the mobility of users, terminal, networks and services). Our approach is also based on QoS models for the management of end-to-end services, insuring a continuity of services with maximal transparency. The personalization of the user workflow (which is now in the heart of the mechanism) leads to a cross-organizational context where session mobility must be handled.

In the context of the ANR UBIS project, we have proposed a new cross-organizational structure of personalized services, based on dynamic service composition under QoS constraints in a generalized mobility context [986, 999, 1100, 1053, 1102, 1104, 1077, 1078, 1079, 1063, 1080, 1012, 1061, 1062, 1060]. Self-management is introduced through the management of the interest communities and through QoS management at the level of each service component. The global organization relies on an ubiquitous and mutualized service composition. The main originality of our approach is to move away from the legacy client-server model, by proposing to implement a user centric service logic (workflow) in a single mobile session based on mutualization of service components. We have proposed in particular the SIP+ protocol that allows for integration of application services. Our results led us to propose our expertise for the FNS CloudForce project that has been accepted (2012-2015).

**Cloud Computing.** Two aspects of Cloud Computing are strongly related: market-oriented constraints and computing/storage/networking resources allocation [962]. In this matter, we have considered a discrete time approach for dynamic resource allocation under flexible scheduled traffic in the context of layer-2 virtual private networks (VPN). Our objective was to exploit the end-users time requirements in order to provide a fair management of the various resources while in considering the economical constraints of the CSP. For that purpose, we have introduced a weighted cost function enabling a service differentiation relying on time constraints disparities between customers' requests. This cost function has been itself introduced in an ILP formulation considering the various constraints and objectives of the problem [1008], [1009], [1010]. In the

context of the Sebastian2- research project, we have considered the same type of problem applied to an original application: the collaborative production of digital high definition movies via a private Cloud. For that purpose, we have introduced two additional innovative services: multicast stream data transfers and distributed storage [1011]. In the context of the Compatible-1 research project, we proposed extensions to bin packing strategies enabling to take into account the dynamicity of computing, storage and networking resources consumption. In accordance with one of our industrial partners in this project, we have assumed that each job could be characterized statistically by a specific resource consumption profile. We have exploited such traffic profiles to define a quadratic distance enabling to optimize the fit of each job (each Virtual Machine) onto a physical machine [1040], [1103]. We have also worked in the context of the BONE Network of Excellence with the team of Prof. Dimitra Simoneidou (Essex University) on the impact of the level of abstraction of the network resources onto the efficiency of the resource allocation problem.

**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 works concentrated on this congestion control dedicated for low priority traffic defined within the LDBAT IETF working group. In particular we have identified a weakness ('latecomer unfairness', where the latest flow can monopolize network resources) in the original algorithm [1092], and proposed some solutions to overcome this problem [1030]. These solutions have contributed to the evolutions of the LEDBAT protocol (and are cited in the IETF document). We have also compared LEDBAT with similar proposals (e.g., TCP-LP, NICE) [1029] and studied the performance of the implementation of this protocol made by BitTorrent [1093]. Finally, we studied the impact of LEDBAT on the bitTorrent system, in particular regarding the download completion time (the main performance metric in this system). These on-going works [1105] have allowed to discover some possible solutions to further reduce the downloading times (that shall be explored in the future).

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 [1086, 994]. The recent explosion of video traffic has led us to particularly focus on P2P-TV applications. We have studied the topological awareness<sup>1</sup> of the most widely used P2P-TV applications [992] and their impact on the Internet [1001].

## 9.2.2 Wireless Networks and Mobility

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

**Projects** ANR 3MING, TEROPP; SYSTEMATIC URC, NimbleNet; External research contracts with Orange Labs and Cassidian.

**Cellular Network Dimensioning.** We are working with Orange Labs with the aim of deriving easy-to-use outage probability formulas in multi-cellular networks. These formulas are taking into account path-loss, shadowing and fast fading [965], assume Alamouti MIMO transmission [1015, 1014], Zero-Forcing Beamforming [1016], or best server policy [1067]. They have been efficiently used to evaluate the capacity or coverage loss when base-station transmit power is reduced in so called green cellular networks [1059]. There are all based on a fluid model developed at Orange Labs [983]. We also had a special attention to OFDMA networks (WiMAX, LTE, LTE-Advanced). For example, dimensioning rules with multi-profile traffic have been proposed in [976]. Frequency reuse schemes are analyzed in [990, 1118]. LTE uplink control is optimized in [1037]. As relay based cellular networks will be part of future systems (IEEE 802.16j and LTE-Advanced), we have

<sup>1</sup>By topology awareness, we mean the potential capability of an application to consider in priority peers that are close geographically or within the same Autonomous System, which would reduce ISP transit costs.



started performance evaluations assuming the presence of relay nodes in [1068] in collaboration with NTU (Singapore).

In the context of a joint work with S.E. Elayoubi, A. El Falou, J.B. Landre (Orange Labs), we study the radio capacity improvement provided by an HSPA+ key feature, dual-cell, combined with MIMO [1024]. The proposed method combines drive test measurements, link-level simulations, and a queuing theory-based statistical capacity model, thereby providing a reliable estimate of the network radio capacity. Simulation results show that dual cell combined with MIMO and non-linear receivers using Successive Interference Cancellation (SIC) significantly increases network radio capacity. These results confirm that HSPA networks evolutions are promising.

**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 (commonly referred as "holes"). That methods have recently arise significant interest in the community of wireless and mobile communications. Our contributions lay in the design of decentralized algorithms that do not require location information on sensor nodes. The results obtained have been in published in [1108, 975] and submitted [1003]. This is a joint work with L.Deucreusefond from the MIC2 team of Telecom ParisTech.

Stochastic geometry and Point Process theories can be used to design capacity and to obtain dimensioning models for mobile communications networks. Our contributions in that area are twofold. On the first hand, new dimensioning methods have been proposed for OFDMA networks. Concentration inequalities have been applied to obtain an analytical upper bound of the loss probability in terms of resources blocks or sub-channels. The upper bound is less accurate than classical approximation methods such as Gaussian or Edgeworth expansions. However it is more robust to systems parameters inaccuracy [1039]. Other works, carried out in cooperation with NCRL (National Mobile Communications Research Laboratory, Nanjing , China), have proposed average transmission capacity and upper bound transmission capacity expressions, for cognitive radio systems in a primary/secondary network scenario [964, 1013].

**Dynamic Spectrum Management and Cognitive Radio.** We have studied inter-operator spectrum sharing schemes within the URC project [1038]. In [982, 1056], we have proposed optimal, Q-learning based and heuristics algorithms for the dynamic spectrum allocation problem that take benefit from the time heterogeneities of the traffic. Spatial heterogeneities have been then taken into account in [1058, 1057]. In the ANR project TEROPP, we have studied distributed radio resource allocation schemes for cognitive radio networks in collaboration with LRI - University of Paris XI Orsay [1033]. We have first proposed an auction mechanism [1034, 974]. We have then proposed and analyzed an algorithm that both solves the Multi-Armed Bandit problem and controls the switching cost of secondary users [1035]. We are now working on large populations scenarios [1054, 1055].

**Random access schemes.** In conjunction with M.Feuillet (INRIA), we analyze the performance of CSMA in multi-channel wireless networks, accounting for the random nature of traffic [971]. Specifically, we assess the ability of CSMA to fully utilize the radio resources and in turn to stabilize the network in a dynamic setting with flow arrivals and departures. We prove that CSMA is optimal in ad-hoc mode but not in infrastructure mode, when all data flows originate from or are destined to some access points, due to the inherent bias of CSMA against downlink traffic. We propose a slight modification of CSMA, that we refer to as flow-aware CSMA, which corrects this bias and makes the algorithm optimal in all cases.

We also worked on wireless mesh networks with UMPC/LIP6, where we designed OFDMA based MAC protocols [1036].

**Handover management in heterogeneous and simultaneous access.** We have developed expertise in the field of mobility and handover management in heterogeneous and simultane-

ous mobile access. Studies on dynamic interface selection, considering various attributes such as network characteristics, applications requirements, and user preferences, were carried out [1107]. A prototype (a linux based mobile terminal with Wi-Fi and 3G) has been developed with the collaboration of Bell Labs France for performance evaluation and validation. The prototype implements the IEEE 802.21 standard to discover network parameters.

Layer-2 handover solutions have also been investigated. The developed solutions take advantage of multi-homing to enable soft handover and make-before-break handover in the integrated and tight coupling architectures of WiMAX and UMTS. The solutions aim at achieving lossless and short latency handover procedures [989, 988, 1066].

While the integration of heterogeneous radio access is seen by the network operators as a solution for providing their customers with a large variety of services with a seamless access, the simultaneous access provides many interesting benefits enabling traffic to be distributed over the available networks taking into account the application requirements and/or network congestion situations.

The problem of distributing simultaneously multiple applications to the suitable network interfaces while maximizing terminal global utility is first addressed. Stochastic heuristic optimization methods are studied and a novel diversification technique of the Tabu search has been proposed [1072]. We have also investigated the flow/interface association strategies using evolutionary game theory [1106]. In the game, the terminals compete for common network resources and seek for maximizing their utility by associating the application flows to the radio interfaces. The network orients the association choices of the terminals while seeking for optimizing the system global utility.

### 9.2.3 Future Internet, Internet of Things

**Faculty** Thomas Bonald, Claude Chaudet, Nadia Boukhatem, Daniel Kofman, Jean-Louis Rougier.

**Main events** Organization of EuroNGI 2010.

**Projects** CELTIC TRANS; FP7 EuroNF, ETICS; ANR DIAFORUS, 3MING, SUN; External research contract with Orange Labs; I-GATE (Institut Telecom/ Futures et Ruptures).

**Wireless Sensor Networks / Internet of Things.** Our objective is to create distributed algorithms that are lightweight alternatives to the functions of a classical network. Solutions shall be efficient in terms of energy, complexity and memory usage to be embarked on low-cost, low-power and low-capacity nodes. Our contributions are on the topics of network self-organization, localization and on experimental platforms.

We participate in the DIAFORUS project in the conception of a middleware for wireless sensor networks, designing an efficient publish/subscribe-based communication brick that relies on an overlay of brokers. We compared various criteria to build this overlay in order to optimize energy efficiency, memory space and raw performance [1032, 1031]. We are currently working on a distributed algorithm that builds and maintains such an overlay.

We also work in the smart home environment to provide accurate indoor localization techniques for wireless terminals without adding dedicated hardware. We show that in an indoor environment, the signals captured by the radio interface cannot be correlated with distance without calibration of the environment and of the node and constant update of this calibration parameters. Localization algorithms using RF signals for trilateration are bound to be imprecise unless a strong collaboration exists between a large number of nodes. We are currently looking at alternative, using RF signals to deduce relative positions rather than absolute distance measures. Within the SUN ANR project, we investigated location management systems and developed an IP-based RFID architecture for indoor location management [1002, 1119].

We have started in 2011 to build a federated platform that aims at becoming a reference for mobile sensor networks. The platform will be composed of fixed and mobile sensors and will focus on the interactions between the environment (composed of LEDs and sound generators) and the

sensors. At the first stage, Telecom ParisTech is conceiving a scenario description language that aims at being simple, descriptive and provable in order to automate experiments.

**Towards a multi-path Internet** Routing diversity has been identified as essential for both network robustness and traffic engineering. The Internet possesses by its very nature a large path diversity. However this diversity cannot be fully exploited due to several architecture limitations, in particular at the level of routing protocols (namely BGP) and transport layers. Our contributions covers both the routing and transport aspects.

On routing aspects, our work first concentrated on possible collaboration schemes between providers. Today, each carrier uses selfish routing policy (e.g. preference of a free peering link over a transit link) in order to choose the route used to transit traffic. If it is quite natural for 'best effort' traffic, this approach clearly limits the range of potential inter-domain services that can be offered in the Internet. We have formulated a simple but realistic non-cooperative routing framework that arises between two ISPs on their peering links. Our approach allow to select pareto-efficient routes, which allows to greatly reduce congestion and improve route stability. At the same time, our approach is based on non-collaborative game theory, thus protecting operators' independence and incentives [1098, 997]. We proposed an multi-path extension of this approach which further improve performances [1097, 998]. This is a joint work with Prof. A.Patavina (Politechnic of Milano, Italy) funded by ANR ACTRICE and IGATE projects. The proposed approach was also enhanced to offer a high resiliency against network failures [1099, 996], in collaboration with H.Ma and Prof. B.E.Helvik (NTNU, Norway).

We also studied a higher level of collaboration between carriers within a alliance of carriers. In this context, a routing architecture for end-to-end MPLS services was proposed [995] where disjoint routes are computed for resiliency purposes. We also studied how the distributions of incomes within this context of an alliance can be naturally linked to network dimensioning [1076].

In the context of the european ETICS project, we are currently studying solutions based on a *maps-and-encaps* scheme to by-pass current BGP limitations in order to use arbitrary paths and thus utilize the inherent Internet path diversity.

**Exploiting path diversity** We also focused on multi-path transport layer solutions able to utilize route diversity. We developed a forward predictive scheduling mechanism which alleviates the out-of-order data reception problem. It estimates the delays incurred to data on each path, and then schedules the transmission of a data packet such that the re-ordering cost is minimized [1071, 1070].

The scheduling scheme has been integrated to both SCTP and MPTCP (multi-path TCP) implementations. A prototype was developed with the collaboration of BearsTech Enterprise within the 3MING project[1069]. In collaboration with UPMC/LIP6, a cross-layer extension of the scheduling algorithm has been proposed. It contributes to accurate path delay calculations using layer-2 information for 802.11 wireless links [1073].

Dynamic load balancing (DLB) also represents a powerful traffic engineer tool as it leads opportunistically to an optimal network utilization without any prior knowledge of traffic (e.g. like traffic matrices). Most existing DLB mechanisms are however based on simple unrealistic cost functions (such as M/M/1 delay formulae). We proposed instead new load balancing schemes based on cost functions measured through non-parametric regression [1094, 985]. Thanks to modern learning heuristics and proposed enhancements, we also proved that our DLB mechanism is very robust w.r.t. abrupt traffic variations. Finally, our proposal is compared on realistic network topologies with robust routing (the most common alternative TE mechanism) [1064, 1065, 973].

We obtained approximations for various performance measures in a multi-rate link sharing bandwidth under an insensitive sharing mechanism called balanced fairness [1025]. Balanced fairness can be viewed as the large system limit of proportional fairness. For a large system, we obtain closed form expressions for the calculation of long run fraction of time that the system is congested, the probability that an arriving flow will not obtain its maximum bit rate and the average fraction of time that an arriving flow is not allocated its maximum bit rate while in the

system. The techniques are based on local limit theorems for convolution measures. This is a joint work with J-P. Haddad and R. Mazumdar (U. Waterloo, Canada)

**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. This is important to insure a certain quality of expectation to critical flows, for instance. Our method is based on both knowledge of the network, P2P systems and on learning theory (like Pearson's statistical Chisquare test, bayesian inference or support vector machines). Our contributions are twofold:

The first approach relies on similarities with verbal communications, with a new class of methods called 'Stochastic Packet Inspection' (SPI), which can be seen as a statistical extension of the well-know DPI. SPI starts with a keyword search in traffic (e.g. like 'GET' for Web traffic or 'BT' for BitTorrent) like in DPI, and uses statistical tools to automatically define stochastic signatures [977]. First designed for UDP traffic, this method was extended for TCP traffic [1045].

Our second approach analyses the behavior of applications solely on traffic characteristics, regardless of the content of packets. The similarity with human interactions is here particularly relevant: e.g. a 'shy' application prefers long communications with a limited number of hosts while 'hearty' applications rather prefers short exchanges with many hosts. This analysis technic, named Abacus [966], as it only keeps track on the number of packets exchanged, is particularly appreciated by network operators as it can directly be applied to Netflow [1087] and robust to sampling [1088].

A software implementing both technics has been provided to the scientific community [1046]. It allowed to compare both technics [1047]. These technics are now used for the observation and classification of network traffic in several european Internet Service Providers (ISP) [1074, 978].

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 [1082] and on performances of traffic classification [1089].

## 9.2.4 Core Networks

**Faculty** Thomas Bonald, Maurice Gagnaire.

**Projects** FP7 DICONET, BONES; ANR ECOFRAME; FIMOB (Institut Telecom/Futurs et Ruptures).

**Transparent WDM network design.** A translucent WDM optical network can be viewed as a transparent optical network in which sparse nodes proceed to electrical regeneration either form traffic grooming or quality of transmission (QoT) purposes. Considering mesh topologies with finite optical channels capacity per fiber and static traffic matrices, we have investigated the most efficient way to proceed to electrical regeneration in order to guarantee an admissible Bit Error Rate (BER) at the end of each established lightpath [979]. Four transmission impairments (namely: amplified spontaneous emission, chromatic dispersion, polarization mode dispersion, and nonlinear phase shift) have been considered in our studies. Electrical regenerators are costly and power consuming. The originality of our approach consists in trying to minimize simultaneously the total number of regenerators while minimizing the number of regeneration sites [1004]. We have shown how these two parameters have a strong impact on the cost of investment and operation and maintenance of the network. In a first step, we have proposed an original heuristic called COR2P (Cross Optimization for RWA and Regenerator Placement) achieving this double objective [1110], [1109]. We have then extended this optimization problem in considering the time-space correlation of the traffic demands. Our objective was to optimize regenerators' utilization [1007]. We have outlined the fact that, whatever the traffic matrix, the nodes with the highest physical degree are good candidates to be regeneration sites [1042]. We have proposed an original exact ILP formulation of this problem. In contrast with existing exact approaches that rely on linear approximations of the signal degradation, we have made use of a realistic estimate

of the optical signal quality taking into account the simultaneous effect of the four impairments mentioned above. We have also investigated a tradeoff between optimized network costs on one hand, and flexibility against traffic uncertainty on the other hand. To this end, we have extended our ILP formulation to multiple traffic forecasts. Our concern is to judiciously deploy regenerators so that network design remains optimized under different traffic forecasts [1048], [963], [1081]. These works have been carried out either in the context of the DICONET European project [1043] or within the BONE European Network of Excellence. In collaboration with the Univ. of Barcelona (UPC), we have contributed to the hardware implementation of the COR2P control plane in FPGA. An experimental testbed has outlined the efficiency of the COR2P algorithm.

**Fault management and traffic engineering in transparent WDM networks.** Two techniques have been recently proposed in the literature for single failure detection in translucent WDM networks: monitoring cycles (m-cycles) and monitoring trails (m-trails). We have proposed an original meta-heuristic called MeMoTA (Meta-heuristic for Monitoring Trail Assignment) enabling to determine the number of m-trails and their routes that is able to deal with very large networks and under dense traffic matrices [981, 1041, 1050]. Our algorithm is inspired from the Tabu Search meta-heuristic. It has been accepted as a European patent [1120]. The main drawback of the m-trail approach is its inherent cost in number of required out-of-band optical channels. We have developed the concept of "monitoring-tree" that considerably increases network capacity while enabling a non-ambiguous single failure localization. The concept of m-tree has been the subject of a European patent [1121]. An ILP formulation has been proposed to determine the most efficient tree to be mapped onto any meshed network topology. In parallel, we have investigated dynamic lightpath rerouting strategies that can be used after a fiber cut. The same strategies can also be used in order to provide a better usage of the network resources while the network is active [984]. The originality of this study consists in considering simultaneously three types of traffic: permanent, scheduled and random.

**Optical burst switching.** We analyze different network architectures based on optical burst switching for metro networks [1023, 1022, 1026]. In particular, we propose a novel MAC protocol for a ring slotted WDM network. The protocol is based on both opportunistic access ensuring efficient utilization of slots and dynamic reservations that maintain a certain degree of fairness between stations. We show that, while a purely opportunistic access scheme is perfectly efficient, the impact of introducing the proposed reservation algorithm is limited in terms of lost capacity in any realistic traffic scenario. This is a joint work with R-M. Indre, S. Oueslati and C. Rolland (Orange Labs).

**Radio over Fiber** We have worked on the specification of an innovative all-optical WDM access infrastructure that could be used as a Next-Generation Radio Access Network (RAN). This infrastructure relies on traditional Passive Optical Networks considered today to connect fixed broadband users to the Internet. Thanks to reflective modulators, optical add-drop multiplexers and a low-cost AWG optical router, we exploit the potentialities of analog Radio-over-Fiber to distribute in parallel to fixed traffic, radio carrier frequencies (RF) to a set of antennas connected to the leaves of the optical tree. Optical sub-carrier modulation is considered to transport RFs from the Central Office to the antennas' sites. The main originality of our works consists in designing an ad hoc control plane enabling to redistribute radio equipment between different geographical areas according to their traffic load fluctuations. This control plane operates in a cross-layer mode since the physical layer constraints must be considered imperatively, both in the optical and in the radio domains [1052].

## 9.2.5 Green Networking

**Faculty** Claude Chaudet, Marceau Coupechoux, Maurice Gagnaire, Philippe Godlewski, Dario Rossi, Jean-Louis Rougier.

**Projects** CELTIC TIGER2; FP7 DICONET, BONES; external collaboration with Orange Labs.

**Minimum Energy Routing in IP Networks.** We have studied green networking technologies and issues focusing on fixed networks [967]. One of the main issue we encountered was the lack of reliable figures on energy consumption and the lack of standard measurement methods and evaluation metrics. In particular we pointed out the incongruence of several results published and made several proposals in order to overcome these issues [1019, 967, 969, 968].

We then concentrated on the 'resource consolidation' approach, which consists in concentrating traffic on a subset of nodes/interfaces when utilization is low, thereby allowing to put other equipments in sleeping (low power) modes or simply to switch them off. We formulated the problem of minimum energy routing [1017] and derived results with realistic energy models and network topologies. Results showed that potential energy savings strongly depend on the type of network studied, ranging from very low (in particular for core IP networks) [1018] to significant (e.g. in redundant access networks). We then concentrated on the tradeoff between energy savings and network resiliency. We have proposed a new method for computing the importance of nodes/links in a network, which is based on a collaborative game theory approach (namely on the Shapley value). This ranking is used to decide which nodes/links should be switched off [1020]. Results highlighted better network resilience properties with similar energy gains.

Our previous solutions to the 'resource consolidation' problem were centralized. We have then started to investigate distributed green routing mechanisms ('à la' OSPF) [1021], which result easier to be deployed when considering current and foreseen network devices.

**Power aware routing in optical networks** In current WDM networks, transceivers are powered-on permanently, whatever the activity of the data sources at the electrical layer. Our objective is to minimize network's power consumption in considering the transceivers with fixed data rates actually deployed in carriers' networks. In this context, we have proposed an optimal mapping of a set of scheduled traffic demands at the electrical layer onto an optical mesh infrastructure. The number of optical channels per optical fiber being upper-bounded, this mapping also enables to minimize connection rejection. This optimization problem has been solved by means of an ILP formulation [1111].

**Green cellular Networks.** In the field of green cellular networking, we have started a study with Orange Labs with the aim of evaluating the impact of power reduction on the coverage and the capacity of cellular networks [1059]. Power reduction is directly beneficial on energy consumption, potential risks for health and on interference mitigation, which stimulates the deployment of opportunistic radios in the same spectrum. Power control is however likely to degrade network performances. We have established closed form formulas of outage probability by taking into account shadowing, thermal noise and base stations (BS) transmitting power impacts. We have shown that transmit power can be significantly reduced without affecting the quality of service and that increasing the BS density results in a reduction of the global power density in the network.

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# Chapter 10

## Software, Systems and Services (S3)

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## 10.1 Objectives

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 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 focussed 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 artefacts: from requirements down to resources, platforms, application components, infrastructure components, etc.

For instance, the applicability of MDE to Distributed Real time Embedded systems (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 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.

## 10.2 Main Results

### 10.2.1 General Achievements and results

#### Distinctions, Awards and Positions in Scientific Societies

M. Lafaye and L. Pautet received the Best Paper Award at the IEEE Digital Avionics Systems Conference for their paper : *Model Driven Early Exploration of IMA Execution Platform*.

Isabelle Demeure was nominated "Officier" dans l'ordre des palmes académiques (decoration for services to education).

E. Najm is the elected Chair of Working Group 6.1 of IFIP.

E. Najm received the silver core medal from IFIP.

#### Organized Events

ETR'09 organized by L. Pautet

NEPTUNE'10 organized by E. Najm and L. Pautet

NOTERE'11 organized by A. Serhouchni, I. Demeure and T. Robert.

MAASC'11 organized by A. Diaconescu

ICSSEA'10 and ICSSEA'11 organized by E. Najm and T. Robert

AADL Standardization Meeting (June 2010)

DIAG 21 Workshops organized by T. Robert

#### Participation in Joint Labs

The S3 group is member of the new Chaire (joint lab) relative to complex systems that was officially set up on November 7 (duration 3 years). The joint Lab 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 research and reference master program in France regarding complex system architecture and engineering.

### 10.2.2 Model driven development for High-Integrity Real-Time Embedded Systems with realistic resource consumption modeling

**Faculty** E. Borde, L. Pautet

**Main events and external collaborations** Jan Carlson (Univ. de Malardalens, Sweeden), Olivier Hachet (Thales Communications), Marc Gatti (Thales Avionique), Jérôme Hugues (ISAE), Peter Feiler (SEI/CMU). Best Paper Award at IEEE Digital Avionics Systems Conference. Patent with Thales on "Procédé de modélisation, simulation et évaluation en avance de phase d'une plate-forme de calcul". Active participation to the AADL standard committee. Specification of the ARINC653 annex for AADLv2.

**Projects** finalization of Etienne Borde's post-doc, ANR/PARSEC, PhD thesis of M. Lafaye (CIFRE), PhD thesis of M.Lasnier (Ministry scholarship).

Building High-Integrity Distributed Real-time and Embedded Systems (DRE) is a tedious task. Such systems come with strong requirements to ensure safety, reliability and security properties. Model Driven Engineering (MDE) and Component-Based Software Engineering (CBSE) are two distinct but not incompatible approaches that are recognized to be efficient in improving the

design process of these systems. MDE allows a better control on the individual steps of the process and thus reduces development time, complexity and cost. Pursuing a parallel objective, Component-Based Software Engineering (CBSE) is also meant to ease the reuse and integration of existing software libraries into a software application. MDA and CBSE are also useful for the early validation of a system under the condition that the component model exhibits an analyzable semantics.

Hence we worked on the development of a combined MDE and CBSE approach, with specific aims. Our endeavor is to ensure that properties satisfied by the semantics exhibited at some higher modeling stage is enforced at deployment time. To reach this objective, the sought process needs to satisfy two requirements: (i) to preserve the component model semantics along the compilation process, and (ii) to provide for a sufficiently rich and faithful representation of software and/or hardware components so that hardware capacity and behavior is reflected in early design models. These two requirements are not straightforward to fulfill. Considering the first, it is well established that higher level models have different concurrency semantics than the ones underlying execution models and semantics equivalency is difficult to achieve in model transformation. With respect to the second requirement, problems are twofold (i) the characteristics of each hardware component is usually provided as sets of predefined properties corresponding to the general category of the component and hence they are raw approximations, and (ii) the interactions between components in terms of distribution over time lack precision for performance evaluation since the resource consumption estimates are obtained independently of the usage context of these resources, as opposed to the real execution.

We addressed the above problems and we defined and developed a model transformation and code generation process that (i) refines an architectural model into an equivalent one where the semantics properties of the initial model have been mapped into representations of interactions between the applicative components in the underlying runtime environment, and that (ii) integrates compositions of hardware components so as to model and simulate their interactions and to evaluate real resource consumption. Our new refinement approach uses AADLv2 and the AADL behavior annex. We participated to the standardization process as advanced users and contributors of this annex. It led to several internship with the team in charge of this component model at SEI/CMU. It helped us to specify the middleware as a set of AADL architectural components with their explicit behavior. The successive refinements allow to integrate the middleware components in an AADL architectural description, to configure them with the system properties extracted from the model and to analyze the overall system including both the application and middleware components. Also, interactions among hardware components can be described with different levels of granularity, in order to provide early estimates of the hardware resources consumption. This part of the process takes advantage of two standardized languages, AADL for high-level system modeling, and SystemC, for refined execution platform description and simulation thanks to its simulation kernel. We target the TLM abstraction level, which is the best compromise between simulation speed, simulation accuracy and modeling time, and which fits best our expectations of early modeling and hardware resources usage estimation. This work is part of a fruitful long term collaboration with THALES on MDE approaches to provide for early validation of software systems (applied to avionics), and led to several publications in major conferences (DASC and DATE).

### **10.2.3 Model Driven Engineering with reusable components for the design of predictable middleware in safe and secure real-time systems.**

**Faculty** E. Borde, L. Pautet, T. Robert

**Projects** CIFRE contracts, COUVERTURE and CORAC projects, MNESR (J. Delange).

Our work aims at enabling the design and assessment of Fault Tolerant Architectures through

component based middleware frameworks with predictable dependability and security attributes and encompassing software failures.

Two main tracks are followed in the field of Model Driven engineering. On the one hand, many formal models acquired an operational semantics enabling code generation processes from models. This kind of approach is identified as a key technology to produce so called "fault-free" code. In this field, we can notice the growing community building around synchronous execution models and model based approach designed to prove that the code deployed is predictable. On the other hand, fault-free software is an odd concept for assessing dependability or security, and another track of research is followed which is based on further decomposition of system architectures aiming at understanding and assessing fault confinement architectural patterns and their properties with respect to dependability and security attributes.

Thus, we developed and improved the state of the art in test based and fault injection methodologies especially through the COUVERTURE project. Nevertheless, our work mainly belongs to the second track of investigation. Especially, we apply our research to partitioned systems for which fault containment is a key issue to ensure system security as well as for system dependability. In that context, we rely on mature dependability assessment approaches based on model-checking. It is now possible to perform model checking on non-trivial dependability and security models (like CTMCs or Markovian Decision Processes, and even hidden markov models). Yet, no method provides a clear interpretation of failure probabilities for software systems in terms of fault or attack models and this is due to the various possible meanings that can be associated with this notion of failure probability: likelihood, possibility, or absolute failure rate. For this reason our approach is based on Architectural Description Languages (ADLs) which are dedicated for embedded system (e.g. MARTE, AADL), and which provide means to model systems with both their software and hardware artifacts and to explicitly define dependencies between these two domains with respect to fault activation and propagation. This ability to model both aspects helped us solve many issues related to dependability assessment. The CORAC projet provides us the means to continue this effort in building a unifying modeling framework for both security and dependability integrity concepts together with verification methodologies.

#### **10.2.4 Advanced scheduling approaches for new hardware and software architectures in real-time embedded systems**

**Faculty** E. Borde, L. Pautet, T. Robert

**Projects** PARSEC, MESR PhD thesis.

This work is concerned with new scheduling schemes that address the issues of scheduling in the context of task execution overhead and energy consumption management.

Schedulability analysis validate task models with respect to various assumptions made on the properties of the execution platform that will host the task set. But it is still a major issue to assess schedulability when the execution platform induces overheads on the execution of tasks. Many scheduling methods have been proposed to deal with different types of overhead costs. Nevertheless, these methods do not cope with the increasing complexity of hard-real time systems. Indeed, the number of services integrated on embedded execution platforms is increasing, thus diversifying the possible sources of overhead. Hence, defining a scheduling scheme and associated feasibility analysis method to handle various sources of CPU consumption overheads is still an open problem.

Several approaches have been proposed to schedule real-time systems while reducing the energy consumption. They extend classical scheduling techniques designed for mono-core architectures. Basically, they take advantage of two mechanisms available on processors which

offer energy management. The first (DVFS) provides Dynamic Voltage and Frequency Scaling. The second one (DPM) Dynamic Power Management allows switching off the processor for a period of time. During the last decades, new algorithms have been designed to schedule real-time systems on multi-core architectures. But these algorithms have not yet been revisited to manage energy consumption.

Hence, our global aim is to design new scheduling algorithms and their middleware counter parts to take into account non-functional properties such as system overheads or energy consumption. To handle these properties, our approach is to provide for system models analysis resulting either in the definition or in the selection of an application specific scheduler. More precisely, we have defined a scheduling scheme and a feasibility analysis method to handle new issues in real-time embedded systems such as non-determinism due to CPU consumption overheads or energy consumption in multi-core architectures. This work is related to our results from the PARSEC project but go beyond the boundaries of this project. Our approach is generic to take into account various kinds of overhead sources. It is based on exploiting high-level execution traces which integrate and test overhead sources incrementally with respect to the initial execution model. Application properties are extracted to propose a scheduling scenario taking into account overhead sources. Our generic approach is currently integrated in our Eclipse environment with other model transformation works like those conducted in the context of the PARSEC project. It is currently experimented on various avionic case studies.

### 10.2.5 Architectures and Frameworks for Autonomic Systems

**Faculty** I. Demeure, A. Diaconescu

**Main events and external collaborations** Philippe Lalanda (ADELE team, LIG laboratory), University Joseph Fourier, René Doursat (The Complex Systems Institute).

**Projects** CIFRE EDF R&D, Cube (University of Grenoble), MEDICAL (Minealogue project).

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. The design and development of such systems is rather complex and should be assisted by well defined architectures, patterns and frameworks. The field is active, however few frameworks and architectures have been proposed since the introduction of this concept by IBM about 10 years ago. The existing ones are limited either in the purpose (dedicated to specific systems), in the scale of the targeted systems, or their ability to integrate or federate various autonomic systems.

Our research focuses on 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 pervasive or enterprise applications. We have two main contributions that we realized in the past two years. The first contribution lies in the development of a generic model-based approach and framework for enabling software systems to self-grow and self-maintain in highly dynamic and unpredictable environments. This work is carried out as part of the Cube project (in collaboration with University of Grenoble). The Cube framework has evolved through two incremental iterations. A comprehensive prototype for large-scale distributed applications is expected by the end of 2011.

The second contribution consists in the design and development of generic architectures and frameworks for facilitating the creation and maintenance of autonomic management systems. A number of reusable design patterns have been identified and defined for facilitating the integration of complex and adaptive autonomic management systems based on simpler reusable modules.

We also have a contribution in the realm of micro-smart grids. We adopted a scenario-driven approach and identified and then specified (jointly with designers from the SES department) a number of application scenarios relative to micro-smart grids where the objective is to leverage energy consumption in homes. Another scenario was identified and prototyped for dynamic surveillance of electricity consumption in ultra large scale systems (with help from researchers of the BiLAB).

### 10.2.6 Middleware and distributed algorithms for ad-hoc network based systems

**Faculty** C. Chaudet (RMS team), A. Diaconescu, I. Demeure, Annie Gentes (SES department), S. Tardieu.

**Main events and external collaborations** Pierre Sens (REGAL team, LIP6, UPMC).

**Projects** Transhumance (ANR 2006-2009), DIAFORUS (ANR 2009-2012), 2 EDITE PhD grants (sources: MESR and CNAM).

Distributed systems built on top of ad-hoc networks, must adapt to the evolving topology of such networks. When the network involves limited capabilities such as sensors and smartphones, they must also take these limitations into account. This work seeks to develop middleware solutions and distributed algorithms adapted to these constraints.

We have designed publish/subscribe based middleware solutions and distributed algorithms for information dissemination and information sharing targeting systems relying on ad-hoc networks.

In a first project, we were concerned with the design and development of a middleware for a small scale mobile ad-hoc network of internet tablets. 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 of this project was the design of original distributed algorithms for data sharing in stable neighborhoods in such networks. They used semantic information to do statistical replication of data over the participant devices. The project was conducted with a scenario-driven approach. This allowed us to design and develop a treasure hunting game that very well demonstrated the essence and the results of the project.

In a second ongoing project, we are concerned with the design of a publish/subscribe based middleware for a wireless sensor network. We are currently designing a solution taking into consideration the limited capabilities of the network nodes as well as the limited energy (the sensors are battery operated). The choice of the proper number of publish/subscribe brokers as well as their placement is a key problem. Finally, we are investigating algorithmic solutions for information dissemination in large-scale ad-hoc networks. We have proposed a new criterion named "effective fanout" for the comparative study of epidemic algorithms over a variety of random topologies.

### 10.2.7 Architecting convergent and orchestrated services

**Faculty** E. Najm

**Main events and external collaborations** K. Sbata (Orange Labs).

**Projects** MOTELI (Digiteo), Orange bilateral project, PhD CIFRE.

This work is concerned with architectures and engineering methods for the provision of Web and Telco services. The general endeavour is to foster a business model offering rich and convergent services. Our results are twofold: the first is related to an end-to-end architecture for convergent Web and Telco services. The second addresses the issue of enforcing compatibility between orchestrated web services. We describe these two results hereafter.

Over the last few years, significant evolutions such as the mobile phones' enhanced Web-browsing capabilities and the technical incursion of Web major players into the Telco world (e.g. Google, Facebook) have reduced the gap between Telecom and Web worlds. In this context, converging IMS (Internet Multimedia Subsystems) and Web service platforms have become a key challenge that needs to be addressed by both Web and telecom players. Several interesting solutions, illustrating different convergence approaches, have been proposed so far. Unfortunately, none of them has been able to provide an efficient way to set up end-to-end converging services. Indeed, Web-based applications are synchronous, as they rely on HTTP. On the other hand, IMS services can be provided in both asynchronous and synchronous modes. We define synchronous applications as services in which each provided resource or piece of information has to be explicitly requested by the consumer and asynchronous applications as services that can notify their consumers anytime they need. But recently, the W3C and the IETF have released new standards (HTML5 and WebSocket protocol), introducing important evolutions in the Web paradigm. In particular, the WebSocket technology allows a native support for asynchronous Web applications. Our proposal is a converging framework (called WSE, standing for WebSocket Enabler) that takes advantage of this new technology to achieve end-to-end service convergence.

In the context of web services described using the BPEL orchestration language, services may interact in an inappropriate and incompatible manner resulting in run-time errors and/or complex exception handling when unexpected messages or when messages containing values with unexpected types are received. Current approaches to solve this problem are limited to checking the syntactic compatibility between sent and received operations. Our approach to solve this issue is using a session based approach. We enhanced BPEL with the session paradigm, and we made sessions as first class citizens. 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 compatibility and a subtyping 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.

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## **Part III**

# **Economics and Social Sciences**



# Social and Economic Sciences (SES)

The department of economic and social sciences (which composes one single "team" for the purposes of this evaluation document) is an interdisciplinary department for teaching and research. At the 1<sup>st</sup> of November 2011, it is composed of 29 permanent members in teaching and/or research positions (among which 4 researchers from CNRS and 1 from INRIA), 8 associate researchers, 28 ongoing Ph.D projects, 19 non permanent members and post-doc (among which four visiting professors from abroad for various durations), and 3 persons employed in administrative capacities.

It is original in the French landscape by being highly multi-disciplinary: it involves researchers in economics, management sciences, sociology, information and communication sciences, cognitive psychology and ergonomics, liable to several sections of the CNRS, 29, 34, 36, 37, 40 and 44, as well as CNU section 71 (not represented in CNRS). Its focus is therefore not disciplinary but thematic. It aims to cover the Information and Communication Technology (ICT) "human"-oriented perspectives, with two sets of equally stringent, and sometime cross-cutting exigencies: operating at the cutting edge of each disciplinary field, while also participating to collaborative and innovative research projects (involving cooperation either between social sciences or between social science and more 'technology-oriented' departments and industries) which directly benefit from the involvement of multiple disciplines. But in this particular domain, trying to satisfy both exigencies as much as possible is a key to original, innovative research which may shed new light on the uses of ICTs, for these are usually oriented with respect to multiple normative orders, economic, social, technological, etc.

For management purposes, the department is organized in three research groups, two in Paris and one in Sophia Antipolis. Its research activities are structured around three axes which are deliberately not congruent with the boundaries of the three groups (because they aim towards stimulating various forms of interdisciplinary collaboration). These three research axes each explore significant issues regarding mediated interactions and transactions, but at several scales. At the "macro level" Axis 1 one looks at regulation and innovation-related phenomena in the telecommunication sector. At the "meso level", Axis 2 studies the production, circulation and reception of media and cultural contents with an eye towards the blurring of the boundaries between producers and consumers, professional and amateurs, etc. At the "micro level" Axis 3 focuses on mediated interactions and the local management of situations and activities relying on communication technologies and services.



# Chapter 11

## Social & Economic Sciences

### 11.1 Regulation and Innovation (RINNO)

**Faculty animators** Maya Bacache (MdC) and Marc Bourreau (P).

**Faculty members** Maya Bacache, David Bounie, Marc Bourreau, Myriam Davidovici-Nora, Dana Diminescu, Laura Draetta, Valerie Fernandez, Laurent Gille, Thomas Houy, Rémi Maniak, Gerard Pogorel.

**External Research associates** : Michael Ballé, Philippe Barbet, Godefroy Beauvallet, Abel Francois, Chiraz Karamti, Tommaso Valletti.

**Doctoral students** : Yassine Bouhdaoui, Benjamin Chevalier, Joeffrey Drouard, Germain Gaudin, Christian Grèce, Tania Horquin, Lionel Janin, Yun Jiang, Bruno Karoubi, Carine Khalil, Laurie Marraud, Serge Pajak, Raphael Raieb, Lilia Rebai, Dominique Vian, Winston Maxwell.

**Post-doctoral students** : Frago Kourandi (2010-2011), Mattia Nardotto (2010-2011).

**Visiting researchers** : Carlo Cambini (2010), Martin Peitz (Nov. 2011).

#### **Research contracts**

SportViews European project, COST Action IS0605 EconTel (2008-2011), Research contracts with the Department of Regulatory Affairs of France Telecom (2007-2011), Research contracts with the Groupement Cartes Bancaires "CB"(2005-2011), Contracts with regulatory authorities in developing countries, Chaire "Regulation and Innovation in Digital Services" Orange-Ecole Polytechnique-Telecom ParisTech, Contract with the Department of Justice (2011-2012), Project LETTI (2009), CNRS ANR Corpus -Mobicit (2007-2010)

#### **PhD projects**

Yassine Bouhdaoui, (started 2010): "Currency systems, technological changes and the social cost of cash."

Benjamin Chevallier (started 2006, ended 2010): "The structuration of new market services and the management of regulation costs by mediated communities."

Joeffrey Drouard (started 2006, ended 2010): "Competition and investment in telecommunications."

Germain Gaudin (started 2009): "Innovation and regulation in the telecommunication industry."

Christian Grece (started 2006): "Management and pricing of the hertzian spectrum."

Tania Horquin (started 2007): "The forms of emergence of the markets for teleservices."

Lionel Janin (started 2009, ended 2011): "Competition and regulation."

Yun Jiang (started 2004, ended 2010): "The structuration of the value chain for mobile technology in the context of the growth of multimedia technologies: which economic models?"

Laurie Marraud (started 2010): "Mobilité équipée par les TIC : analyse de comportements émergents."

Bruno Karoubi (started 2006): "Economics of payments."

Carine Khalil (started 2008, ended 2011): "Les méthodes de développement agile et les dynamiques d'organizing : une approche par la pratique."

Serge Pajak (started 2007, ended 2011): "Intellectual property and innovation strategies."

Raphael Raieb (started 2011): "Gouvernance des communautés médiatisées : le cas d'un collectif d'auteurs de livres scolaires numériques."

Lilia Rebai (started 2004, ended 2009): "Identifying relevant telecom markets in Tunisia."

Dominique Vian (started 2006, ended 2010): "From the assessment of invention to its transformation in innovation: cognitive processes."

Winston Maxwell (started 2011): "Achieving audiovisual policy objectives via telecommunications regulation."

Alexis Maingard (started 2009): "Reforms, sector outcomes and economic growth in Telecommunications in Africa".

Hai Xiaodong (started 2009): "Pricing strategy for App stores"

Aude Shoentgen (started 2011): "Risk assessment in valuation of telecom investments in Africa".

### 11.1.1 Context and objectives

The dynamics of ICT industries are influenced by a tension between innovation and regulation [1341]. Indeed, these industries are characterized both by a high pace of innovation (affecting the supply side and the demand side), and strong regulation (through intellectual property, the scrutiny of competition authorities, and sector-specific regulation). On the one hand, due to the endogenous relationship between technological progress and industry structure, regulatory policies clearly affect the speed of technological change, via two different channels. First, price regulations (e.g., the regulation of interconnection charges and retail prices in telecoms, the regulation of the interchange fee in the payment industry, the control of prices in the health sector, etc.) alter industry profits, and hence the incentives to innovate. Secondly, both price and entry regulations (e.g., spectrum licenses, patents, banking licenses, ...) change the terms of entry, and hence innovation decisions regarding new entry. But on the other hand, to the extent that technological changes alter the organization of the industry, the speed of innovation – particularly in the new markets – should also be reflected in any regulatory intervention. If regulatory authorities cannot respond fast enough to follow the rapid change of the market, many regulatory measures then become either inefficient or obsolete.

Consequently, new flexible forms of regulation are called for. Indeed, though a regulation which would not adapt fast enough to changes in technologies or market structures would be inefficient, an unregulated environment would probably also lead to inefficient outcomes, as the current economic crisis illustrates. We therefore need to rethink public policy, by taking into account innovation dynamics and the institutional constraints.

This research project tackles the two dimensions of the relation between innovation and public policy through two different areas of research:

Sub-theme 1: Innovation in Regulated Industries. In this second area of research, we study innovation strategies in industries where regulatory constraints are binding (intellectual property, constraints on R&D collaboration in Europe and US, specific regulations, etc.).

Sub-theme 2: Regulation in Innovative Industries. In this first area of research, we study the design of public policy in innovative industries. In particular, we examine how sector-specific regulation should be designed to take into account its effects on innovation strategies.



### 11.1.2 Sub-theme 1: Innovation in Regulated Industries

In this area of research, we focus on innovation strategies, and on the effects of innovation on the industrial organization of specific markets.

#### Innovation strategies, value and organization

A first research project focused on the impact of a modular product design on (i) component-sharing between competitors [1190], and (ii) cooperation strategies at the R&D stage [1191, 1368]. The main idea behind this research is that sharing technologies may bring forth some benefits in terms of economies of R&D costs, but also has costs due to lower possibilities of differentiation. We have therefore explored the consequences of these benefits and costs on market competition.

We have also continued our research on the different regimes of value, which was started by Laurent Gille 10 years ago with a book on the sources of value (published at L'Harmattan in 2006). This reflection is going forward, with questions of trust and complementary currencies as the main areas of interest, and it should result in a book in 2013.

We recently expanded our research program about value in the management science discipline. This led us to settle the concept of "Full Value" which designates the indirect profits generated by one or several companies selling an innovative product – in analogy to the "full cost" logic. We initiated this research program with two communications [1405, 1406]. It is now the foundation of two research contracts initiated in the automotive industry, and one public research program (with ADEME, to be confirmed). We build methodologies to evaluate the provisional profitability of innovations regarding a wide spectrum of values, in one firm or in one innovative ecosystem. At least one article and one book are in the pipe regarding this research program.

Regarding the issue of "organization for innovation", we ended a 5-year research program initiated with the Innovation Management Chair of Ecole Polytechnique, which compared the organizational settings for innovation of 9 car makers based on the detailed study of 26 innovative features. We submitted an article in the best specialized journal –the "Journal of Product Innovation Management"— to promote the results [1168]. A book is also currently under editing.

#### Money, payments, and technological innovations

The payments industry has experienced profound changes in the last decades, due in part to many technological innovations: debit and credit cards, electronic money, private money, electronic payment systems on the Internet, mobile phone payments, ATMs, automated compensation procedures, etc. These innovations affect consumer choices in terms of payment instrument and in turn affect economic, monetary and banking activities.

First, the characteristics of payment instruments (in terms of cost, safety, etc.) impact the willingness to pay of consumers and, therefore affect how (well) markets can operate. Second, the use of payment instruments determine partly banks' income, the magnitude of deposits and, in turn, the possibilities of financial intermediation. Third, and finally, the use of payment instruments orient the demand for money (both cash and central bank money) of economic agents. While these questions were for long considered as a by-product in the economic model of the bank, our research has shown that the payment instruments, that lie at the intersection of the economic, banking and monetary spheres, constitute a field of original and fundamental research for banking and monetary economics.

Our contributions have focused on three areas. First, prior to analyzing the impacts of technological innovations, it is important to understand first what are the determinants of the consumer choice between payment instruments. As a first step, we have regrouped the contributions that seek to validate and extend the theoretical models explaining consumer choices in the use of payment instruments [1176, 1177]. Then, in a second step, we have evaluated how technological innovations associated with payments affect the economic, monetary and banking spheres [1172, 1187]. Finally, in a last step, we question the effectiveness and cost of cash

payments primarily in the context of the development of new competing payment technologies [1176, 1180, 1169, 1171, 1170].

A final research project, still ongoing, is to study innovations in payment systems, how they can diffuse and how to encourage firms to develop and implement these innovations. We are particularly interested in mobile payment technologies. In this area, we have shown that there are different business models, whose main characteristic is the degree of dependence with the three pillars of a mobile payment offer: access to the payer's bank account, access to the acceptance network, access to the mobile terminal [1194].

### **ICT and the health sector**

ICT innovations profoundly affect both the supply, demand and market structure of care [1342]. Our research has attempted to address two general questions: what could be the right market design (particularly in relation to issues of technology standards and interoperability of technological systems)? What are the factors of emergence of business ecosystems for a market of e-health? First, we look for recommendations for innovative projects in the medico-social sector. Our research [1342] stresses that, in order to create a business model able to support the deployment of a device, one needs to anchor the technological device in an area, to develop a business model which incorporates the key skills of the health ecosystem, and to clarify the value proposition of the innovation.

Second, we analyzed what are the characteristics of the health ecosystem in the medium- and long-term and what role will ICT play in the future health ecosystem. Our research [1419] emphasizes the possible emergence of a "duty of health" in compensation for the "right to health", which represents a possible displacement of the cursor to a more preventive and restorative medicine.

Third, we have analyzed how the characteristics of demand and supply of care in France will evolve over time. The answer to this question depends on our mastery of emerging health risks, new regulations of the productive sphere, acceptance by the population to undergo preventive courses, the sustainability of the system of risk pooling. We proposed different scenarios of evolution [1420, 1421]. The answer to the question of the evolution of supply will depend on the nature of the relationship between patients and health professionals, the path followed by the organization of the production of care, the place of the protocols in medicine, and the position of health players in the value chain.

Finally, we studied the specificities of the management of hospital information system (HIS) (publications in progress). The issues are those of governance of increased interoperability, the constraints created by the nature of supply of HIS, a change management which is atypical and opportunistic use of the structuring effect of IS.

### **Information systems and lean management**

Lean management is a radical innovation in the production and management process [1251]. What are the specificities of lean management in terms of Human Resource Management? We focus on middle managers in support of production, upstream from other support services, on new tasks operators have in charge with respect to their role in the dynamics of improvement of production processes of the company.

We also analyzed whether the acquisition of a demand forecasting tool by a company can be considered as a substitute for stockpiling by the same company. Counter-intuitively, using a heuristic model, we show that there are situations where protective behaviors (precautionary stock) and prediction behaviors (acquisition of a demand forecasting tool) are complementary to a company [1249].

The "lean" philosophy is also used for the management of computer science projects. It is argued that these approaches are in line with the "interactionist" current in Management Science that highlights the managerial issues of "Organizing." This reflection is going forward [1396].

### 11.1.3 Sub-theme 2: Regulation in innovative industries

#### Regulation, competition and investment

A first research project was interested in the functioning of wholesale markets in network industries, where many companies have an infrastructure of its own. The results of this research [1200] showed that network competition on the wholesale market may not emerge. In a similar vein, we studied foreclosure incentives in input markets [1294].

A second research project concerned the so-called ladder of investment in telecoms. This approach has been popularized by the British economist Martin Cave to regulate access to telecommunications networks. It allows new entrants to enter the market rapidly while building an infrastructure gradually [1197, 1199]. The research project (Marc Bourreau, Maya Bacache, Pinar Dogan (Harvard Kennedy School), Germain Gaudin (PhD) and Matthieu Manant (Université Paris XI, Sceaux)) had an empirical component and a theoretical component. First, we tested empirically, from a database of 15 European member States, if the ladder of investment approach has favored the deployment of new access networks by new entrants, as is often claimed. Our results show that this has not been the case. We have also adopted a theoretical approach by modeling the impact of this type of regulation on investment.

We focused more recently on the relationship between regulation and deployment of fiber optic networks. On this subject, our research (a collaboration between Marc Bourreau, Pinar Dogan (Harvard Kennedy School), Carlo Cambini (Politecnico Torino), and Steffen Hoernig (University of Lisbon)) has focused on (i) the relationship between the regulation of traditional (copper) networks and the migration to fiber, (ii) the differentiation of access remedies according to the geography and its impact on the deployment of fiber networks, and (iii) strategies of co-investment in fiber and the relationship between the regulation of access and co-investment decisions [1316, 1196, 1198].

We have also a specific interest in the economics and telecommunications regulation in Africa [1340]. The explosion of demand for services in Africa raises specific business model and regulation issues to address the very specific characteristics of these markets and their context. Whether through the work of students in our courses (“Badge en régulation des télécommunications” opened in sub-Saharan Africa), through specific contributions (Communication to the ITS 2010 Biennial in Tokyo), in researches related to contractual problems of network’s interconnection, or the organization in October 2011 of the first edition of the CARET conference (African Conference on Regulation and Economy Telecommunications - 200 participants), research on the conditions for the development of networks and services in Africa is progressing. A textbook is also being prepared.

We have finally examined the paradigmatic example of the taxi market and the impact of the regulation of entry into the market on competition. Bacache and Janin [1253] have quantified the sensitivity of demand for taxi to the waiting time, and therefore to the number of taxis, and they have shown that an increase of over 70% of the number of taxis would not be sufficient to rent that is due to the barrier to entry. Implications are drawn in terms of public policy and the political determinants of such policy.

#### Territorial governance of ICT

Our thesis is that the question of strategic management of ICT in their relationship to space (and the specific forms of spaces, such as territories and places) requires the use of new analytical tools. In terms of territorial governance, for example, the object is not to question the classical opposition public vs. private, but the issue of new management methods in synergy between these two spheres [1332].

### Political economy of regulation

The normative study of public policy must be associated to a positive study with a political economy approach [1233]. The regulator has introduced ICT in its relation to the user. Our research question [1161] is whether e-government was granted to users who have the highest demand for public services or whether, because of a digital divide, it has benefited to the wealthiest. We show by an econometric study controlling for selection bias that the users of e-government are the beneficiaries of social transfers.

A second question concerns the specific methods of economics of human resources in the public service. Bacache [1157] shows the negative effects of variable compensation on equal treatment of users and Bacache and Audier [1158] shows the transformation of the business of regulator, in particular that of prosecutor.

Finally we are concerned with the paradoxical situation of the European market of mobile broadband, or rather the absence of such a market. The European regulatory framework for telecommunications has resulted in a fragmented market, with as many markets as member states. The construction of a European telecommunications sector has not occurred and operators located in several markets are benefiting from this fragmentation, to the detriment of consumers and businesses. The lack of access to pan-European services makes that Europe is lagging behind the U.S. and China, and that it is losing the leadership achieved at the time of GSM. We have made proposals that go beyond those of the European Commission to remedy this situation and create a single market for mobile broadband.

## 11.2 Mutations of Cultural Industries in a Digital World (MI-CEN)

**Faculty animators** : Nicolas Auray (MdC) et Patrick Waelbroeck (MdC)

**Faculty** : Nicolas Auray (MdC), Maya Bacache (MdC), Valérie Beaudouin (DE), David Bounie (P), Marc Bourreau (P), Antonio Casilli (MdC), Myriam Davidovici-Nora (MdC), Olivier Fournout (IE), Isabelle Garron (MdC), Michel Gensollen, Annie Gentès (MdC), Ludovic Lebart DR CNRS émérite), Dominique Pasquier (DR CNRS), Patrick Waelbroeck (MdC),

**PhD students** *Defended (dates are for the defense):*

**Post-docs, engineers and sabbaticals** : Brigitte Bleuzen, Michael Bourgatte, Fanny Georges.

**External collaborators** : Serge Proulx (UQAM)

### Research contracts:

- ANR (program "Content and Interaction") PANIC : "User as Prosumer, active audiences and digitization of Cultural Industries" (2008-2011).
- Contract with the Adami (the french civil society for the administration of the rights of artists and musiciens), M. Bacache, M. Bourreau, M. Gensollen
- Contrat with the Ministry of Culture on the evolution of cultural diversity: M. Bourreau, M. Gensollen
- Contrat with the Département des Etudes from Ministry of Culture, July 2011 to January 2013, " Rise of amateur critics and new forms of cultural recommendations: AlloCiné "; D. Pasquier
- FUI (Fonds unique Interministériel) SOLEN : " Interoperable mobile electronic reading " (2010–2012) ; I. Garron

- FUI (Fonds unique Interministériel) CINECAST 2010-2012, Film annotation systems - V. Beaudouin
- DIME SHS (Equipex), Platform for the collection and dissemination of data for qualitative and quantitative research in SHS, leadership: IEP Paris, Valérie Beaudouin.

### PhD thesis

- Bora Eang, supervisors : P. Waelbroeck, D. Bounie, *Economics of electronic commerce*
- Sébastien François (Futur and Ruptures), supervisor : D. Pasquier, *Fan fictions and derived texts*
- Irène Bastard (CIFRE Orange), supervisor : D. Pasquier, *Readership contribution in the press industry*
- Bruno Vétel (CIFRE Orange), supervisors : M. Bourreau, N. Auray, *Virtual currencies in videogames*
- Benjamin Chevalier, supervisor: M. Gensollen, D. Bounie, *Communities of practice and consumers*. Graduated in 2010.
- Etienne Chantrel, supervisor : M. Bacache, *Competition and Innovation in the press industry*
- Sisley Maillard (CIFRE Orange), supervisor : M. Bourreau, *New forms of cultural assessments*

### Research assistants:

- Stagiaire : Marlène Plard (Paris 1) 3 mois Juin-sept 2011 Financement ANR Panic
- Stagiaire : C de Vulpian (Paris 1) 1 an 2009-2010.
- Tomas Legon (EHESS) 18 mois 2011 -2012.

### 11.2.1 Objectives

The research project studies the transformation of media content and cultural activities in the digital era. Although some cultural activities have already experienced disruptive technological change, today's fast and easy access to digital content over the internet has revolutionized all cultural industries. Moreover, productivity gains associated with digital copies and internet communications go beyond the productive system and have generated new activity and participation from audiences. This leads us to question the linear model of production.

Beyond the empirical studies detailed below, the project proposes a multidisciplinary approach to the understanding of new forms of coordination and cooperation between authors, editors, producers, retailers and broadcasters, as well as an in-depth study of the transformation of formats linked to new forms of interactions between producers and consumers. The strength of MICEN lies in a comparative analysis of the main cultural industries: music, books, movies, videogames, and press. Three approaches complement each other in this project; each of them has met international standards of visibility and publications.

Cultural economics to understand how cultural industries supply and consumer demand adapt to new forms of digital communication:

1. A pragmatic approach that analyzes culture as performance, and that seeks to understand how material conditions affect cultural activities and how consumer tastes and amateur work are reflected by different forms of attachment between an individual and an artistic object.

2. A sociological approach to cultural audiences that analyzes the collective dimensions of the process by which cultural products and performances are perceived in a community.

The axis is led by researchers who have already studied the four main cultural industries (music, movies, book, videogames) and therefore offers a perspective on how different supports have adapted to the media convergence. The interdisciplinary component and the competence across different cultural industrial sectors allow this project to target a comparative analysis, which is promoted by regular seminars.

In 2011 we have organized 5 sessions:

- March 2011 : general presentation of the research in the axe
- June 2011 : presentations by Valérie Beaudouin on film annotation, Maya Bacache on public subsidies to multimedia artists and David Bounie on the electronic commerce of cultural goods
- October 2011: Presentation by Marc Bourreau on self-releasing entrepreneurs in the music industry.
- November 2011: Presentation by Nicolas Auray on the sociology of overchoice
- December 2011: Presentation by Antonio Casilli on the use of algorithms in sociology

### 11.2.2 Open Innovation and "economy of contribution"

The digitization of cultural industries allows some users to adjust, transform, or co-create cultural products. This section proposes empirical studies of the new creative role of readers, viewers and listeners as well as a review of "open innovation" strategies which allow spillovers and avoid cannibalization.

Beaudouin [1167] identifies the mechanisms that have gradually made the consumer an active participant in the process of producing cultural commodities.

In videogames industry, Davidovici-Nora [1206] studies the control of open innovation and the strategies of promotion by editors. "Open innovation" leads to the topic of the new forms of organizations of online communities. Auray [1148] studies the governance issues and the management of online communities. Auray [1305] has studied the three main explanations of the contribution and participation to online communities.

### 11.2.3 Autoproduction, autopromotion and the professionalization of amateurs

The structure of cultural industries traditionally modeled as an oligopoly with a competitive fringe is challenged by the digital transformation of the value chain. Lower entry barriers allow amateurs to build their own reputation and reach their audiences. The diffusion and promotion of cultural products now includes the self promotion of niche artists.

Bacache, Bourreau, Gensollen and Moreau [1308] study the impact of digital technologies on musicians. Using a survey of French professional musicians, they show that adopting digital technologies allow musicians to increase their revenues. Besides, they show that digital tools increase the propensity of artists to self-release their music, both for star artists and for musicians with less notoriety.

François [1235] studies challenges in identity construction among fanfiction writers.

Beaudouin and Fréard are pursuing a research project that aims at determining how the careers of a sample of online writers have evolved over a period of 10 years. They distinguish among star contributors who do not update frequently their content and newcomers who experiment new formats.

### 11.2.4 Transformation of practices, new formats and new esthetics

This section analyzes newly invented formats related to the increased participation of active audiences. Pasquier [1351] analyzes the evolution of press coverage of cultural events and releases in two newspapers on the time period 1960-2000. She also studies how cultural practices may be used for gendered presentation of self in youth society [1291]. Next, Auray and George [1400] investigate the organizational schemes of a "digital culture" where users enrich contents produced by publishers of video games: the machinima avantgarde. Beaudouin and Garron study how new reading technologies such as the iPad changes editorial strategies and content creation (V.Beaudouin et I.Garron Les revues à l'ère du Web et de l'ipad, manquant dans la base). Finally, in an article submitted to peer-reviewed journal, and arising from the CINECAST contract, Beaudouin and Fournout show how users of a film annotation technology collaboratively interact to produce a new way to watch movies.

### 11.2.5 Parallel distribution by consumers

Bacache, Bourreau, Gensollen and Moreau study whether the opinions of artists on piracy are in line with their economic interests. Using a survey from French musicians, they show that those who do more live performances are more tolerant of piracy, whereas the attitude of self-released artists is closer to that of the record companies –they are less tolerant of piracy [1349]. Bounie and Waelbroeck [1181] use survey data from the INSEE to analyze the impact of piracy on the purchase of legal online audio-visual content.

### 11.2.6 New forms of recommendation

The increasing visibility of online communities allows consumers to broadcast and share their views and comments. Audiences are becoming more active, often led by expert consumers. This process is interactive and self-reinforcing as the frontier between consumers and artists, between amateur and professional critics has become blurred.

Pasquier, in a forthcoming book, analyzes advice networks on plays and groupings for theater going (D.Pasquier, *Le théâtre, une sortie sociale*, Paris DEPS Questions de Culture, 2012). In parallel, she characterizes forms of sociabilities in a group of female theater goers in France (D.Pasquier - " Les sociabilités de la culture cultivée : étude des groupes d'amis du théâtre de Chaillot " in PJ Benghozi et T. Paris (eds), *Howard Becker et les mondes de l'art*, Paris, L'Harmattan, sous presse 2012). Finally, Pasquier studies how families regulate the use of Internet by their children.

Beaudouin, Bleuzen and Garron are studying how communities of readers influence the way people read content on iPads as well as book recommendations. In a related research, Auray [1359] examines search engines and their influence on the exploratory behavior of members of online communities, such as folksonomies.

Finally, Bourreau, Gensollen, Moreau and Senellart have measured how the diversity of consumption of music has evolved over the last decade [1201].

### 11.2.7 New business models

Research in the section analyzes how online distribution technologies have transformed the value chain in cultural industries and their impacts on business models. Researchers associated with contract PANIC have published a book on the transformation of four cultural industries in the digital era [1306].

Bounie, Eang, Sirbu and Waelbroeck analyze online price dispersion of cultural products sold on various Amazon marketplaces. They show that internet users do not necessarily purchase from the seller with the lowest price [1189]. They also argue that new online platforms that gather buyers and sellers represent an opportunity for producers of niche or old cultural products [1188].

Finally, they compare online to physical sales of books and show that new online distribution channels segment the demand for books [1186].

Auray [1149] studied the construction and reception of "unlimited" commercial offers. Users trade off between curiosity and anxiety, under anomic dynamics.

### 11.2.8 Elements of visibility

#### Scientific Committees; Editorial Boards, Research Fundings:

- N.Auray, Scientific Board of *Game and Entertainment Technologies* (IADIS) 2011, *Genre et Jeu Video Conference* (Lyon 1, 2012)
- N.Auray, Scientific Board of *Reset* (Recherches en sciences sociales sur Internet)
- M. Bourreau, co-editor of *Information Economics and Policy*, member of the editorial board of *Telecommunications Policy* and *Communications & Strategies*.
- D.Pasquier, Scientific Board of *Réseaux*, *Northern Lights*, *Popular Communication*, *Journal of Children and Media*, *Télévision*.
- D.Pasquier - Vice-chair of comité de suivi de l'appel d'offre " Formes et mutations de la communication " ANR, 2008-2012
- D.Pasquier - Présidente du comité d'évaluation de l'appel d'offre " Communication and Information Sciences" de la Fundação para a Ciência e a Tecnologia (Portugal), 2007, 2009, 2010, 2011
- D.Pasquier -Responsable de l'équipe française du programme de la Commission Européenne " EUkids Online ", 2009-2011.
- D.Pasquier, Guest Editor of the special issue- " Les séries télévisées ", *Réseaux* 2011, n° 165 (avec O Donnat)
- D.Pasquier, Guest Editor of the special issue- " Enfance et cultures " *Réseaux*, 2011 n° 168/169 (avec S Octobre)
- P. Waelbroeck, member of the editorial board of the *Journal of Cultural Economics*
- P. Waelbroeck, member of the board of the association European Policy for Intellectual Property
- M. Bourreau & P. Waelbroeck, member of the scientific committee of the Telecom ParisTech international conference on the economics of ICT, 2009, 2011
- P. Waelbroeck, member of the scientific committee of the Applied Econometric Association on the econometrics of the internet, 2009

#### Organization of workshops and seminars:

- I.Garron, Workshop coordinator for the Chair " Modélisation des Imaginaires"(mars-avril 2011)
- D.Pasquier - Co organisatrice du colloque international " Enfance et cultures ", Paris, 15-17 décembre 2010
- M. Bourreau & P. Waelbroeck, co-organisateurs du workshop recherche du groupe économie et gestion,
- P. Waelbroeck, co-organisateur du séminaire "économie et économétrie de l'innovation avec U. Paris 1, U. Paris 2, Mines ParisTech



## 11.3 Interaction, technology, activity (INTERACT)

**Team leader** Françoise Détienne (DR CNRS) and Christian Licoppe(P).

**Faculty** Nicolas Auray (MdC), Michael Baker (DR CNRS), Valérie Beaudouin (DE), Béatrice Cahour (CR CNRS), Jérôme Denis (MdC), Françoise Détienne (Dr CNRS), Dana Diminescu (IE), Valérie Fernandez (MdC), Annie Gentès (MdC), Christian Licoppe (P), Julien Morel (MdC), Marc Relieu (IE), Willemien Visser (CR INRIA)

**PhD students** (*starting - ending*)

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### Research contracts

As principal Coordinator:

- *ANR*: EPE "Ecologies and politics of writing" (2006-2009); CCCP-prosodie (2009-2012)
- *CNRS* : Graphic ecologies of public spaces (2009);
- *Others* : Géovélo Nantes (2011); Géovélo Paris (2011-2012); Paris Métropole (2011)

As active funded participants:

- *ANR*: COMUT (2009-2011); PLUG (2009-2009); Myblog3D (2007-2010); MOBITIC (2007-2009); e-diasporas-atlas (2008 -2012); ADAM (2010-2013); INTERMED (2008 – 2011); UrbanD (2010-2012); PROSE (2010-2012)
- *FUI* : Turbulences (2009-2011) ; WITE2.0 (2010-2012)
- *European projects* : Mignet (2009-2013), 3DLife (2010-2013), Bridge IT (2008-2011); Avidicus 2 (2011-13)
- *Institut Supérieur de Communication du CNRS* : MOTISTAR (2008-2009)
- *Joint Research laboratory* : Alcatel-Lucent Bell Labs- Institut Télécom "Ubimedia"
- *Others* : GIP justice

### Chaire

Modélisations des imaginaires, Innovation et Création, Pierre Musso (coord), (Télécom Paris-Tech, Université Rennes 2, Dassault Systèmes, Ubisoft, Orange, PSA Peugeot-Citroën)

### 11.3.1 Objectives

The INTERACT research axis deals with the a) way people interact, collaborate and move in complex information ecologies; and b) the ways in which artefacts and larger scale infrastructures supporting interaction and mobility are designed as collective endeavours. On the one hand this research axis is the locus for fundamental research on the dynamics of interaction, mobility and infrastructure (Part 1). On the other, it uses the growing expertise on these topics to support and initiate transverse thematic cutting edge research projects which interweave these themes (Part 2), such as "Migration and communication", and more recently, "Reflexive technologies".

This axis is interdisciplinary in several respects. First it actually combines research done in psychology, ergonomics, sociology, information and communication sciences, management sciences. Second, through its strong orientation towards the direct observation of practice it combines several qualitative methodologies (participant observation, video recording, explicitation interviews, auto-confrontations, as well as more traditional forms of interviews and surveys) and explores their interplay and its limits. Third it tries to treat human practice and the information ecologies it unfolds in symmetrically. Hence there is an autonomous focus on infrastructure studies and design, and an effort to collaborate with technology-oriented specialist fields. Within this project there is a high potential for developing a dialogue between social and human sciences on the one hand and computer sciences on the other.

### 11.3.2 Fundamental research on interaction, mobility and infrastructure

#### Sub Theme 1: Collaboration, emotion and presence in technology-mediated contexts

Human-human interaction either in co-presence or at distance is more or less transformed by ICT. Our research is focused on three fundamental mechanisms on which technology mediation may operate: collaboration processes as related to collective knowledge elaboration, relations between social, affective and cognitive dimensions of interactions, and the formats of presence.

#### Collaboration and knowledge co-elaboration in online communities

Collaboration and cooperation, between humans through technology mediation and between humans and machines, is a first topic of research addressed to understand new forms of knowledge co-elaboration at a distance, online epistemic communities [1329] and technology-mediated design [1412, 1413] as compared to presential design situations [1401, 1299, 1417] [1358] [1418], as well as new forms of services offered to customers through speech interaction [1364]. Fundamental research issues addressed in two ANR projects (CCCP Prosodie; Intermed) on online communities concern: the new forms of "open regulations" [1304]; the interplay between design and regulation activities [1399, 1328]; design-use mediation [1377, 1165, 1363]; inequality of participation and digital divide.

As a transversal issue, research for understanding quality or "qualities" of collaboration [1370, 1379, 1413] is conducted for better approaching the relationship between collaboration, its outcomes and characteristics of tools that mediate collective action. An international workshop [1409] was organised by F. Détienne and M. Baker on this theme in mid-2010, that has given rise to the coordination of a journal special issue (CoDesign Journal, ed Taylor & Francis, to appear in 2012).

**Emotion and affective regulation in interactions** Emotions are an integral part of human activities, they frequently give orientation to action, reflexion and relations towards others [1203]. Research carried out on the topic of interaction and emotion aims to understand how different types of technological mediation exert influence on the interactive circulation and regulation of emotions [1380], and on the way that different collective activities like risk management or online social support [1352] are carried out. In this context, there is a need to further develop

methodological approaches for understanding the relations between social, affective and cognitive dimensions of interactions [1303]. A workshop funded by the European Science Foundation was organised by M. Baker on this theme in mid-2009, that has given rise to the publication of a book [1314, 1317].

Furthermore, a promising avenue of research that is being explored concerns the interrelations between the analysis of the dynamics of emotions as observed in interactions, and the reflexive study of emotions experienced by interactants, using explicitation interviews, or auto-confrontation [1204, 1404]. Since 2008, this research topic has been reinforced in LTCI by B. Cahour's coordination of one of the five themes (emotions and cognitive load in activity) of the CNRS G.D.R. "Psycho Ergo".

**The formats and repertoires of presence.** The development of ICT and the proliferation of the modalities of electronic communication also transform the formats and repertoires of presence. One direction of research has been to promote videoconference and its technology-augmented variants as a way to achieve the promise of remote presence or "telepresence", that is a way for remote participants of "being there" that might be dense enough to mimic co-presence to some extent. We have launched a large scale study of the uses of video communication regarding both interpersonal and professional or institutional communication. We have constituted several corpora of Skype-based video calls, mobile video calls, meetings in advanced telepresence rooms at OrangeLabs, and Second Life meetings. Our research has highlighted the sequential importance of the 'talking heads' format in mobile video communication [1275], the organization in family-based multi-party video calls, through which participants are "doing being a family" and the interrelation between participation frames and uses of communication media in professional second life meetings [1381]. This has led to new studies being under way, such as how participants are using video communication and camera motions to show or point at something and the management of heterogeneous participation frames in video communication.

A large scale research has also been launched regarding the introduction of video conference technologies in the courtroom for remote testimonies and interrogations. Judiciary settings offer an interesting field to study the articulation of communication technologies and institutional concerns into new politics and regimes of presence. We have been authorized to video record courtroom hearings, which is exceptional, and to constitute a unique corpus of distributed courtroom hearings, in the frame of two successive projects funded by the G.I.P. Justice. This has led to a systematic study of the development of video communication in French courtrooms [1223, 1264], of the way distributed judicial hearings are accomplished as multimedia performances requiring specific competences, and of the way some formal speech acts characteristic of the judiciary ritual could be omitted in distributed hearings [1267]. Current research focuses on the pragmatics of mediated appearances and interactions in the courtroom, on how participants handle the choice between appearing in presence or through the video, and specific problems regarding the dual mediation of the video technology and the use of an interpreter (the latter through participation to the European project AVIDICUS).

**The limits of the classical model of presence: from focused engagements to multi-activity**

Beyond efforts to constitute a sense of presence as a capacity for involvement, the development of ICT also seems to weaken it. For instance, the explosion of communication resources lead to the proliferation of calls and notifications, which threaten the very possibility of keeping focused commitments in a given activity. Presence seems to waver between the kind of layering and fragmentation which characterize multi-activity and its fading away through ever increasing levels of sheer dispersion. We have been studying the design and accomplishment of technology-related dispersive events such as notifications or 'mediated appearances' and shown how their proliferation might lead to a "crisis of the summons" [1263, 1266]. The occurrence of such mediated events in increasing number also seems to favor the development of 'multi-activity'. In the framework of the ANR project COMUT, we have been studying both its positive and negative facets,

on one hand the skillful and methodical management of multiple engagements and, on the other hand, negatively valued dispersion.

### **Sub Theme 2: Mobility and locative media**

Communication and mobility practices are deeply interwoven and affected by the current development of ubiquitous computing, and this sub theme explores their various articulations.

**Innovative methodologies for studying mobile uses on the move.** The direct observation of users on the move requires innovative methods. In the frame of this project, a growing expertise has been developed in the recording of mobile terminals (phones, smartphones, iphones) activity, combined with the video recording of contextual information (with mobile users wearing various forms of camera or glasscams). We are currently trying to build on this expertise to develop a mobile multimedia recording facility which will be available for teaching and research alike.

**Mobility as an accomplishment in transport situations.** This methodological expertise in recording mobilities as an accomplishment has led us to assemble a growing corpus of mobility situations. Though progress is being made on the study of public transport situations, the most advanced domain of study in that respect today is car driving in various innovative configurations:

- The experience of driving in GPS-augmented cars.
- Fundamental research in the use of verbalization techniques to study car driving as an activity.
- The use of the battery gauge as an affordance in the experience of driving electric cars [1408], in the frame of collaborations with Renault (through the Institut de la Mobilité Durable).
- Autolib and car sharing experiments, via the participation to large scale projects just submitted (Sysmo 2015, Vedecom)

**Mobile communication.** In the frame of this methodological expertise, we have started to build several corpora of mobile phone conversations, Skype-based video communications, and mobile video communication. This serves as a basis for a thriving effort at understanding better the specific dynamics of mobile communication, as well as the way mobile talk refer to space and place [1276, 1271]. Our research has also oriented towards mobile communication organization and the practices of mobile workers, based on interviews and mobility diaries, within the frame of the MOBITIC project and one PhD [1398].

**Mobile communication and locative media.** We have done ethnographic studies aiming at understanding the ways in which various forms of location awareness or proximity awareness supported urban sociality and the development or avoidance (due to privacy concerns) of mediated encounters between acquainted or non-acquainted users, either in a GPS-tracking case like the uses of the Mogi game in Japan [1261, 1346, 1269], or a proximity-sensitive game in France and Japan. These studies provide a global and advanced picture of how locative media are reaping our sense of mutual proximity and the social implications of such an awareness.

### **Sub Theme 3: Infrastructures, design and the production of space**

Amongst the researches that analyze the role of artifacts in social life, more and more studies have highlighted the importance of infrastructures and design, which give forms and consistence to the material and technological texture of exchanges. We address three main issues in this

domain: the nature of work in the backroom of information production, the political stakes of design and infrastructures in urban settings, and the renewal of accountability through ICT.

Since this domain is emerging in our department, we both present here our first results and point to ongoing projects.

**Invisible work** has long been an essential issue in science and technology studies, and is today deeply renewed. In a time where information services draw on such notion as transparency and immateriality, there is a urge to conduct in-depth studies about the nature of the work done in the backstage of information and to study the "**back-offization**" of the world it leads to [1210]. Analyzing work and its invisibility is notably a way to re-address the question of the sociomateriality of information. Thus, our first results in the domain show that **fragility** can be an important mode of existence for information technologies [1209] and emphasize the role of **maintenance** in the day-to-day production of our "information society" [1212].

Nowadays, more and more information technologies tend to become infrastructure for **public settings**: present, but invisible for users ("pervasive", "ubiquitous"). Numerous researches in our department address this phenomena, trying to understand how such devices produce new geographies, and to study the **fabric of territories by ICTs** at the articulation of infrastructures and uses [1332]. Several issues are analyzed in this perspective: the emergence of new forms of **urban fragmentation** [1224]; the production of specific **attention politics** in public displays; the **tension** between **civic inattention** and **connectedness** in pervasive technologies [1270]. We are also working on a research project on Distributed Architecture and Multiple Multimedia Services, studying **mobile P2P networks** aiming at harnessing

contextual resources in communicative environments (Project ADAM, Gentes, Huguet).

Finally, we question the configuration and uses of ICTs dedicated to **accountability** and **visualization** in/of public settings. We recently studied their ability to equip **sustainable practices** such as transportation [1388], and deal today with several under way projects: a study aiming at understanding the **mobility of things** its transformation through the use of RFID-based tracking technologies (FUI project ASPECT, Delanoé, Draetta, Kornig and Licoppe); an analysis of the role of design and ICTs in the renewal of **urban heritage** (Project "Mémoires Métropolitaines", Gentes, Bourgatte); or a study of the emergence of **new geographical knowledge** through the use of participatory devices (Projects Geovelo — Nantes and Paris, Denis).

### 11.3.3 Transverse projects

These are large scale thematic projects which cover important or strategic issues and which builds on the kind of expertise developed above on the dynamics of communication and mobility, infrastructure and design. One is well developed and mature ("Migration and ICT") and one is currently emerging as a significant domain of research ("Reflexive technologies").

#### Migration and ICT

Studying Migration & ICT is a natural transverse project between the axes mobility and interaction at distance as well as infrastructural and web studies. The development of communication practices —from simple 'conversational' methods where communication compensates for absence, to 'connected' modes where the services maintain a form of continuous presence in spite of the distance — produced the most important change in migrants' lives, their experience of mobility, their relational design and integration social strategies [1187], [1220].

In the frame of the FP7 Mignet project we have been looking at how video-communication technologies influence everyday-life patterns of communication in transnational milieus. Based on empirical case studies conducted in the three partner cities (Paris, Athens and Ljubljana) the research will exemplify the complex combinations of global media use and face-to-face encounters that emerge in response to the specific needs of transnational populations and bring about new global forms of "being at home".

The Internet has displaced both the space of diaspora (from physical geography towards network topology) and the media of collective memory (from oral and written traditions to digital formats and networked, media environments). In the ANR Project atlas of e-diasporas, we have adapted and developed web cartographic tools. We have thus archived 28 corpus of diasporas; we propose an innovative digital methodological chain, we developed tools like Navicrawler and Gephi and we have designed a collaborative platform ([http://ks20876.kimsufi.com/eda\\_proto\\_final/](http://ks20876.kimsufi.com/eda_proto_final/)) to map and analyse the occupation of the web by diasporas. We have thus archived 28 corpus of diasporas through the collaboration of more than 80 persons from 14 countries, several institutions, involving a close dialogue between developers, designers and social scientists.

### **"Reflexive Technologies"**

Digital network activities always leave traces. There is a growing interest in the way these traces could be used to induce new forms of awareness for users regarding their own practices (hence the concept of 'reflexive' technologies) as well as that of related relevant others, and thus set in motion bottom-up forms of behavioral regulation [1204]. This could be particularly useful in domains for which public policies are insufficient or inadequate such as sustainability issues, as well as in settings in which individual users' willpower fails them such as weight control. Such regulatory systems always articulate advanced data-mining infrastructures (to construct real-time representations of practice), interface design (to frame the visibility of such representations and shape users' awareness) and ethnographic observations (to understand how users relate to such reflexive affordances). Work has started in this field in the domain of energy consumption through the Gridteam project, funded by the PACA region via the PACALABS, which was awarded the "Prix de la croissance verte".

### **Modelizing imagination, innovation and creation**

The Chair of Research and Training was founded in late 2010 for a period of five years by two academic institutions, Telecom ParisTech and Rennes 2 University. Four industrial partners follow us in this project: Dassault Systemes, Ubisoft, PSA Peugeot Citroën and Orange, later joined by Alcatel Lucent Bell Labs. The "official" launching was on October 6 at the Palace of the Discovery in Paris. The financing has been brought by Paris-Tech Telecom, Rennes University and by the partners.

Imagination and imaginary refer here to the many stories and complex dynamic worlds that shape technical objects in the innovation process. Information technology and communications are saturated with social representations, fictions and images, producing differentiation or mimicry. These "technologies of the mind" such as video games, virtual worlds or 3D world, seize the "raw material" of the imaginary, model and transform it. Conversely, those imaginaries are always more technological producing an intensification and an acceleration of innovation. But another temporality acts deeply, that of social representations that operate over very long periods, such as a memory broadcasts, informing imaginaries of actors and objects. At the intersection of those trajectories, social and cultural representations are crystallized in concepts and objects, aggregating themselves into "new artificial worlds", in turn feeding on new imaginaries. The challenge of this new chair is to explore the possibility of modeling those worlds at the intersection of computer science, design and the humanities.

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**Part IV**

**Signal and Image Processing**



# Signal and Image Processing (TSI)

The research topics covered by the Signal and Image Processing department at TELECOM Paris-Tech are: the study of image processing in its various formats, digital, optical... for different applications like medical imaging, remote sensing, fine arts..., the study of speech, music and sound, the study of the multimedia chain, from production to distribution. Our goal is to develop new mathematical tools to process all these kinds of signals, and to apply these tools to a large variety of concrete situations.

The department is organized into four groups:

- “Statistics and applications” - STA - is a group that is devoted to the applications of statistics and probability to the field of information society at large, which has become increasingly dependent on the collection and interpretation of data and, more generally, quantitative information. The research area covers a wide spectrum from the development of new techniques and new algorithms to various applications. The activities of the group comprises the following topics: statistical learning, blind source identification and separation, distributed estimators for sensor networks, time series, independent data and complex random systems, Markov Chain Monte-Carlo techniques, sequential Monte-Carlo techniques (particle filters), array processing, geolocalization, models estimation.
- “Image Processing and Interpretation” - TII - has, as its main purpose, the development of methodologies and theoretical tools for image processing, scene analysis and 3D objects. This implies global treatment of complex image processing problems, integrating multiple techniques that cover the path from raw data to high-level interpretation. The concerned applications are art items (sculptures, paintings), biomedical images, aerial and satellite images, natural image analysis. Contributions of the group can 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 models for large and complex data sets), and at applicative level.
- “Audio, Acoustics and Waves” - AAO - develops signal processing techniques while keeping strong connections with the physical phenomenon that is at the source of the signals. In digital audio signal processing, the activities span the entire acquisition chain, from sound capture and transmission up to its restitution, with the goal of proposing solutions to the main problems centered around the sound, speech or music, in multimedia applications. Its contributions at the methodological level cover adaptive methods for high resolution sinusoid tracking, sparse representations, nonnegative matrix factorisations, source separation. A central domain of applications is the analysis of audio and multimedia scenes: segmentation of broadcast streams, analysis of music, its decomposition and understanding (polyphonic separation, rhythm, melody, chords). Research on biomedical signals has been recently reinforced in the group, and will be further strengthened with the ongoing recruitment of an associate professor.
- “Multimedia” - MM- is a group that covers the life cycle of multimedia documents in the framework of a complete chain going from authoring tools for on-line and offline production of multimedia contents to multimodal interaction for the final user; this also includes

automated processing like enhancement of degraded pictures, verification of the identity of the user, modification of auditive and visual appearance, image segmentation and pattern recognition. The group also works on techniques that allow the analysis, compression and robust transmission of these media in heterogeneous networks. It also works on the dynamic and distributed adaptation of the transmitted data flow (including meta-data and in particular those concerning the digital rights management) with respect to context, transport conditions and terminal type.

One research topic is common to all groups, this is indexation and data mining. Summarizing and extracting informations from multimodal databases requires statistical tool for learning and mining, which are among the activities of the STA group with a particular focus on text indexation and retrieval. Indexing satellite images, extricating informations from primitives to semantic annotations was the main goal of the “Center of Competence”, a joint lab between CNES, DLR and the TII group, until mid 2010. This group also develops the same kind of tools for biomedical images and for 3D objects. The AAO group is concerned by many aspects of music information retrieval: identification of rhythms, main melodies, instruments, styles, moods, tonalities either from plain audio or from mixed audio and video. Video signals are also a core activity in the MM group together with complex documents analysis (mixing printed texts, handwritten texts, pictures, graphics) and with multimodal analysis for biometry (voice, faces, fingerprints).

Our most recent recruitments were aimed towards the reinforcement of two topics: 3D images and virtual worlds on one hand, biomedical signals on the other hand.

Permanent staff [ <i>Institut ; CNRS</i> ] ; post-docs	[39,8 ; 13.5] ; 30.5
PhDs	58.9
Defended PhDs	58
Defended HDR	11
Journal papers [published, in press]	[238 ; 58]
Chapters and books [published, in press]	[38 ; 9]
Conference papers	455
Patents and software	2
Contractual income 2009 (july)–2011 [Private ; Public ; European] (k€)	[2255 ; 5950 ; 1218]

# Chapter 12

## Audio, Acoustics and waves (AAO)

**Head** G. Richard (P)

**Permanent staff** R. Badeau (MC), B. David (MC), Y. Grenier (P), N. Moreau (P, until March 2010), S. Essid (IE), J. Prado (MC);

**PhD students** 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-); R. Foucard (10/09-); M. Moussalam (10/09-); G. Ladreyt (10/10-); F. Rigaud (10/10-); A. Liutkus (01/10-); N. Lopez (05/11-); A. Masurelle (10/11-); X. Jaureguiberry (10/11-);

**PostDocs, engineers and sabbaticals** M. Lagrange (Postdoc, 10/08-09/09), T. Fillon (Postdoc, 10/08-), B. Mathieu (Engineer, 10/08-12/10), A. Dielmann (PostDoc, 11/10-03/11), A. Drémeau (PostDoc, 09/11-).

**External collaborators** L. Daudet (ESPCI ParisTech), O. Derrien (LMA-Marseille), E. Vincent (IRISA), L. Devillers (LIMSI-CNRS), T. Sikora (Technical Univ. of Berlin), L. Girin (GIPSA-Lab), N. O'connor (Dublin City University).

Permanent staff [ <i>Institut ; CNRS</i> ] ; post-docs	[6.3 ; 0] ; 1.9
PhDs	9.3
Defended PhDs	9
Defended HDR	1
Journal papers [published, in press]	[24 ; 2]
Chapters and books [published, in press]	[7 ; 1]
Conference papers	64
Patents and software	[1 ; 1]
Contractual income 07/2009–12/2011 [Private ; Public ; European] (k€)	[121 ; 673 ; 275]

The AAO (**A**udio, **A**coustical and waves) research group is now focused on the activities previously reported under the Audio Signal Processing (*AudioSig*) project. The activities of the Optical Signal Processing (*TOS*) project have been transferred to the INFRES department in March 2009 and are entirely reported in section 8.

## 12.1 Objectives

The aim of this research group is to develop digital audio signal processing methods in order to propose innovative solutions to the main problems linked to audio (speech, music,...) in multimedia applications. Our interests encompass the complete processing chain from sound capture and transmission to sound restitution. Work is conducted on a methodological level to develop new sound representations and models especially for musical signals on their application to practical problems. In particular, the group is interested in Adaptive methods for high resolution sinusoidal components tracking, sparse representations, Non-Negative Matrix factorization or hierarchical models and on their application to practical problems such as automatic indexing, compression or EEG signal processing. *Source separation* also appears to be at the heart of this research group with contributions at the methodological level and with applications in nearly all the individual research themes. *Audio and multimedia scenes analysis and indexing* currently is the central research theme of the group and includes topics such as broadcast streams segmentation into broad classes of audio events (speech/music/silence/singing,...), musical signals automatic analysis, decomposition and understanding (polyphonic audio source separation, rhythm extraction, multiple fundamental frequencies estimation, main melody extraction,...). Concurrently, a novel research direction on biological signals for Brain computer Interfaces is receiving a growing interest and will be further strengthened with the arrival in march 2012 of a new associate professor in the group.

On a different level, the group has initiated the development of a multimedia indexing and mining platform (called PLATO) which now involves several other groups and has developed a number of software tools, some of them being distributed in open source (YAAFE - an audio feature extractor [1511], DESAM toolbox - a set of tools for spectral analysis of musical audio [1504, 1436], ...).

The group is also maintaining tight links and collaborations with both academics (Queen Mary University of London, Dublin City University, Technical University of Berlin, Institut Langevin, IRCAM, INRIA-IRISA, LABRI-CNRS, GIPSA-Lab,...) and industry (RTL, INA, Audionamix, Arkamys, Parrot, ...).

## 12.2 Results

### 12.2.1 Audio and multimedia scenes analysis and indexing

**Researchers** R. Badeau, B. David, S. Essid, Y. Grenier, J. Prado, G. Richard;

**Highlights :**

**Collaborations:** With industry (RTL, INA, Audionamix) and academics (Queen Mary University, Dublin City University, Institut Langevin, IRISA, IRCAM, LABRI,...)

**Projects** Network of Excellence IST-Kspace (*Knowledge Space of Semantic Inference for Automatic Annotation and Retrieval of Multimedia Content*), Network of Excellence 3DLife (*Bringing the Media Internet to Life*), OSEO-QUAERO (*Towards multimedia and multilingual search engines for professional and general public applications*); ANR DreAm (*Active music listening*);

**Prize** PhD prize in 2010 (jointly awarded by EEA club, GRETSI and ISIS) (N. Bertin)

### Models and signal representations

This activity is following several research axes. The first direction, which is on a rather methodological level, aims at developing generic signal models and representations with a specific focus on audio signals, recently extended to multimodal signals. An increased effort was dedicated to



sparse signal representations with a particular interest on those based on Matching Pursuit (MP), Probabilistic Latent Component Analysis (PLCA) or Non-negative Matrix factorisation (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 ([1422, 1468], or the description of beta-divergence as a subclass of Bregman divergence [1431]. Several extensions of the NMF were also explored including the introduction of a new generalized model for High-Resolution NMF [1466], the extension to multichannel [1444], and the proposal of a general formulation of underdetermined source separation of Gaussian Processes [1438]. The applicability of these methods to generic problems such as audio indexing in the (scalable) compressed domain [1446], 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 [1423, 1469, 1447], use of source production or timbre models for source separation [1425, 1426], use of time-frequency activations to model non-stationary audio events [1430],...). This methodological effort explores both deterministic and statistical approaches.

### Audio indexing and blind source separation

The second direction concerns the different facets of audio indexing and audio source separation which are two intricate problems. Indeed, efficient source separation eases the transcription of the resulting sources and efficient audio indexing facilitates the source separation. 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 [1429, 1447, 1485]), *rhythmical information tracking* (tempo and beat estimation [1501], *harmonic information estimation* (recognition of the chords sequence [1528, 1442, 1443]) and *timbre recognition* (musical instrument recognition in polyphonic audio [1432]). 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.

Source separation approaches were developed for specific music transcription tasks such as piano transcription [1429]) and main melody estimation (by use of a NMF-based source-filter model for separating the singing voice from the musical accompaniment [1426]) but also for specific audio rendering tasks such as stereo signal remastering [1444]. A novel research direction was also pursued along these lines for situations where prior information is available about the sources [1439]. This so called *Informed Source Separation* problem bares several similarities with multichannel audio coding in the extreme cases where the sources are available at the coding side and a novel framework was recently proposed to close the gap between audio source coding and source separation domains [1520].

### Multimedia streams segmentation

The third research direction is dedicated to the multimedia streams segmentation into broad classes of events with application to *broadcast multimedia streams* (speech/music segmentation [1521], TV show structuring [1527, 1456]) and *musical streams* (Audio fingerprint [1481], musical sound objects decomposition for electroacoustic music [1489], music similarity [1482, 1483, 1435], audio-to-score alignment [1433] or more recently to dance performance analysis [1486, 1478]). At the methodological level, our efforts in this field are mostly based on statistical discriminative approaches and a special interest has been directed to kernel-based methods (Support Vector Machines, sequence kernels, probabilistic distances, kernel change detection, kernel LDA,...) and more recently to hybrid kernel and Bayesian network based methods. Our emphasis is targeted to the incorporation of prior knowledge on the nature and

structure of the streams processed, typically temporal dependencies and/or inter-stream correlations/dependencies, both at the signal level and the semantic level, possibly using ancillary information attached to the content (available meta-data, tags, notices,...) and/or user interaction (relevance feedback).

### 12.2.2 Sound capture, separation and rendering

**Researchers** B. David, Y. Grenier, J. Prado, S. Essid, G. Richard;

**Highlights :**

**Collaborations:** K. Abed-Meraim (STA), European project partners

**Projects** CapDigital-ROMEO (*a project within "ipôle de compétitivité"¿ CapDigital, led by Aldebaran Robotics and aiming at creating a humanoid robot*), Network of Excellence 3DLife (*Bringing the Media Internet to Life*), FP-7 Reverie (*REal and Virtual Engagement in Realistic Immersive Environments*)

The objective of this theme is to improve sound field analysis and synthesis capabilities by developing specific digital signal processing methods.

Current work tackles 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 work is part of the Romeo project that aims at building a 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. Promising results were obtained with several different configurations and highlighted the merit of the fixed beamforming preprocessing for improving the separation performances [1509, 1440]. 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 scheme [1510].

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 been recently started to develop novel dereverberation algorithms. Finally, under the framework of the two European projects 3Dlife and Reverie, a growing effort has been dedicated to multimedia scene capture (e.g. dance scenes) using a large variety of heterogeneous sensors. Such parallel heterogeneous data captures imply complex synchronization mechanisms but permit to tackle unexplored directions for complex multimedia scenes analysis and interpretation. This was already highlighted by the two preliminary studies on dance scene analysis that were selected as finalist for the 2011 Grand Challenge of the ACM Multimedia [1486],[1478].

### 12.2.3 Sound sources compression and informed source separation

**Researchers** N. Moreau, G. Richard, R. Badeau

**Highlights** ANR-Dream, academic collaborations (Univ. of Toulon, INPG Grenoble, ESPCI ParisTech, IRISA-Rennes)

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 [1474].

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 over-complete representations are used to decompose the audio signals over a redundant union of bases (such as Modified Discrete Cosine Transform bases at different scales). It was also shown that the high flexibility of the signal representations used in this coder allows to tackle various audio indexing tasks (such as beat tracking or musical genre recognition) directly in the transform domain [1446] or to perform a large variety of music similarity tasks or structural-based audio coding [1512, 1515]. More recently, a novel Random Matching Pursuit algorithm was designed which allowed to simulate a local search in a larger dictionary while operating at the cost of a search in a sub-sampled dictionary. On a more transversal axis, a comparative study of sparse greedy algorithms that were separately introduced in speech and audio research communities was conducted. It was in particular 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 [1427].

In parallel, our work on Informed source separation allowed us to propose a novel framework to link the two domains by exploiting source separation models and principles for multichannel audio coding. This novel method led to higher performance than those possibly achievable by standard approaches such as the standardized Spatial Audio Object Coding (SAOC) [1520].

#### 12.2.4 Biomedical signals analysis

**Researchers** J. Prado, S. Essid, Y. Grenier;

**Highlights** DGA Project MEEGAPERF (*Monitoring EEG pour l'Anticipation des PERFormances* European Project FP7-Verve (*Vanquishing fear and apathy through E-inclusion: Personalised and populated Realistic Virtual Environments for clinical, home and mobile platforms*))

The other research direction is dedicated to the analysis of biomedical signals and especially electroencephalogram (EEG) signals recorded on asleep subjects using a single pair of sensors. Our approach to this problem has two technological breakthroughs since it aimed at an automated analysis (and not only visual) and uses a single channel EEG. The efficiency and robustness of the method developed have been measured and experimentally validated. Another application of interest concerned the analysis of biological 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 [1424].

The effort of the group in the domain of biological signals processing (and especially multichannel EEG analysis) has been recently strengthened with the acceptance of two research projects. The first project (MEEGAPERF), started in september 2009, aims at automatically providing information in real time on the psychological state of a patient from the analysis of cerebral activity using portable devices. 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. Our planned work is to automatically analyze the user's emotional state based on the processing and fusion of various biological signals, be it the audio-visual

stimuli presented to the patient, or the signals captured by the different audio-visual, motion and biological sensors (including EEG and ECG electrodes) used to monitor him/her. The arrival of a new associate professor in biomedical signal processing for Brain Computer interfaces will also allow to further develop this research direction.

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# Chapter 13

## Multimedia (MM)

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Faculty [IT, CNRS]	[7, 3.6]
PhD students	13.6
Post-docs, engineers and sabbaticals	14.6
Defended PhD theses	7
Defended HDR	2
Journal papers [published, in press]	[44, 13]
Papers in conference proceedings	126
Chapters, edited books	[6, 8]
Standardization contributions	60
Grants [public, private, european] (k€)	[3190; 455; 942]

## 13.1 Objectives

The research in the “Multimedia” (MM) group covers the life cycle of multimedia documents in the framework of a complete chain, going from authoring tools for on-line and off-line production of multimedia contents to multimodal interaction for the final user; this also includes automated processing like enhancement of degraded pictures, verification of the identity of the user, modification of auditive and visual appearance, image segmentation and pattern recognition. The group also works on techniques that allow the analysis, compression and robust transmission of these media in heterogeneous networks. It also works on the dynamic and distributed adaptation of the transmitted data flow (including meta-data and in particular those concerning the digital rights management) with respect to context, transport conditions and terminal type.

## 13.2 Main Results

The main research results obtained during the period July 2009 - December 2011 are presented below for the research areas of the Multimedia team.

### 13.2.1 Robust Compression and Transmission of Visual Data

**Faculty** B. Pesquet-Popescu, F. Dufaux, M. Cagnazzo

**Main events** F. Dufaux is Editor-in-Chief of the *Elsevier Signal Processing: Image Communication journal*.

In this period, B. Pesquet-Popescu was a member of the IEEE SPS Image, Video and Multidimensional Signal Processing (IVMSP) TC, of the IEEE SPS Industry DSP Technology (IDSP) standing TC, a member of the IEEE SPS Multimedia Signal Processing (MMSP) TC, Associate Editor for *IEEE Trans.on Circuits and Systems for Video Technology*, *IEEE Trans. on Image Processing*, *IEEE Trans. on Multimedia* and *Elsevier Signal Processing: Image Communication* journals. She was also a General Co-Chair of the IEEE MMSP conference (Oct.2010).

M. Cagnazzo is Area Editor of *Elsevier Signal Processing: Image Communication* and of *Elsevier Signal Processing*.

**Projects** pôle CapDigital Sebastian2 (2008-2010), pôle CapDigital PINGO (2008-2010), CEDRE (2009-2010), ANR blanc PERSEE (2009-2012), ITEA2 AC/DC (2010-2012), FUI8 NEXEX (2011-2014)

## 2D and 3D video coding

Even though traditional (or 2D) video coding has been studied by the research community for more than twenty years, new methods for improving the existing compression techniques steadily pop up. This is testified by the fact that a new coding standard is under development by ISO and ITU. Our group contributed to 2D video coding with new and efficient methods based on motion vector quantization [1530], differential motion estimation [1598], efficient lossless coding [1535], adaptive wavelet coding [1678, 1599, 1576].

However, much attention has been addressed to three-dimensional and multiview video, since they are the *enabling technology* of many exciting new applications, such as 3D TV, immersive communication, immersive gaming, *etc.* Our team has been studying novel representation formats for this kind of data, proposing new compression techniques.

We have designed novel techniques for *disparity* estimation and coding in multiview video (disparity describes the spatial relationships between a couple of images taken from different points of view), allowing improved performances with respect to standards for multiview video coding. [1546, 1538, 1568]

We have also been considering an emerging representation format called multi-view plus depth (MVD). In MVD, for each view we have a traditional color image plus a *depth image*. The latter allows to synthesize new viewpoints at the decoder. We developed several techniques to efficiently encode the depth information [1568, 1615, 1600], or to use it to improve the user experience (jointly with distributed video coding techniques, see Section 13.2.1 [1693]).

The research of the group in 2D and 3D video compression perfectly fits the framework of the project *ANR Blanc PERSEE* (PERceptual Scheme for 2D and 3D vidE(E)o coding), in which the members of the group are involved.

## Robust video streaming through cooperative networks

Real-time multimedia streaming over computer networks is one of the most active research fields in the last years. The best performing solutions are based on the concept of *cooperative networks*, i.e. networks where each node contributes to the distribution of the content. We studied this problem in the cases of wired and wireless networks.

For the wired case, we built over an existing protocol with the aim of a system meeting video multicast requirements. We developed a new algorithm which mitigates the main problems of the previous one (slow overlay construction and potentially high end-to-end delay) [1558].

For the wireless case, we considered mobile ad-hoc networks (MANETs), which are an active research field since they promise scalable and robust audio/video delivery without infrastructure. We studied the problem of real-time video streaming over MANETs and proposed a content routing/delivery protocol inherently designed for the ad-hoc wireless case, exploiting the intrinsic broadcast property of the medium [1547]. This problem has several common features with peer-to-peer routing, but the additional sensible parameters of MANETs make wired solutions unfit to this case; therefore, we had to design a brand new protocol.

The resulting protocol is very effective in building and managing the overlay network. Nevertheless, it can suffer from congestion if high density or sudden churns are considered. Therefore we designed and implemented a new version of the protocol that optimizes the rate/congestion trade off. The result is a remarkable reduction of delays and of undecodable images, with a clear improvement of the user's *quality of experience*.

All these systems for video streaming must face with the problem of unreliable connections. Packets can be lost on wireless networks, or can be too delayed on wired networks. In both cases, the video decoder must be able to cope with the case where not all data produced by the encoder are available at the play-back time. A common solution to mitigate this problem is multiple description coding (MDC). In MDC, the encoded stream is structured into independently decodable elements, called descriptions, such that the decoded video quality increases for any new description received. This robustness comes at the price of a reduced rate/distortion performance. All the proposed streaming protocols work on a MDC video stream. Instead of

using some existing MDC scheme, we proposed some new methods, based on temporal split and motion-compensated image interpolation [1639].

Finally, MDC is not the only technique used to adapt a video stream to a lossy channel. Among the alternatives, network coding (NC) is gathering a lot of attention. We are working on the combination of MDC and NC to obtain a robust and low-delay technique for video streaming over unreliable networks [1667].

### **Distributed video coding**

Distributed video coding (DVC) is an emerging framework for video compression that allows to greatly reduce the encoder complexity provided that the decoder can sustain an increased computational burden. Theorems from information theory assure that this paradigm has the same performance bounds as the classical encoding schemes. Therefore DVC perfectly lends itself to applications such as low-complexity video communications, sensor networks, and, more recently interactive multiview video streaming [1694, 1693].

We have proposed several methods to improve the performance of DVC systems, based on high-order motion interpolation [1692, 1690, 1691], resulting in considerable gains with respect to state-of-the-art solutions.

We also proposed a new approach that iteratively improves the side information after decoding of each DCT sub-band [1585, 1586]. This leads to significant rate-distortion gains compared to state-of-the-art, especially for video sequences with complex motion. Another direction explores the combination of global and local motion estimation to improve side information [1657]. A second activity focuses on the multi-view distributed coding. In this context, we proposed the use of machine learning (Support Vector Machine) to fuse side information obtained from temporal and inter-view predictions [1623].

### **Semantic Video Coding**

Compression standards such as H.264/AVC encode video sequences to maximize fidelity at a given bitrate. However, semantic-oriented and content-aware compression remains a challenge. In this activity, which is part of a CIFRE thesis with Thales, we have developed a new semantic video compression method using seam carving [1620]. Seam carving changes the dimension of an image/video with a non-uniform resampling of each row and column while keeping the rectangular shape of the image. Our main contribution is a new approach to identify areas where seams are concentrated. On the one hand, it allows to transmit supplemental seams data at low cost. On the other hand, seams can be synthesized at the decoder in order to recover the original frame size and to preserve the scene geometry. Experiments show that our seam carving method results in significant bitrate savings while maintaining the same quality in semantically significant regions. A patent has been filed.

### **High Dynamic Range Video**

This activity is part of the FUI project NEVEX which began in October 2011. A complete HDR (High Dynamic Range) video system, from content creation to display offers the user the possibility to receive more immersive images. Indeed, HDR images offer a wide range of brightness that can reproduce details in all areas of the image, even bright or dark. This more realistic rendering is closer to human vision than standard HDTV images.

A first objective is to develop new algorithms for inverse tone-mapping to convert existing videos to HDR. In the absence of sensor capable of directly acquiring HDR images, the operation of inverse tone-mapping is a method to create HDR content. Moreover, inverse tone-mapping is also interesting to view legacy video content on new HDR displays, which are now becoming commercially available, maximizing the potential of these screens and thus the quality of the rendered image.

A second objective is to develop a specific coding scheme suitable for HDR video. It should take into account the constraints of backward compatibility with existing schemes. The standardization of such a format will also be explored.

### Visual Quality Assessment

Research in the field of video quality assessment relies on the availability of subjective scores (Mean Opinion Scores or MOS), collected by means of experiments in which groups of people are asked to rate the quality of video sequences. The availability of subjective scores is fundamental to enable validation and comparative benchmarking of the objective algorithms that try to predict human perception of video quality by automatically analyzing the video sequences. In this activity, a publicly available database of subjective quality scores and corrupted video sequences has been created, including 156 sequences at CIF and 4CIF spatial resolutions, encoded with H.264/AVC and corrupted by simulating the transmission over an error-prone network, along with MOS [1542].

Current and future activities are looking into visual quality assessment for 3D video.

## 13.2.2 Rich Media, Adaptation and Open Source Software

**Faculty** C. Concolato, J.-C. Dufourd, J. LeFeuvre, J.-C. Moissinac

**Main events** Edition of several ISO and W3C standards, Organization of SVG Open 2010

**Projects** ANR Radio+(11/08–11/10), ANR HybRadio (), Cap Digital PINGO(04/08–04/10), IST FP6 NoE INTERMEDIA (10/06–10/10), ANR Georacing (01/07–03/09), FUI8 OpenHbb (10/09 – 02/12), SOA2M project/Alcatel Lucent/Institut Telecom joint laboratory (12/08–12/11), FEDER Project VUE (11/10–11/11), FUI8 End2ToEnd, ANR Calder.

### Rich Media Representation

The term "Rich Media" designates the methods, algorithms, tools or technologies required for the processing of the new generation of multimedia content, i.e. content that encompasses natural or synthetic audio-visual material but adds animation and interactive capabilities. Rich Media technologies target a wide range of application domains: from digital TV or radio, to mobile multimedia and the Web 2.0.

The research topic that the team pursued in this area are numerous. Some work has been done towards finding the best representation for such content, as well as designing compression approaches for multimedia scene description languages, with features such as error protection and scalability. Other works focused on improving the visualization of such content [1565], in particular on mobile phones. Finally, the problems related to the delivery of such content on diverse networks such as broadcast networks have been also investigated. As part of this work, the team is an active participant to standardization bodies such as W3C and ISO. The team has contributed (more than 80 contributions) and participated to the editing of the following international standards: MPEG-4 Systems, MPEG-4 BIFS, MPEG-4 LAsER, and W3C SVG.

### Interactive Services and Transmedia

New ways to structure, package and transport interactive content have been studied. The first form is "widgets": the team is an active contributor and implementer of the W3C Widgets suite of standards. In order to investigate the full potential of widgets, in particular in the home environment, the team has spearheaded the development of the MPEG-U standard, which extends W3C widgets to add communication capabilities between widgets and to/from external services. The team is now reformulating the developed concepts for use within the home network with web technologies, as part of the work in the W3C Web and TV IG and the Device API WG. The

second form is interactive TV: the team is active in the development and promotion of the Hybrid Broadband Broadcast TV standard, opening the way for a convergence of TV, Internet and mobile into a new model for distributed, communicating services [1536].

### **Multimedia Adaptation and Multimodal Interaction**

The adaptation of multimedia content to its context of use (terminal capabilities, network characteristics, user preference) is a very active research topic, with tight link with standardization activities such as MPEG-21 or W3C. The team explores specific problems in the adaptation of multimedia content: adaptation of protected content, adaptation of human-computer interface, and the authoring of adaptable services [1565]. These problems are addressed along different axis either by defining software architectures for such adaptations (in relationship with the ASTRE Team) or by defining methods and languages facilitating the adaptation of multimedia documents. A new form of multimedia consumption is emerging: our environment is days after days enriched by more and more multimedia capabilities -displays, sensors, speakers, microphones, touch screens... Our work places the user at the center of such environment and defines tools to get the best benefits of such environment when using multimedia services. Work has been done about implementation and extension of the MMI framework proposed by the W3C [1613].

### **Multimedia Transport**

Starting from 2010, the group has been actively involved in the MPEG standardization process of adaptive streaming over HTTP, through the MPEG DASH specification (Dynamic Adaptive Streaming over HTTP, ISO/IEC 23009-1). The group has proposed various modifications to the specification, published articles on the topic of DASH and interactive content delivery, and hosted one of the DASH standardization meeting in Paris. Technical tools helping creation and consumption of DASH content have been released as part of the GPAC project, and some of these tools will be given to MPEG as utility software. These tools will also be used to generate conformance sequences to be given to MPEG in early 2012.

### **GPAC Open Source Software**

The team maintains an Open Source platform called GPAC [1653], GPAC Project on Advanced Content (<http://gpac.sourceforge.net>), distributed under an LGPL license. This platform offers various tools for the encoding, the delivery and the playback of multimedia content, ranging from simple audio/video to full-fledged Rich Media. These tools implement state-of-the-art algorithms, methods and protocols from many standards organizations (MPEG, W3C, IETF, ETSI) and are kept in close sync with new industrial deployments. GPAC is used by the academic world (42 citations in journals or international conferences), the industrial world (integrated in several R&D projects) and the internet community (e.g. used for iPod file management). GPAC constitutes the back-bone for the implementation of the team's work (Rich Media representations and adaptation) and is often demonstrated in conferences or standardization meetings.

## **13.2.3 Document Imaging and Interaction**

**Faculty** L. Likforman, M. Sigelle, C. Faure

**Main events** L. Likforman was the General Chair of the Document Recognition and Retrieval (DRR) DRR 2010 conference.

**Projects** FUI Rome Mobile (2010-2012), DGA and Futur et Ruptures (2010-2013), A2iA (2008-2010), ltesoft (2011-2014)



The team has developed several HMM-based (Hidden Markov Models) approaches for handwriting recognition (work performed within projects A2iA, DGA, Futur & Rupture and ltesoft). These approaches are based on the Hidden Markov Model framework, especially sliding window systems. In such systems, it is not required to segment the word into smaller units (words or characters). Context-dependent character models have been constructed during the PhD of A-L Bianne for a word recognition approach. Parameter tying is performed through a clustering process based on binary decision trees. Original questions on characters' shapes have been proposed [1534]. The word recognition approach has been extended to text-line recognition [1666]. Different language models have been constructed and the whole approach evaluated on a mail reading task (DGA, Futur & Rupture; PhD thesis Olivier Morillot).

A related and new study (started in 2010) is the characterisation of handwriting for retrieving similar documents (with respect to the handwriting). A retrieving application, REX, [1584] has been developed which compares documents from orientation-based features [1583]. Such features are extracted from normalized histograms of edge pixel orientations.

A new subject (within project Rome Mobile) started in 2010 which aims at decomposing web pages into functional blocs (header, content, footer, title...). Such decomposition is useful for web page adaptation to small screens and mobile phones. Our approach is based on machine learning (Support Vector Machines) using a set of efficient features (based on both content and typography) extracted from web page's blocks.

Document Image restoration based on seminal work of J. Darbon and M. Sigelle on Total Variation has been applied to ancient documents [1588]. A new approach resulting from the combination of Total Variation (TV) and Non Local Means has been proposed [1554] in collaboration with J. Darbon (CMLA and UCLA) and E. Barney Smith (Boise State Univ.) TV was also used for image denoising, by exact sampling (CFTP) and a relation was highlighted with the sub-modularity for Markovian models by Marc Sigelle, in collaboration with J. Darbon (CMLA ENS Cachan) and S. Peyronnet (LRI Orsay).

M. Sigelle continued the collaboration with I. Jermyn (INRIA ARIANA) and S. Perreau (UNISA Adelaide Australia) on the topics of (discrete) diffusion processes, which can be applied both to modelling of traffic routing in ad hoc networks and to image restoration [1703, 1702]. The same techniques have been applied with success in stochastic and markovian optimization of the base station placement, in collaboration with M. Coupechoux (INFRES) and J-M. Kélif (Orange Labs)

Finally, we continued the work on markovian segmentation of multispectral and multivariate images and Stochastic Expectation Maximization (SEM) hyperparameter estimation, with application in teledection (joint work with E. Bratsolis from Univ. of Athenes).

### 13.2.4 Audio-visual Identity/Imposture and Virtual Worlds

**Faculty** G. Chollet, C. Pelachaud, M. Sigelle, M. Charbit

**Main events** C. Pelachaud and T. Boubekeur, co-editors special issue on Facial Modeling, IEEE Computer Graphics and Applications, to appear in 2010; C. Pelachaud co-organizer of a Workshop held in conjunction with AAMAS 2009; she is since 2007 secretary of the Humaine association on emotion; she is part of the selection committee of ANR CONTINT (since 2008), ANR Blanc CSD9 Sciences Humaines et sociales (in 2009).

**Projects** ANR-SurfOnHertz (2010-2013), ANR-ORGAMI2 (2010-2013), AAL-vAssist (2011-2014), FUI-ARHOME (2011-2013), ANR KIVAOU (2008-2010), ANR MYBlog3D (2006-2010), CompanionAble: IP de IST (2008-2012), ANR blanc OUISPER (2006-2009), IST IP-CALLAS (2006-2010), IST STREP-SEMAINE (2008-2011), IST NoE-SSPNet (2009-2013), COST Action 2102 (2006-2010), ANR CECIL (2009-2011), ANR GV-Lex (2009-2011), ANR IMMOMO (2009-2011), Projet Web2.0 MyPresenting Avatar (2009-2011), ANR IMMOMO (2009-2011), Bilateral Contract Dialonics (2011-2013), Feder Anipev (2011-2014), FUI Play Serious (2011-2014), ILHAIRE (2011-2014), TARDIS (2011-2014), REVERIE (2011-2014), VERVE (2011-2014), STIC-Asie IMEI (2011-2013)

Two main directions of investigation are present in this theme:

### **Biometry and Speech/Face Synthesis/Recognition/Verification**

The speech team was created in 1983 when Gérard Chollet joined TELECOM-ParisTech (called ENST at the time). The focus was centered on coding, synthesis and recognition. In the 1990, speaker verification was added, followed by language identification seven years ago. At that time, audio-visual speech and speaker recognition became a topic of interest. The Biosecure network of excellence was an opportunity to promote open-source software for major biometric modalities (face, voice, audio-visual speaker, signature, iris, hand shape...) This led to the publication of a reference book ([1724]) and to the development of databases, reference systems and benchmarking protocols. The FP6-Securephone project was an opportunity to integrate audio-visual identity verification on a mobile phone. Audio-visual identification also finds applications in video indexing (InfoM@gic project, PhD theses supported by OrangeLabs, ANR-SurfOnHertz...) Face tracking, super-resolution and 3D morphable models of faces are issues under study in the ANR-KIVAOU, ANR-ORIGAMI2 and FET-ILHAIRE projects and are evaluated in the context of the NIST-MBGC campaigns. 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 projects such as the ANR-MyBlog3D, the FP7-IP-Companionable, AAL-vAssist and FUI-ARHOME in the context of Spoken Dialogue Systems. Our team contributed to the development of the french version of the OpenMary TTS system. Our coder still needs to be improved in terms of speaker and language independence. A similar approach is developed in the context of the ANR OUISPER project aiming at the development of a Silent Speech Interface (driven from tongue and lip movements).

### **Interaction and Embodied Conversational Agent**

We have been developing an interactive platform of an Embodied Conversational Agent GRETA (virtual entity endowed with human-like communication capabilities) (work done within the National projects MyPresentingAvatar, ANR IMMEMO, ANR CECIL, ANR GV-Lex and European projects NoE SSNet, Fet-Open ILHAIRE, STREP TARDIS, IP VERVE) [1563, 1673],[1540]. Greta is open source platform under GPL licence (<http://www.tsi.enst.fr/~pelachau/Greta/>; more than 100 downloads in 1 year; it is used in several international projects as well as material for academic purposes).

We have continued our research on expressive embodied conversational agents over several research directions:

- Emotional behaviors: we have developed a model to compute expressions of emotions as sequences of multimodal signals ordered through time and space [1560, 1671, 1669, 1668]. A language was derived to encapsulate these temporal and spatial relationships. Evaluation of this model has been undertaken. Perceptual studies were conducted to measure if such an approach increases recognition rate of emotions from the six basic set or of complex emotions. We use this model to increase the lexicon of emotional behaviors of the virtual agent. This work is part of the project ARN CECIL. Within this project, we have also developed a realistic skin rendering model of the face [1640]. Within the project ANR IMMEMO, we are investigating the relationship between emotions and nonverbal behaviors using machine learning approach.

- Social behaviors: we are studying one particular behavior: smile [1562, 1672],[1676]. It can take several conformational shapes (asymmetry of lip corners), temporal values (fast onset, short duration) and communicative functions (amused, polite, embarrassed smiles). At first we have developed an interface to allow human users to design a large variety of smiles onto a virtual agent. Then we have evaluated these signals in a discourse context. We are using the obtained results to develop a model to compute the user's potential perception of the virtual character's social stance depending on its smiling behavior. This work is part of the project EU NoE SSPNet.

- Interactive agents: within the EU project SEMAINE, we have developed a real-time platform allowing users to converse with virtual agents exhibiting different personality traits [1532, 1557,

1570, 1540],[1593, 1619, 1595, 1594, 1618, 1592, 1658]. We are using this platform to several of our work. In particular regarding the modeling of behavior synchrony as a sign of engagement (part of SSPNet and Telecom-ParisTech Synch project) [1574, 1698, 1697].

- The platform of the virtual agent Greta has been rewritten to be independent on the technology it runs on, as well as on its embodiment (part of the project Web 2.0 MyPresentingAvatar) [1673]. The new version can also control the NAO robot [1649, 1651, 1650, 1635, 1679]. This work is part of the ANR project GV-Lex.

Perspectives: in the near future we will continue our work on social signals (EU project SSP-Net) and will work on laughter (EU project ILHAIRE). We will continue our work on synchrony not only in dyads but also in large conversational groups (EU project VERVE). We will extend our work on human-agent interaction system, in particular regarding dialog system (EU project TARDIS).

## 13.3 References

## 13.4 References

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## Chapter 14

# Statistics and Applications (STA)

**Team leader** F. Roueff (P, on sabbatical leave at Univ. Catholique de Louvain, Belgium, 09/2010–12/2010).

**Faculty** K. Abed Meraïm (MC), G. Blanchet (DE), P. Bianchi (MC), O. Cappé (DR CNRS), J-F. Cardoso (DR CNRS), M. Charbit (P), S. Cléménçon (P), C. Févotte (CR CNRS), G. Fort (CR CNRS), A. Garivier (CR CNRS), J. Jakubowicz (MC, until 10/11), C. Lévy-Leduc (CR CNRS), E. Moulines (P), J. Najim (CR CNRS), F. Roueff (P).

**PhD students** A. Attaya (11/10–), S. Audière (10/08–12/11), S. Barembuch (10/07–09/10), A. Bader (12/10–), E. Chautru (10/09–), A. Dematteo (10/11–), M. Depecker (10/07–12/10), M. Jala (11/10–, also with Orange Labs Issy-Les-Moulineaux), E. Kaufmann (09/11–), M. Kharouf (01/07–06/10), O. Kouamo (09/07–01/11, also at Univ. Yaoundé 1, Cameroon), N. Ksairi (10/08–03/10, also with Supélec), S. Le Corff (10/09–), A. Lefèvre (10/10–, 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–), S. Philippi (10/07–11/10), S. Robbiano (10/09–), P. Sendorek (04/11–), A. Schreck (09/2011–), N. Sokolovska (11/06–02/10), M. Thameri (10/10–), J. Villard (11/08–12/11, also with Supélec), T. Wohlfarth (02/10–), J. Yao, R. Zhang (10/10–), B. Zheng (02/10–).

**Post-docs, sabbaticals** T. Rebařka (12/09–09/10), O. Dikmen (02/10–01/12), C. Dhanjal (11/09–10/11), B. Miasojedow (10/11–08/12), R. Gaudel (09/10–08/11), A. Kammoun, L.-V. Lozada (02/10–08/10, 02/11–08/11), N. Mahler (08/11–), L. Oudre (10/11–01/12), D. Rohde (07/10–06/11), A. Saumard (11/10–11/11); M.S. Taqqu (Prof. at Boston Univ., 3 months), V. Reisen (MC, Vitória Univ., Brazil, 3 months).

Faculty [IT, CNRS]	[5.5, 5.3]
PhD students	7.2
Post-docs, sabbaticals	4
Defended theses	6
Defended HDR	4
Journal papers [published, to appear]	[75,32]
Papers in conference proceedings	96
Grants [public, private] (k€)	[655,576]

## 14.1 Objectives

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 of the ParisTech institute (Ecole Polytechnique, ENSAE) and universities (M2 *Modélisation aléatoire* at Paris 7 Denis Diderot, M2 *Modélisation Vision Apprentissage* at ENS Cachan, 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 and CERTIS, Ponts) and with the Ecoles Normales Supérieures Ulm (INRIA projects TREC and WILLOW) 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 (through CIFRE conventons). 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, Renault, France Télécom R&D and Direction Générale de l'Armement (DGA), Amesys, Natixis, Liligo.com.

The group enjoys a high national and international recognition with editorial board members in high quality journals such as Bernoulli, ESAIM P&S, Stoch. Proc. and their Appl. (E. Moulines) and the Journal of the Royal Statistical Society, Series B (O. Cappé), DSP journal (K. Abed Meraïm) as well as regular participation as program comity members in the major international conferences (IEEE ICASSP, IEEE statistical Signal Processing workshop, International Conference on Machine Learning, Neural Information Processing Systems, European Signal Processing Conference) or associate editors of special issues (Journal on Advances in Signal Processing). The group regularly organizes or co-organizes scientific events such as the summer school (C. Févotte, *Ecole d'Eté en traitement du signal et des images* in Peyresq (2010)), special sessions in international conference (G. Fort, AMSDA 06/11); national workshop (G. Fort, GDR ISIS

11/11, P. Bianchi, GDR ISIS 02/12), as well as recurrent scientific seminars in the Parisian region (*séminaire parisien de statistiques*, ParisTech Machine Learning reading group *Smile*). E. Moulines received the Silver Medal of CNRS in October 2010, for his work on Probabilities applied to Signal Processing and Machine Learning. He was awarded the FRANCE TÉLÉCOM award of the french Science Academy (grand prix de l'Académie des sciences).

C. Lévy-Leduc and F. Roueff were invited to give talks at the 58th World Statistics Congress of the International Statistical Institute (2011) and at the “Journées MAS” in 2010. P. Bianchi was invited to give talks at the 5th ICST International Conference on Performance Evaluation Methodologies and Tools (2011) and at the “Journées MAS” in 2010, along with C. Lévy-Leduc and F. Roueff.

## 14.2 Main results

### 14.2.1 Statistical Learning

**Contributors** O. Cappé, A. Garivier, S. Cléménçon, C. Févotte, C. Lévy-Leduc, E. Moulines, F. Roueff.

**Projects** ANR projects MGA (Graphical Models and Applications, 2008–2011), BEMOL (Prediction of internet users' behavior, simulation and collaborative filtering, 2008–); Contracts with France Telecom R&D (two theses) and and Liligo.com (1 phd thesis), Renault (1 phd thesis).

The group has a long standing interest in **graphical models** and, more generally **Bayesian methods**. In the context of the MGA project, we contributed both to general methodological questions (in particular regarding the online learning of parameters [1977, 1952]) 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 [1814], we developed an highly efficient software called *Wapiti* [1928]. *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. On the other hand, we have continued our statistical investigations on Variable Length Markov Models (see for instance [1778]).

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 Labs, was motivated by cognitive radio problems [1752] and targetted internet advertisement [1906]. These non-stationary applications brought us into investigating adapted bandit algorithms [1909]. We also strongly defend the use of Kullback-Leibler divergence in optimistic algorithms: we proved in [1908] the optimality of a resulting upper-confidence bound algorithm for bandit problems, and we proposed in [1872] an improved algorithm for reinforcement learning in discrete Markov Decision Processes. Recently, we joined the ANR project Bandhits and co-advise a new PhD thesis on Bayesian methods for bandit problems. Moreover, in the PhD thesis of Marjorie Jala funded by Orange Labs, we propose active learning methods for the estimation of upper quantiles of the exposition to electromagnetic fields which are strongly inspired by bandits algorithms.

In the context of supervised learning, significant advances in the ranking problem from practical and theoretical perspectives both at the same time have been made in [1758], [1759], [1760] and [1762]. Strong empirical evidence supporting the efficiency of the techniques thus developed are presented in the PhD thesis defended by Marine Depecker (2007/10, in collaboration with Renault Technocentre). This work is now prolonged by the PhD thesis of S. Robbiano, currently considering “multi-class” extensions and plug-in approaches, see [1880].

Unsupervised ranking, sometimes termed 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 [1879], [1892] and [1910], offering promising alternatives to the classical "median approach". In the unsupervised domain, theoretical grounds for pairwise clustering methods are set in [1876].

Statistical learning based on functional data is another emerging topic of the group. Whereas, the PhD thesis of N. Mahler (2008/10, in collaboration with ENS Cachan and Strategic Risk Management) and that of R. Zhang (2010/13, in collaboration with ENS Cachan and BNP Exane) deal with applications of machine-learning to Finance, where input and output data are naturally multivariate time-series, the PhD thesis of Till Wohlfarth focuses on travel price forecasting, cf [1956] and [1955], and also faces issues raised by time-series in the context of nonparametric prediction. Extensions of recently developed nonparametric scoring methods have also been proposed in the functional situation, see [1877]. More generally, techniques for dealing with structured data such as graphs have also been studied within the group (projects ANR Viroscopy, Digiteo Bemol), see [1878], [1888], [1889], [1980] or [1891].

Finally, the design of model selection techniques based on data-dependent complexity penalization is a future line of research of the group, see [1954] (Futur & Rupture "Meta-Rank" 2010/11, Digiteo project "Crank-Up" in collaboration with the Lip6 of UPMC 2011/12).

### 14.2.2 Blind Source Separation and Identification

**Contributors** K. Abed Meraïm, J-F. Cardoso, C. Févotte, M. Charbit, E. Moulines, A. Garivier, P. Bianchi.

**Projects** ANR project TANGERINE (Theory and applications of nonnegative matrix factorization, 2009–), research contract with CEA, PEA project AINTERCOM with DGA/Amesys (Plan d'étude amont, 1 phd thesis), Cap Digital project ROMEO funded by Ile-de-France region (1 thesis with AAO team), research contract with WITHINGS (Master thesis).

Blind source separation is an important topic of statistical signal processing. In the ROMEO project, in collaboration with AAO team, our task is focused on the blind source separation (BSS) topic using a microphone array. Source separation is a very important step for human-robot interaction: it allows latter tasks like speakers identification, speech and motion recognition and environmental sound analysis to be achieved properly. Within this framework, we focused on the challenging problem of blind source separation in a real reverberant environment using combined beamforming and sparsity based BSS techniques [1940, 1941].

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 [1773], factorization with structural constraints [1932, 1902], online and stochastic algorithms [1933, 1905]. Several applications have been considered such as music transcription [1800, 1801], audio source separation [1802, 1978] and identification of dietary behaviors [1761].

A final field of interest for non-cooperative communications is **blind signal source identification** (or detection). It is assumed that the signal coming from an unknown transmitter has been intercepted. In the context of AINTERCOM project, we developed blind demodulation approaches using approximate Maximum Likelihood methods [1738], [1737].

### 14.2.3 Sensor Networks

**Contributors** K. Abed-Meraim, P. Bianchi, M. Charbit, G. Fort, J. Jakubowicz, E. Moulines, J. Najim, F. Roueff.



**Projects** ANR projects SESAME (consistent estimation and large random matrices), SVELTE (Système d'évaluation de la dépense énergétique et de la condition physique pour la prévention et le traitement de l'obésité), C-FLAM (Coordination Flotilla Localization and Mapping), research contracts with THALES-Valence (1 phd Thesis).

Our interest lies in applications of mathematical and statistical tools to the performance evaluation and the optimization of sensing and communication systems. The term *sensor* should be understood in a wide sense, including physical sensors (accelerometers, microphones, etc.), smart phones, processors or mobile robots. Both centralized and decentralized network architectures have been investigated. Centralized systems are characterized by the existence of a fusion center which gathers and processes the sensors' observations as a whole. On the opposite, decentralized systems are formed by autonomous sensors and rely on distributed algorithms to achieve the global mission. A large part of the results in this theme have been obtained in collaboration with the COMNUM research group (COMELEC) (see [1792, 1862] for some examples of joint works).

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 [1841]. An industrial contract with CEA led to original algorithms for the localization of infrasound sources and the estimation of their angles of arrival [1968].

Motivated by application to *cognitive radio* and sensor networks (ANR project SESAME), we investigated several problems related to hypothesis testing in centralized sensor networks. We analyzed the error probabilities of different test statistics for various probabilistic model [1747, 1748, 1841]. In the later references, original methodological tools are developed in the asymptotic regime where the number of sensors tends to infinity, allowing to obtain closed form expressions of the **error exponents** associated with the tests. In particular, the design of relevant quantizers maximizing the error exponent is an important issue, which has been studied in [1841]. On the other hand, **random matrix theory** has been used 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 [1747]. In parallel, random matrix theory has also been extensively used for solving wireless communication problems. We have recently been able to complete the performance analysis of *Ricean* Multiple Input Multiple Output (MIMO) channels [1770, 1783]. The analysis of Ricean channels is difficult because of the presence of a line-of-sight component. A thorough study of the mutual information of Ricean channels has been performed, culminating with the computation of the ergodic capacity.

In the framework of **decentralized systems**, we investigated the issue of distributed optimization and distributed statistical estimation by means of **gossip algorithms**. Gossip algorithms provide efficient cooperation techniques which allows the sensor to exchange messages and share their local information in an efficient fashion, in such a way that a consensus is eventually achieved in the network. We study the convergence of these algorithms in [1859] and in a recent journal submission, and analyzed the asymptotic behavior of the estimation error in [1862] where we also discuss application to power control. Applications to smart grids have been investigated in [1893]. In the context of ANR project C-FLAM, we also investigate an application to motion coordination of autonomous underwater vehicles in a recently submitted paper. In the scenario of large wireless communication networks, we also investigated distributed resource allocation in [1792]. Finally, a new communication protocol for *relay channels* has been proposed and analyzed in [1924] and in a journal paper currently in revision.

#### 14.2.4 Monte Carlo Methods

**Contributors** O. Cappé, S. Cléménçon, G. Fort, E. Moulines.

**Projects** ANR Projects BigMC (Issues in large scale Monte Carlo, 2009–2012), C-FLAM (Coordination Flotilla Localization and Mapping, 2008–2011); Simino1e (Large-scale simulation-based probabilistic inference, optimization, and discriminative learning with applications in experimental physics, 2011–2014) and Viroscopy (Stochastic modeling and statistical inference for propagating infectious diseases: from micro to macroscopic behavior, 2008–2011). Digiteo project Bemol (2009–2011).

The group has acquired a high reputation in the domain of Monte Carlo methods by working on Sequential Monte Carlo (also called Particle Filtering), Markov chain Monte Carlo (MCMC) and novel Monte Carlo approaches at large. The group contributes actively to methodological and theoretical advances in Monte Carlo methods and also works on selected applications, most often in the context of collaborative projects.

New challenges in MCMC methods deal with adaptive methods and interacting Monte Carlo processes. The group has a strong expertise in convergence analysis of classical MCMC algorithms; in the past two years, the group answered to some of these new challenges by developing new tools for the theoretical study of these new MCMC samplers. These works have been developed in collaboration with researchers from Paris 6, Univ. Paris Est (in the context of the BigMC project), and Univ. of Michigan (USA) [1733, 1734, 1976, 1776].

In the context of the ANR project C-FLAM, lead by the LIRMM, the group developed new Simultaneous Localization and Mapping algorithms. Our approach consists in answering the Localization problem by using Sequential Monte Carlo methods, and the Mapping problem by adapting online Expectation-Maximization algorithms (previously proposed by our group [1750, 1977]) [1930, 1907].

Interacting and branching particle system techniques and sequential Monte-Carlo methods have been developed and used for *rare event simulation/probability estimation* in the context of food risk analysis and that of mathematical epidemiology (ANR project Viroscopy - 2008/11), see [1757] and [1743]. In [1910] (Digiteo project Bemol - 2009/11), dedicated MCMC techniques have been developed in the purpose of 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 [1842, 1788] (with associated distributed software implementation [1788]) for Bayesian analysis of multi survey cosmological data, we launched a new project in this field in 2011. This project called Simino1e 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.

### 14.2.5 Time Series

**Contributors** O. Cappé, M. Charbit, S. Cléménçon, C. Lévy-Leduc, E. Moulines, F. Roueff.

**Projects** Research contract with Natixis (1 phd thesis), Research contract with Echosens (1 phd thesis), 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).

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 ([1789]), non stationary (change-point and locally stationary) long memory modelling ([1979, 1790, 1810]), non-Gaussian and non-linear long memory processes ([1755, 1811]). 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 [1796]. These results have been established thanks to the asymptotic properties of general  $U$ -processes in the long-range dependence context of [1795]. 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 [1797] and [1938] 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 [1784].

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 means, U-statistics and extreme-value statistics based on general Markovian data, in [1742], [1756] and [1744]. Preliminary extensions to Hidden Markov Chains are developed in [1886].

Ongoing applications in statistical signal processing based on time series or random fields modelling include radar processing and medical diagnosis [1951, 1849].

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## Chapter 15

# Image processing and understanding (TII)

**Team leader** I. Bloch (P).

**Faculty** A. Almansa (CR1 CNRS, HDR), E. Angelini (Assoc. P, HDR in 2011, on leave in Australia for six months in 2010), I. Bloch (P), T. Boubekour (Assoc. P), H. Brettel (CR1 CNRS, HDR), M. Campedel (Assoc. P), J. Delon (CR1 CNRS, HDR in 2011), E. Eisemann (Assoc. P, since 12/09), Y. Gousseau (P, HDR in 2009), S. Ladjal (Assoc. P), H. Maître (P), P. Memari (CR2 CNRS, since 10/11), J.-M. Nicolas (P), S. Rital (Research Engineer), M. Roux (Assoc. P), H. Sahbi (CR1 CNRS, HDR in 2011), T. Tanzi (P, until 2010), J. Tierny (CR2 CNRS, since 10/10), F. Tupin (P).

**PhD students** *Defended (dates are for the defense)*: 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. Leheureau (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. Facciolo (3/11, with Univ. Pompeu Fabra), 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).

*Current (dates are for the beginning of PhD)*: C. Aguerrebere (4/11), N. Bourdis (1/10), B. Buchholz (10/09), J. Caron (10/08, with Univ. Amiens), F. Dellinger (10/10), N. Faraj (12/09), M. Gargouri (11/11), N. Geeraert (9/11), I. Ghorbel (2/09), A. Graciano (9/08, with Univ. Sao Paulo), T. Guillemot (10/10), C. Herold (12/10), M. Hollander (1/10), J. Huang (10/09), Q. A. Le (10/09), Y. Le Montagner (10/10), B. Mazin (9/10), A. Newson (9/10), G. Pizaine (6/09), J.-B. Poisson (10/10), G. Quin (9/10), A. Roman Gonzalez (9/09), L. Schemali (1/11), P. Schmitt (10/11), X. Su (10/11), G. Tartavel (10/11), J.-M. Thiery (10/09), Y. Traonmilin (7/11), G. Vialaneix (12/09), U. Verma (10/10), P. Vo (10/10), Y. Yang (10/10), F. Yuan (9/10-9/11).

**Post-docs, engineers and sabbaticals** 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 (10/11-12/11), J.-P. De la Plata (8/09-7/11), E. Erdem (7/09-3/10), F. Fayard (5/10-4/11), G. Fouquier (7/09-3/11), M. Horta (4/11-9/11), 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), T. Ritschel (5/10-9/11), X. Rondeau (10/09-3/11), Y. Rouchdy

(10/09-12/10), H. Sportouche (4/11-12/11), O. Tankyevych (1/11-8/11), C. Vanegas (1/11-4/11), A. Zureiki (7/09-10/09).

**External collaborators** M. Datcu (CoC chair, until 6/10).

Faculty [IT, CNRS]	[11, 4.6]
PhD students	29
Post-docs, engineers and sabbaticals	10
Defended PhD theses	36
Defended HDR	4
Journal papers [published, in press]	[105, 12]
Papers in conference proceedings	177
Chapters and books	25
Grants [public, private, european] (k€)	[1461, 1203, 120]

Table 15.1: The reference period for the main TII figures is from July 2009 to December 2011, except for publications in journals, conferences and books where it covers January 2009 to December 2011.

## 15.1 Objectives

The objective of the group is to develop methodologies and theoretical tools for image, scene and 3D object processing and interpretation. The main approach consists in solving globally complex problems, based on rigorous theoretical bases, and integrating multiple and complementary techniques, for deriving 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. The group is well recognized, in both academic, institutional and industrial domains. 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 strong features of the group.

Over the last two and a half years, two professors left, one to join a research team in Sophia-Antipolis at Mines ParisTech, and the other at the end of the CoC joint laboratory with CNES and DLR. On the other hand, during this period the group has benefited from the appointment of two CNRS researchers and one associate professor, strengthening research axes mainly in computer graphics, but also in medical imaging. 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 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.



## 15.2 Main results

The main research results obtained during the period mid-2009-2011 are presented below for the research areas of the TII team, both from a theoretical and methodological point of view, and from an application perspective.

### 15.2.1 Mathematical methods for images

**Faculty** A. Almansa, I. Bloch, J. Delon, Y. Gousseau, S. Ladjal, H. Sahbi, F. Tupin.

**Projects** ANR projects (CALLISTO, MATAIM, OTARIE, FREEDOM), FUI (9th call) CEDCA, Cifre and CNES PhD fundings, CNES research funding, DGA/REI MRIS and Tracking, ECOS Sud (U06E01), STIC AmSud (MMVPSCV).

**Collaborators** L. Alvarez (U. Gran Canaria, Spain), J.-F. Aujol (U. Bordeaux 1), F. Cao (DxO Labs), V. Caselles (UPF, Spain), T. Buades, A. Desolneux, S. Durand, B. Galerne, T. Hurut, L. Moisan (U. Paris Descartes), S. Dubuisson (UPMC), M. Lindenbaum (Technion, Israël), S. Masnou (U. Lyon 1), J. Darbon, J.-M. Morel, M. Nikolova (ENS-Cachan), L. Denis (U. Saint-Etienne), P. Musé (U. de la República, Uruguay), J.-C. Olivo-Marin (Institut Pasteur), A. Pardo (U. Catolica, Uruguay), M. Mejail (UBA, Argentine), P. Pérez (Technicolor, Rennes), G. Peyré and J. Salomon (U. Dauphine), J. Rabin (U. Caen), J. Salmon (U. Denis Diderot), M. Sigelle (Télécom ParisTech), A. Sobolevskii (Poncelet Lab., Moscou), L. Vese (UCLA, USA), W. Wang (U. Wuhan, China), A. Bretto (U. Caen).

#### Texture and natural images modeling

This research theme deals with the stochastic modeling of natural images. First, generative models taking into account scaling phenomena in natural images have been developed. These models (dead leaves, shot-noise, transparent models) are grounded in the theory of marked point processes, whose marks are geometrical structures. The most recent works in this area are concerned with texture synthesis using spot-noise models, see [2039] and the companion online IPOL demo <sup>1</sup>, as well as the stochastic modeling of transparency [2038]. 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 [2009, 2022, 2023]. 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 as such is routinely used by the main industrial actors in the domain, ranging from Nikon to the NASA. Oriented toward public audience, the model has appeared in the 2011 FNAC summer catalogue for DSLR cameras.

#### Image analysis and computer vision.

These last years, we have developed or applied various mathematical tools for the analysis, indexing or matching of images.

Among these tools, let us first mention optimal transportation equations. These equations enable the definition of metrics between weighted features and yield elegant ways to compare images. We have recently proposed two complementary studies on the subject of optimal transportation on the circle, one in a continuous setting [2012] and the other one in a discrete setting [2072, 2074]. This last study compares for different retrieval tasks the transportation metrics with the classical distances used in computer vision.

Another methodological aspect of our researches deals with *a contrario* methods, developed by Desolneux et al. to automatically fix detection thresholds for image analysis. In particular,

<sup>1</sup><http://www.ipol.im/pub/algo/ggm-random-phase-texture-synthesis>

we applied these 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 (relying on optimal transportation), an unsupervised matching criterion, and a validation, RANSAC-like step [2072, 2275]. In the particular case of block-matching of epipolarly-rectified stereo pairs, the *a contrario* methodology, complemented with more classical criteria to avoid self-similarity and fattening effects has proven very efficient to build up dense sets of reliable matches [2079]. This yields disparity maps computed up to an unprecedented accuracy level, closely matching our theoretical accuracy estimation [2080]. Check also the accompanying online demo <sup>2</sup>. The *a contrario* methodology also allows for parameterless and unsupervised graph-based clustering [2087] 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: a change detection algorithm was introduced, based on a new interest point matching approach combined with the epipolar geometry. The main contribution of our method includes: (i) a statistical-based criterion combined with the geometry of scenes, able to reliably detect changes in pairs of images and (ii) the extension of the method in order to handle archives of videos where the temporal coherency is exploited to further enhance the performances. In this context, the validity of our method is demonstrated through a realistic ground truth including many labeled changes [2170].

Still in a probabilistic framework, during the PhD of A. Shabou, new graph-cut based optimization approaches of Markovian models have been proposed. They rely on a random sampling of sub-sets of states for three global moves (expansion, swap and jump) with associated graph constructions. They allow an efficient compromise between memory size and quality of the obtained optimum [2289].

Among the other tools that we have investigated and applied, let us quote topographic maps. This tool turns out to be particularly efficient for the indexing of satellite images [2057], the indexing of texture [2093] or the analysis of artistic line-drawings [2047], even in the presence of a wide range of geometrical and radiometric changes. The method developed in [2093] is an extension of the classical granulometry from mathematical morphology.

### 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 in-depth studies of Non-Local Means methods. In [2023], we propose an in-depth study of such denoising methods and give a method for the automatic and local setting of parameters. In [2009], it is proposed to use adaptive and generic patches to improve denoising results. In [2007], 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 [2008].

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 [2022]. The TV regularization model under local L2 constraints showed effective in the context of irregularly sampled blurred and noisy data [2032, 2146]. It was also shown useful for destriping MODIS images [2062].

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 [1994], 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 [2051]. Some of the previous works require an accurate knowledge of internal camera parameters like the intrinsic blur kernel (PSF). In [2006] we showed that accurate estimation of the PSF is well posed, without regularization,

<sup>2</sup> [http://www.ipol.im/pub/demo/bms\\_binocular\\_stereo\\_pipeline/](http://www.ipol.im/pub/demo/bms_binocular_stereo_pipeline/)

provided an appropriate white noise image is used for calibration. See the accompanying IPOL demos<sup>3 4</sup>.

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 one ANR project (ANR FREEDOM JCJC 2007-2011) on movie restoration, one collaborative project with the firm DxO Labs, and one PHD thesis supervised in collaboration with the firm Technicolor. As part of the 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 [2010], and the second one is an efficient method for the removal of artifacts [2073] introduced by contrast and color changes. Another contribution deals with the detection and restoration of occluding defects in movies [2174].

### Tracking

Another contribution based on probabilistic methods addresses tracking issues in image sequences, by incorporating different types of information in the probabilistic model [2029, 2092]. 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 15.2.2), 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 [2186, 2187] (collaboration with Institut Pasteur).

Another topic is multi-view tracking of objects in video surveillance, which consists in segmenting and automatically following objects through different camera views. In this work, we present a multi-view object matching and tracking approach based on canonical correlation analysis. Our method is purely statistical and encodes intrinsic object appearances while being view-point invariant. We have shown that our technique is easy-to-set, theoretically well grounded and provides robust matching and tracking results for traffic surveillance [2220].

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 15.2.5).

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).

### 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 [1981, 2152], including description logics for ontological reasoning, fuzzy sets [1989], and more recently hypergraphs [2167] and bipolar information [2166, 1990, 2237] 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.

<sup>3</sup>[http://www.ipol.im/pub/algo/admm\\_non\\_blind\\_psf\\_estimation/](http://www.ipol.im/pub/algo/admm_non_blind_psf_estimation/)

<sup>4</sup>[http://www.ipol.im/pub/algo/damm\\_blind\\_psf\\_estimation\\_from\\_scaled\\_image\\_pairs/](http://www.ipol.im/pub/algo/damm_blind_psf_estimation_from_scaled_image_pairs/)

### 15.2.2 Image understanding and spatial reasoning

**Faculty** I. Bloch, M. Campedel, H. Maître.

**Main events** CIARP 2010 conference.

**Projects** ANR DAFOE, CNES PhD thesis and research projects funding, collaboration with J. Atif (LRI), C. Hudelot (ECP), J. Inglada (CESBIO), R. Cesar (U. Sao Paulo, Brazil).

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 [2086, 2137, 2303]. New fuzzy connections have also been proposed, and applied to filtering problems [2067, 2071]. 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 [2037]. The order in which structures are segmented is adapted to each image, by combining spatial relations and saliency information. In case of failure of a segmentation step, a backtracking procedure was proposed as well. Another approach relies on the search for a global solution by expressing the recognition as a constraint satisfaction problem [2068, 2137], or as an inexact graph matching problem [2069]. Finally ontological reasoning was proposed, by introducing mathematical morphology operators in description logics in order to define spatial relation concepts [2237]. In the same line, a preliminary work 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 [2152].

During the project DAFOE4app (ANR project, 2007-2010), an engineering collaboration between Telecom ParisTech and Mondeca has been initiated. The common goal was to create and develop an interactive tool to assist satellite image interpreters. Results have been obtained, with the support of CNES, in the creation (and free diffusion) of two OWL ontologies: the image ontology is able to describe the image content and the feature extraction process whereas the scene ontology identifies 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 proposed. However further engineering development would have been necessary to make it really operational. Such a tool is an ideal way to demonstrate the usefulness of both low-level image processing algorithms and semantic reasoning in the context of satellite image interpretation.

### 15.2.3 Learning, indexing and retrieval

**Faculty** M. Campedel, M. Datcu (until 2010), H. Sahbi.

**Projects** Infomagic, K-space.

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 [2322] (PhD of E. Aldea).

Two important projects were completed during this period, Infomagic and K-space, leading to the publications of two books [2331, 2335], as major outcomes of the work carried out within these projects.

This research theme was also developed specifically in the context remote sensing imaging, as described in Section 15.2.6.

Most of the work in machine learning during this period was devoted to visual recognition and search, along three main lines.

**Image annotation in interconnected networks & activity recognition.** In this work, we introduced a novel image annotation and retrieval approach based on support vector machines

(SVMs) and a new class of kernels referred to as context-dependent (CD). The main contribution of our method includes (i) a variational approach which helps designing our CD kernel using both intrinsic features and the underlying contextual information, and (ii) the proof of convergence of the CD kernel to positive definite fixed-point, usable for SVM training and other kernel methods. 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 [2284, 2081, 2285]. We also extended this CD kernel in order to handle activity indexing and recognition in video sequences [2320].

**Conditional random fields for Object Class Segmentation (OCS).** In this work, we 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 [2250].

**2D to 3D object retrieval.** In this work, 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 (i) a generative approach for alignment able to find canonical views consistently through scenes/objects, and (ii) 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 [2066].

#### 15.2.4 Computer graphics, digital geometry and rendering

**Faculty** T. Boubekeur, E. Eisemann, J. Tierny (and P. Memari since October 2011).

**Main events** Eurographics Young Researcher Award (E. Eisemann), Honorable mention of the Dirk Bartz Prize for Visual Computing in Medicine [2005].

**Projects** IP Reverie, NoE 3DLife, ANR Ispace&time, MediaGPU, CeCil, KidPocket, FETUS, CIFRE EDF, CIFRE Useful Progress, “Chaire Modélisation des Imaginaires”.

The computer graphics team of the TII group conducts its research activities in 3D geometric modeling, rendering, perception, visualization and computer vision.

In modeling, the group has developed several fast methods for surface simplification, filtering and reconstruction based on linear and adaptive stochastic approaches [1991], separability [2305], locality principles, and variational geometry [2085]. A structuring-curve system has been proposed for deformation, 2D painting [2156], and shape learning to reconstruct scans [2049]. A quad remesher for polygonal surfaces as well as an interactive one has been designed to integrate user constraints in real time [2089]. Another approach has been presented to reuse exemplar databases for generating new quadrangulations from predefined styles [2088]. Some of these contributions have been applied for realistic anatomical modeling (see Section 15.2.5).

In rendering, the group has developed new algorithms for global illumination on GPU [2045], in screen- [2236], object- [2077] and hybrid [2279] spaces, and has proposed a new static [1993] and/or spatio-temporal scene analysis for expressive [2176], amortized [2233], and stereo rendering [2204]. A new real time geometry synthesis stage has also been proposed [2330, 2235]. Optical phenomena stemming from virtual cameras (depth of field, lens flare, motion, etc.) have been studied in detail to improve realism but also to offer artistic control [2046, 2053]. Finally, a remote rendering system has been developed [2070].

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 [2016], and a better detail preservation [2017], as well as higher quality stereo rendering [2018].

In visualization, a new approach was proposed to explore interactively large-scale simulations based on a topology pre-analysis [1992]. Also, a new method for topological verification was able to illustrate the shortcomings of various realizations of isosurface-extraction methods that are publicly available [2031].

In computer vision, a benchmark and a visual research engine [2025] based on a new set of local descriptors and a machine-learning approach have been developed, built around a new system for interactive 2D [2026] and 3D [2085] design, to discover and create content from huge data bases. Another technique registers photos and 3D terrain models to perform automatic geo-localization, object recognition and to add annotations [2155].

### 15.2.5 Medical imaging

**Faculty** E. Angelini, I. Bloch, T. Boubekur, J. Delon (and P. Memari since October 2011).

**Main events** Joint Lab with Orange Labs (WHIST), Honorable mention of the Dirk Bartz Prize for Visual Computing in Medicine [2005].

**Projects** ANR (FETUS, Kidpocket, IPHOT), Visiting Scientist fellowship at CSIRO (Australia), MINIARA, CIFRE PhD theses funding. Collaborations with Siemens, Philips, General Electric, Dosisoft, Fovea, Orange Labs (J. Wiart), Institut Pasteur (J.C. Olivo-Marin), ISEP (F. Rossant), U. Columbia (A. Laine), hospitals (Cochin - Saint Vincent de Paul, Bicêtre, XV-XX, Lariboisière...).

Our work on segmentation of normal and pathological brain structures is strongly related to our research in spatial reasoning (see Section 15.2.2), where anatomical knowledge is represented using structural formalisms, and used to guide the segmentation and recognition [2037, 2068] (PhD of G. Fouquier). These ideas have also been exploited in other medical applications. 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 [1984, 2147] and has led to the launch of a new PhD co-supervised with the Hospital Lariboisière. 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, with close links being built with 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 new strong links between the medical imaging and the computer graphics teams (see Section 15.2.4). 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 [2148, 2150, 2149] (PhD of J. Anquez), and the design of dedicated modeling tools for the construction of pregnant women bodies from segmented medical images [1985, 1986, 2005], deformed in various positions for dosimetry simulations. In the same line, segmentation of whole body MRI children images for anatomical modeling at different ages is currently addressed [2222]. These works were carried out in close collaboration with Orange Labs, within the joint laboratory WHIST.

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 [2249, 2273], 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. The long-term collaboration with Columbia University has led to the graduation of a jointly supervised PhD student working on IVUS images,

for the segmentation of coronary vessels [2239, 2240, 2241] and the joint supervision of a PhD candidate on the quantification of myocardial strain from 3DUS images. We have also continued the work on the reformulation of deformable models with Surface Function Active [2020, 2021] for real-time segmentation performance.

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 [2313]. Dedicated registration tools for protontherapy were also developed (PhD of J. Baussé).

In mammography, we focused on the analysis of tomosynthesis images and developed original filters [2071] (see Section 15.2.1), and segmentation methods, dedicated to masses, using fuzzy approaches, and spiculated lesions, using *a contrario* approaches [2151, 2269, 2267] (PhD of G. Palma).

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 [2186, 2187] (see Section 15.2.1). 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 [2255], temporal acquisition schemes and digital holography imaging [2258, 2060] for fast image sampling and efficient image reconstruction in realistic microscopy imaging setups. This work has received a best student paper award at the conference ISBI 2010 [2258]. A new PhD student is now working on the optimization of the image reconstruction process dedicated to temporal CS microscopy imaging [2246, 2247].

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 [2041] (PhD of I. Ghorbel). A recent technique based on adaptive optics was then exploited to detect photoreceptors and estimate their density [2252]. Finally, eye fundus images were used for the segmentation of blood vessels and their classification into arteries and veins [2078].

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, and their use as control signals for BCI tasks (PhD of Y. Yang). Optimal selection of spatial filters and of the number of electrodes is now addressed.

### 15.2.6 Aerial and satellite imaging

**Faculty** A. Almansa, M. Campedel, M. Datcu (until 2010), J. Delon, Y. Gousseau, H. Maître, J.-M. Nicolas, S. Rital, M. Roux, F. Tupin.

**Projects** CNES PhD theses and research projects funding, ANR EFIDIR, REI-DGA, Magellium, CIFRE Thales, Terra Numerica. Collaborations with DLR (A. Reigber), U. Parthenope II Italy (G. Ferraioli), U. Sao Paulo Brazil (T. Perciano, M. Horta), CEA (R. Binet), U. UPEMLV, IGN.

Within the TerraNumerica project (CapDigital), we extended our work on the processing of **3D point clouds** [2321]. The analysis of 3D point structures with the Hough transform associated to an entropic measure led to the detection of parallel planes and allowed the separation of building facade elements (walls, balconies, windows and doors).

Another axis was the analysis of full-waveform **lidar data** for the automatic classification of urban areas on one side and littoral scenes on the other side. This work demonstrated the

contribution of radiometric calibration features to high classification accuracies [2059, 2058] (PhD with MATIS, IGN).

Concerning the generation of **3D models from multiple images**, our focus was the construction of a low cost system allowing non-specialists to make 3D measurements with minimal set of constraints on the image acquisition [2272]. The concerned applications are related to surface roughness and dendrometric parameters measurements (PhD with UPEMLV).

In **stereovision**, recent research focused on high precision and subpixel approaches, in particular by estimating meaningful matches in order to improve disparity maps [2079, 2080].

For **SAR imagery**, research is led at different levels: at the signal level with the development of statistical models and denoising approaches, and at the region or object level, particularly for the fusion of radar and optical 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. Concerning denoising approaches, non-local means extended to a probabilistic framework are very efficient either for amplitude images [2007], or interferometric / polarimetric data [2008] (PhD of C. Deledalle, see also Section 15.2.1). A Markovian formalism and different estimators with adapted optimization approaches define an elegant context for the fusion of multi-channel interferometric data [2036, 2082] (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, PhD of H. Sportouche) with SVM methods or with explicit object detection and likelihood optimization [2084]. Network extraction has also been investigated with Markovian approaches for SWOT images of rivers (CNES project) and for road detection in a multi-temporal and multi-sensor framework (PhD of T. Perciano). 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 be applied for change detection applications.

During the EFIDIR project (ANR MDCO, 2008-2011), theoretical works have been conducted to better understand the problem of complex data interpolation and phase vortex. Concerning glacier monitoring, correlation based approaches on amplitude images have been developed with adapted similarity criteria [2033] (PhD of R. Fallourd). Man-made corner reflectors have been positioned on Argentiere glacier to serve as ground truth and help understanding the backscattering mechanisms of metric resolution images like TerraSAR-X and Cosmo-SkyMed.

The **joint CNES-DLR-Télécom ParisTech Competence Center (CoC)**, created in June 2005, ended in June 2010. Its activities were focused on information extraction and satellite image understanding for both optical and SAR images. Numerous PhD theses have been defended since 2009 on a high variety of subjects going from low level image description [1987], classification [2055] to (semi-) supervised active learning tools [1988] and knowledge representation [2137].

Even if this project is now finished, strong collaborations with CNES<sup>5</sup> are maintained on specific applicative projects (called EXITER, SAFER European project and KAL-Haïti ANR), which were initiated from 2008 to 2011, in the context of rapid mapping, or more methodological ones, for instance based on hypergraph representations [2207, 2076]. Close relationships with expert interpreters from SERTIT<sup>6</sup> 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 scientifically evaluate information extraction and classification tools and also to derive new products (as processing chains) to be used by interpreters. Hence scientific and applicative evaluations were performed exploiting platforms like KEO (ESA platform) as well as public tools like OTB (Orfeo Toolbox<sup>7</sup>) and GIS (Geographical Information System). Not restricted to engineering tasks, the rapid mapping application leads to research problems like: how to combine information from different images of the same scene? At different times? How to exploit different sources of information like old maps and images? How to integrate object description,

<sup>5</sup><http://www.cnes.fr>

<sup>6</sup><http://sertit.u-strasbg.fr/>

<sup>7</sup><http://orfeo-toolbox.org/otb/>



semantics and reasoning in interpreters tools like GIS?

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