IN PARTNERSHIP WITH:
Institut national des sciences appliquées de Lyon

Activity Report 2013

Project-Team SOCRATE

Software and Cognitive radio for telecommunications

IN COLLABORATION WITH: Centre of Innovation in Telecommunications and Integration of services

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Networks and Telecommunications

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Project-Team SOCRATE

Keywords: Wireless Networks, Radio Interface, Software Radio, Cognitive Radio Networks, Embedded Systems, Network Protocols

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2. Overall Objectives

2.1. Introduction

The success of radio networking relies on a small set of rules: *i)* protocols are completely defined beforehand, *ii)* resource allocation policies are mainly designed in a static manner and *iii)* access network architectures are planned and controlled. Such a model obviously lacks adaptability and also suffers from a suboptimal behavior and performance.

Because of the growing demand of radio resources, several heterogeneous standards and technologies have been introduced by the standard organizations or industry by different workgroups within the IEEE (802 family), ETSI (GSM), 3GPP (3G, 4G) or the Internet Society (IETF standards) leading to the almost saturated usage of several frequency bands (see Fig. 1).

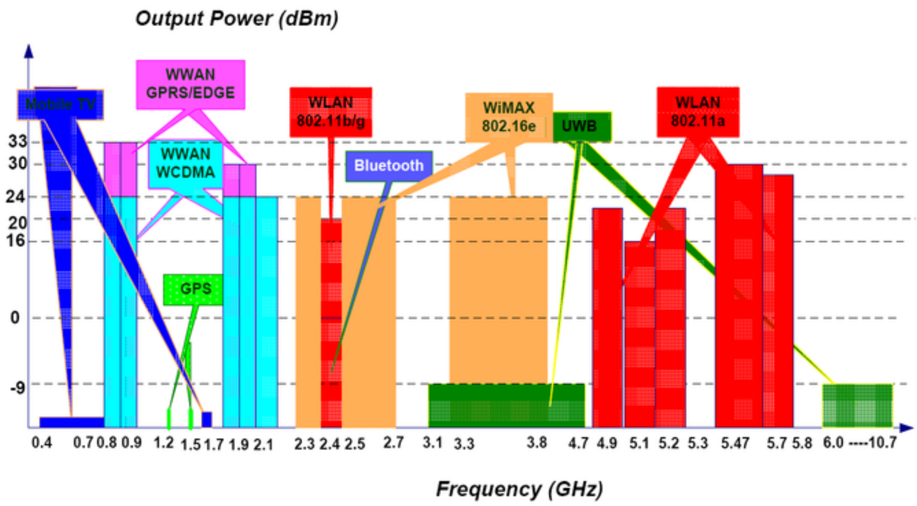

Figure 1. The most recent standards for wireless communications are developed in the UHF and VHF bands. These bands are mostly saturated (source: WPAN/WLAN/WWAN Multi-Radio Coexistence, IEEE 802 Plenary, Atlanta, USA, Nov.2007)

These two facts, obsolescence of current radio networking rules on one hand, and saturation of the radio frequency band on the other hand, are the main premises for the advent of a new era of radio networking which will be characterized by self-adaptive mechanisms. These mechanisms will rely on software radio technologies, distributed algorithms, end-to-end dynamic routing protocols and therefore require a cross-layer vision of “cognitive wireless networking”: *Getting to the meet of Cognition and Cooperation, beyond the inherent communication aspects: cognition is more than cognitive radio and cooperation is not just relaying. Cognition and cooperation have truly the potential to break new ground for mobile communication systems and to offer new business models.* [43]

From a social perspective, pervasive communications and ambient networking are becoming part of more and more facets of our daily life. Probably the most popular usage is mobile Internet access, which is made possible by numerous access technologies, e.g. cellular mobile networks, WiFi, Bluetooth, etc. The access technology itself is becoming *transparent for the end user*, who does not care about how to access the network but is only interested in the services available and in the quality of this service.

Beyond simple Internet access, many other applications and services are built on the basis of pervasive connectivity, for which the communication is just a mean, and not a finality. Thus, the wireless link is expected to even be *invisible to the end user* and constitutes the first element of the future Internet of things [42], to develop a complete twin virtual world fully connected to the real one.

The way radio technologies have been developed until now is far from offering a real wireless convergence [35]. The current development of the wireless industry is surely slowed down by the lack of radio resources and the lack of systems flexibility.

This technological bottleneck will be only overtaken if three complementary problems are solved: *terminal flexibility, agile radio resource management* and *autonomous networking*. These three objectives are subsumed by the concept of *Software Radio*, a term coined by J. Mitola in his seminal work during the early 90's [39], [40]. While implementing everything in software nodes is still an utopia, many architectures now hitting the market include some degree of programmability; this is called Software-Defined Radio. The word “defined” has been added to distinguish from the ideal software radio. A software *defined* radio is a software radio which is defined for a given frequency range and a maximal bandwidth.

In parallel, the development of new standards is threatened by the radio spectrum scarcity. As illustrated in Fig. 1, the increasing number of standards alreay causes partial saturation of the UHF band, and will probably lead to its full saturation in the long run. However, this saturation is only “virtual” because all equipments are fortunately not emitting all the time [35]. A good illustration is the so-called “white spaces”, i.e. frequency bands that are liberated by analog television disappearing and can be re-used for other purposes, different rules are set up in different countries. In this example, a solution for increasing the real capacity of the band originates from *self-adaptive behavior*. In this case, flexible terminals will have to implement agile algorithms to share the radio spectrum and to avoid interference. In this context, cooperative approaches are even more promising than simple resource sharing algorithms.

With Software-Defined Radio technology, terminal flexibility is at hand, many questions arise that are related to the software layer of a software radio machine: how will this kind of platform be programmed? How can we write programs which are portable from one terminal to another? Autonomous networking will only be reached after a deep understanding of network information theory, given that there will be many ways for transmitting data from one point to another, which way is the most efficient in terms of throughput? power consumption? etc... Last but not least, agile Radio Resource sharing is addressed by studying MIMO and multi-standard radio front-end. This new technology is offering a wide range of research problems. These three thematics: software programming of a software radio machine, distributed algorithms for radio resource management and multi-standard radio front-end constitute the research directions of Socrate.

2.2. Technological State of the Art

A Software-Defined Radio (SDR) system is a radio communication system in which computations that in the past were typically implemented in hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented as software programs [39], [36].

2.2.1. SDR technology

The different components of a radio system are illustrated in Fig. 2. Of course, all of the digital components may not be programmable, but the bigger the programmable part (DSP/FPGA part on Fig. 2), the more *software* the radio. Dedicated IPs. In this context, IP stand for *Intellectual Properties, this term is widely used to designated dedicated special-purpose circuit blocks implemented in various technologies: Asic,* FPGA*,* DSP*, etc.* are needed, for these IP it is more suitable to use the term *configurable* than programmable. In a typical

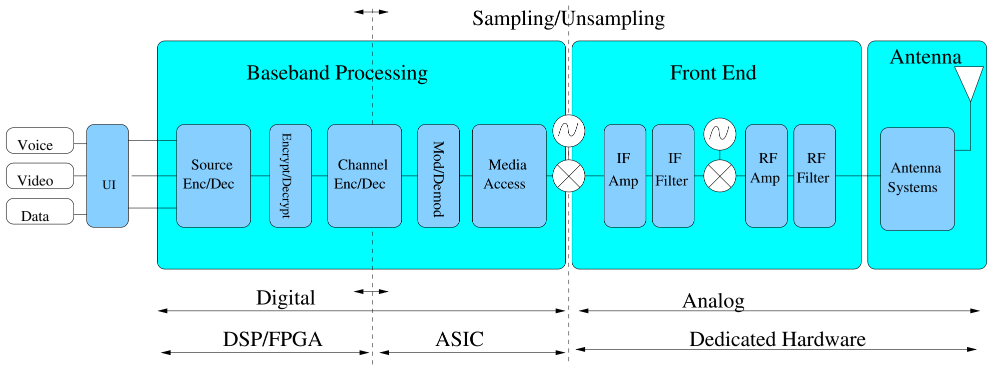

Figure 2. Radio Block Diagram, highlighting separation between digital and analog parts, as well as programmable, configurable and fixed hardware parts.

SDR, the analog part is limited to a frequency translation down to an intermediate band which is sampled and all the signal processing is done digitally.

2.2.2. SDR forum classification

To encourage a common meaning for the term "SDR" the SDR Forum (recently renamed *Wireless Innovation Forum* (http://www.wirelessinnovation.org) proposes to distinguish five tiers:

- *Tier 0 – Hardware Radio:* The radio parameters cannot be changed, radio is implemented only with hardware components.
- *Tier 1 – Software Controlled Radio:* A radio where only the control functions are implemented in software, baseband processing is still performed in hardware, the radio is able to switch between different hardware.
- *Tier 2 – Software-Defined Radio:* The most popularly understood definition of SDR: the radio includes software control of modulation, bandwidth, frequency range and frequency bands. Conversion to digital domain still occurs after frequency conversion. It is currently implemented using a wide range of technologies: Asics, FPGAs, DSPs, etc.
- *Tier 3 – Ideal Software Radio:* Digital conversion occurs directly at the antenna, programmability extends to the whole system.
- *Tier 4 – Ultimate Software Radio:* Same reconfigurability capabilities as in Tier 3, but with a switching between two configurations in less than one millisecond.

The main restriction to build an ideal software radio is sampling rate: sampling at a high rate is not an easy task. Following the Shannon-Nyquist theorem, sampling the RF signal at a rate greater than twice the frequency of the signal is sufficient to reconstruct the signal. Sampling can be done at lower rate (decimation), but errors can be introduced (aliasing) that can be corrected by filtering (dirty radio concept). Building an SDR terminal implies a trade-of between sampling frequency and terminal complexity. For instance, sampling at 4.9 GHz would require a 12-bit resolution ADC with at least 10GHz sample rate which is today not available with reasonable power consumption (several hundreds Watt).

2.2.3. Cognitive Radio

SDR technology enables *over the air programming* (Otap) which consists in describing methods for distributing new software updates through the radio interface. However, as SDR architectures are heterogeneous, a standard distribution method has not emerged yet.

Cognitive Radio is a wireless communication system that can sense the air, and decide to configure itself in a given mode, following a local or distributed decision algorithm. Although Tier 3 SDR would be an ideal platform for cognitive radio implementation, cognitive radios do not have to be SDR.

Cognitive Radio is currently a very hot research topic as show the dozens of sessions in research conferences dedicated to it. In 2009, the American National Science Foundation (NSF) held a workshop on "Future Directions in Cognitive Radio Network Research" [41]. The purpose of the workshop was to explore how the transition from cognitive radios to cognitive radio *networks* can be made. The resulting report indicated the following:

- Emerging cognitive radio technology has been identified as a high impact disruptive technology innovation, that could provide solutions to the *radio traffic jam* problem and provide a path to scaling wireless systems for the next 25 years.
- Significant new research is required to address the many technical challenges of cognitive radio networking. These include dynamic spectrum allocation methods, spectrum sensing, cooperative communications, incentive mechanisms, cognitive network architecture and protocol design, cognitive network security, cognitive system adaptation algorithms and emergent system behavior.

The report also mentioned the lack of cognitive radio testbeds and urged *"The development of a set of cognitive networking test-beds that can be used to evaluate cognitive networks at various stages of their development"*, which, in some sense strengthens the creation of the Socrate team and its implication in the FIT project [37].

2.3. Scientific challenges

Having a clear idea of relevant research areas in SDR is not easy because many parameters are not related to economical cost. For instance, military research has made its own development of SDR for its particular needs: US military SDR follows the SCA communication architecture [38] but this is usually not considered as a realistic choice for a commercial SDR handset. The targeted frequency band has a huge impact as sampling at high rates is very expensive, and trade-offs between flexibility, complexity, cost and power consumption have a big influence on the relative importance of the hot research topics.

Here are the relevant research domains where efforts are needed to help the deployment of SDR:

- *Antennas:* This is a key issue for reducing interference, increasing capacity and reusing frequency. Hot topics such as wake-up radio or multi protocol parallel receiver are directly impacted by research on Antennas. Socrate has research work going on in this area.
- *Analog to Digital Converters:* Designing low-power high frequency ADC is still a hot topic rather studied by micro-electronics laboratories (Lip6 for instance in France).
- *Architecture of SDR systems:* The ideal technology for embedded SDR still has to be defined. Hardware prototypes are built using FPGAs, Asics and DSPs, but the real challenge is to handle a Hardware/Software design which includes radio and antennas parts.
- *Middleware for SDR systems:* How to manage, reconfigure, update and debug SDR systems is still an open question which is currently studied for each SDR platform prototype. Having a common programming interface for SDR systems in one research direction of Socrate.
- *Distributed signal processing:* Cognitive, smart or adaptive radios will need complex decision algorithms which, most of the time will need to be solved in a distributed manner. Socrate has clearly a strong research effort in that direction. Distributed information theory is also a hot research topic that Socrate wishes to study.

2.4. Highlights of the Year

2.4.1. FIT/CortexLab first on-line demonstration

FIT(Future Internet of Things) is a french Equipex (Équipement d'excellence) which aims to develop an experimental facility, a federated and competitive infrastructure with international visibility and a broad panel of customers. FIT will be composed of four main parts: a Network Operations Center (NOC), a set of Embedded Communicating Object (ECO) testbeds, a set of wireless OneLab testbeds, and a cognitive radio testbed (CorteXlab) deployed by the Socrate team in the Citi lab. In 2013 the construction of the room was finished see Figure 3. SDR nodes have been bought after setting two call for tenders, 42 industrial PCs (Aplus Nuvo-3000E/P), 22 NI radio boards (USRP) and 18 Nutaq boards (PicoSDR, 2x2 and 4X4) will now be installed in the room. A first version of the software infrastructure has been deployed and small experimentations (involving 2 USRP nodes) have been made from various places (from Brasil, United States, Villeurbanne).

Figure 3. Photo of the FIT/CortexLab experimentation room before adding SDR *nodes to the ceiling*

2.4.2. Socrate at Paris-Tours cycling race

France Télévisions, Euro Media France and Amaury Sport Organisation have partnered again to deliver the Paris-Tours cycling race, using a wireless sensor solution to geolocate riders in realtime. These sensors where deployed in a collaboration with HikoB (Inria/Citi-lab start-up) and Socrate who provided the distributed cyclocalisation algorithm

In what was claimed as a world first, Euro Media France equipped the 200 competitors with special HikoB sensors at the beginning of the Paris-Tours race in Authon-de-Perche. This enabled to pinpoint the exact position of every rider and feed the information in real-time.

This collaboration is now held in a FUI project called Smacs. Next demostration should occur in the tour de France in 2014 targeting full deployment at the Olympic Games of 2016 in Rio de Janeiro.

3. Research Program

3.1. Research Axes

In order to keep young researchers in an environment close to their background, we have structured the team along the three research axes related to the three main scientific domains spanned by Socrate. However, we insist that a *major objective* of the Socrate team is to *motivate the collaborative research between these axes*, this point is specifically detailed in section 3.5. The first one is entitled “Flexible Radio Front-End” and will study new radio front-end research challenges brought up by the arrival of MIMO technologies, and reconfigurable front-ends. The second one, entitled “Agile Radio Resource Sharing”, will study how to couple the self-adaptive and distributed signal processing algorithms to cope with the multi-scale dynamics found in cognitive radio systems. The last research axis, entitled “Software Radio Programming Models” is dedicated to embedded software issues related to programming the physical protocols layer on these software radio machines. Figure 4 illustrates the three regions of a transceiver corresponding to the three Socrate axes.

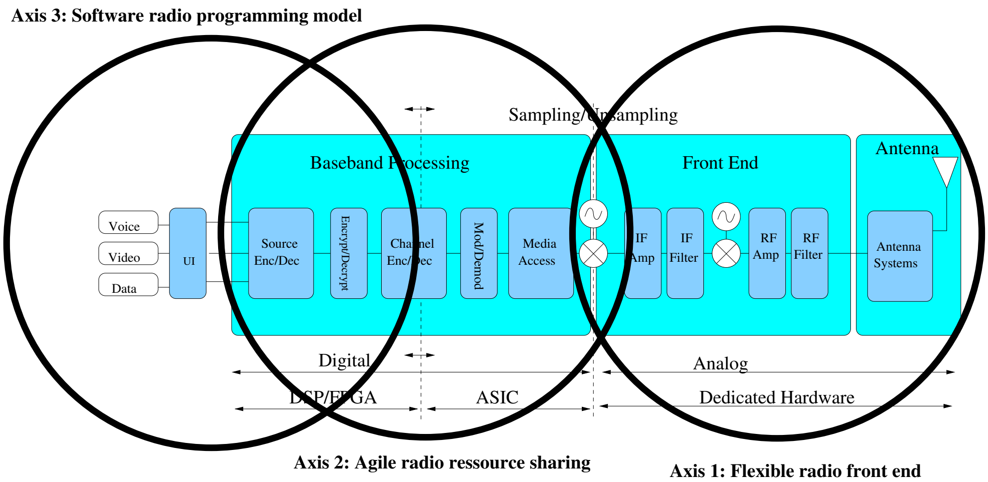

Figure 4. Center of interest for each of the three Socrate research axes with respect to a generic software radio terminal.

3.2. Flexible Radio Front-End

Participants: Guillaume Villemaud, Florin Hutu.

This axis mainly deals with the radio front-end of software radio terminals (right of Fig 4). In order to ensure a high flexibility in a global wireless network, each node is expected to offer as many degrees of freedom as possible. For instance, the choice of the most appropriate communication resource (frequency channel, spreading code, time slot,...), the interface standard or the type of antenna are possible degrees of freedom. The *multi-** paradigm denotes a highly flexible terminal composed of several antennas providing MIMO features to enhance the radio link quality, which is able to deal with several radio standards to offer interoperability and efficient relaying, and can provide multi-channel capability to optimize spectral reuse. On the other hand, increasing degrees of freedom can also increase the global energy consumption, therefore for energy-limited terminals a different approach has to be defined.

In this research axis, we expect to demonstrate optimization of flexible radio front-end by fine grain simulations, and also by the design of home made prototypes. Of course, studying all the components deeply would not be possible given the size of the team, we are currently not working in new technologies for DAC/ADC and power amplifiers which are currently studied by hardware oriented teams. The purpose of this axis is to build system level simulation taking into account the state of the art of each key component.

3.3. Agile Radio Resource Sharing

Participants: Jean-Marie Gorce, Claire Goursaud, Nikolai Lebedev.

The second research axis is dealing with the resource sharing problem between uncoordinated nodes but using the same (wide) frequency band. The agility represents the fact that the nodes may adapt their transmission protocol to the actual radio environment. Two features are fundamental to make the nodes agile : the first one is related to the signal processing capabilites of the software radio devices (middle circle in Fig 4), including modulation, coding, interference cancelling, sensing... The set of all available processing capabilites offers the degrees of freedom of the system. Note how this aspect relies on the two other research axes: radio front-end and radio programming.

But having processing capabilities is not enough for agility. The second feature for agility is the decision process, i.e. how a node can select its transmission mode. This decision process is complex because the appropriateness of a decision depends on the decisions taken by other nodes sharing the same radio environment. This problem needs distributed algorithms, which ensure stable and efficient solutions for a fair coexistence.

Beyond coexistence, the last decade saw a tremendous interest in cooperative techniques that let the nodes do more than coexisting. Of course, cooperation techniques at the networking or MAC layers for nodes implementing the same radio standard are well-known, especially for mobile ad-hoc networks, but cooperative techniques for SDR nodes at the PHY layer are still really challenging. The corresponding paradigm is the one of opportunistic cooperation, let us say *on-the-fly*, further implemented in a distributed manner.

We propose to structure our research into three directions. The two first directions are related to algorithmic developments, respectively for radio resource sharing and for cooperative techniques. The third direction takes another point of view and aims at evaluating theoretical bounds for different network scenarios using Network Information Theory.

3.4. Software Radio Programming Model

Participants: Tanguy Risset, Kevin Marquet, Guillaume Salagnac.

Finally the third research axis is concerned with software aspect of the software radio terminal (left of Fig 4). We have currently two actions in this axis, the first one concerns the programming issues in software defined radio devices, the second one focusses on low power devices: how can they be adapted to integrate some reconfigurability.

The expected contributions of Socrate in this research axis are :

- The design and implementation of a “middleware for SDR”, probably based on a Virtual Machine.
- Prototype implementations of novel software radio systems, using chips from Leti and/or Lyrtech software radio boards [1].
- Development of a *smart node*: a low-power Software-Defined Radio node adapted to WSN applications.
- Methodology clues and programming tools to program all these prototypes.

3.5. Inter-Axes collaboration

[1] Lyrtech (http://www.lyrtech.com) designs and sells radio card receivers with multiple antennas offering the possibility to implement a complete communication stack

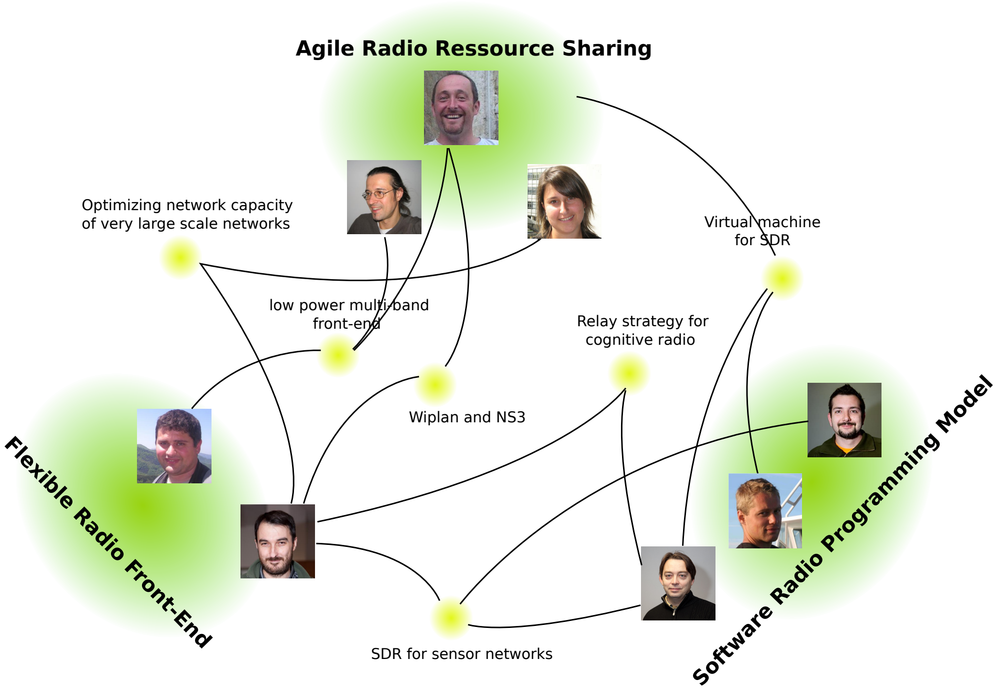

Figure 5. Inter-Axis Collaboration in Socrate: we expect innovative results to come from this pluri-disciplinary research

As mentioned earlier, innovative results will come from collaborations between these three axes. To highlight the fact that this team structure does not limit the ability of inter-axes collaborations between Socrate members, we list below the *on-going* research actions that *already* involve actors from two or more axes, this is also represented on Fig 5.

- *Optimizing network capacity of very large scale networks*. 2 Phds started in October/November 2011 with Guillaume Villemaud (axis 1) and Claire Goursaud (axis 2).
- *SDR for sensor networks*. A PhD started in 2012 in collaboration with FT R&D, involving people from axis 3 (Guillaume Salagnac, Tanguy Risset) and axis 1 (Guillaume Villemaud).
- *Wiplan and NS3*. The MobiSim ADT and iPlan projects involve Guillaume Villemaud (axis 1) and Jean-Marie Gorce (axis 2).
- *Resource allocation and architecture of low power multi-band front-end*. The EconHome project involves people from axis 2 (Jean-Marie Gorce,Nikolai Lebedev) and axis 1 (Florin Hutu).
- *Virtual machine for SDR*. In collaboration with CEA, a PhD started in October 2011, involving people from axis 3 (Tanguy Risset, Kevin Marquet) and Leti's engineers closer to axis 2.
- *Relay strategy for cognitive radio*. Guillaume Villemaud and Tanguy Risset were together advisers of Cedric Levy-Bencheton PhD Thesis (defense last June).

Finally, we insist on the fact that the *FIT project* will involve each member of Socrate and will provide many more opportunities to perform cross layer SDR experimentations. FIT is already federating all members of the Socrate team.

4. Application Domains

4.1. Example of SDR applications

The SDR concept is not new and many research teams have been working on its implementation and use in various contexts, however two elements are in favor of Socrate's orientation towards this technology:

1. The mobile SDR technology is becoming mature. Up to now, Software-Defined Radio terminals were too expensive and power consuming for mobile terminals, this should change soon. For instance, CEA's Magali platform has demonstrated part of LTE-Advanced standard recently. It is important for applied researchers to be ready when a new technology rises up, opening to many new software issues.
2. Rhône-Alpes is a strategic place for this emerging technology with important actors such as ST-Microelectronics, CEA, Minalogic and many smaller actors in informatics for telecommunication and embedded systems.

SDR technologies enable the following scenarios:

- *Transparent radio adaptation:* Depending on the available wireless protocols in the air (e.g. Wifi versus UMTS), a terminal may choose to communicate on the cheapest, or the fastest channel.
- *Radio resource allocation:* In order to minimize expensive manual cell planning and achieve "tighter" frequency reuse patterns, resulting in improved system spectral efficiency, dynamic radio resource management is a promising application of SDR.
- *White space:* By sensing the air, a terminal is able to communicate using a particular frequency which is not used even if it is reserved for another kind of application.
- *Cooperation:* Using the neighboring terminals, a user can reduce power consumption by using relay communication with the base station.
- *Saturated bands:* A fixed wireless object, e.g. a gas meter sending regular data through the air, might check if the frequency it uses is saturated and choose, alone or in a distributed manner with other gas meters, to use another frequency (or even protocol) to communicate.

- *Radars:* With numerical communications, passive radar technology is changing, these radars will have to be updated regularly to be able to listen to new communication standards.
- *Internet of things:* With the predicted massive arrival of wireless object, some reconfigurability will be needed even on the simplest smart object as mentionned above for facing the band saturation problem or simply communicating in a new environment.

4.2. Public wireless access networks

The commercial markets for wireless technologies are the largest markets for SDR and cognitive radio. These markets include i) the cellular market (4G, LTE), ii) the Wireless Local Area Network market (WLAN, e.g. Wifi), and iii) the Broadband Wireless Access market (e.g. WiMax). The key objective here is to improve spectrum efficiency and availability, and to enable cognitive radio and SDR to support multimedia and multi-radio initiatives.

The mobile radio access network referred to as 4G (4th generation) is expected to provide a wireless access of 100 Mbps in extended mobility and up to 1Gbps in reduced mobility as defined by the group IMT-Advanced of the ITU-R(adiocommunication) section. On the road towards the 4G, IMT-2000 standards evolutions are driven by the work of the WiMAX forum (IEEE 802.16e) on the one hand and by those of the LTE (Long Term Evolution) group of the 3GPP on the other hand. Both groups announced some targeted evolutions that could comply with the 4G requirements, namely the Gigabit Wimax (802.16m) and the LTE-Advanced proposal from the 3GPP.

In both technologies, the scarcity of the radio spectrum is taken care of by the use of MIMO and OFDMA technologies, combining the dynamic spatial and frequency multiple access. However, a better spectral efficiency will be achieved if the radio spectrum can be shared dynamically between primary and secondary networks, and if the terminals are reconfigurable in real-time. Socrate is active in this domain because of its past activity in Swing and its links to the telecommunication teaching department of Insa. The developement of the FIT plateform [37] is a strong effort in this area.

4.3. Military SDR and Public Safety

Military applications have developed specific solutions for SDR. In France, Thales is a major actor (e.g. project Essor defining inter-operability between European military radio) and abroad the Join Tactical Radio System, and Darpa focus on Mobile Ad-hoc Networks (MANETs) have brought important deliverables, like the Software Communications Architecture (SCA) for instance [38].

Recent natural disasters have brought considerable attention to the need of enhanced public safety communication abroad [36]. Socrate in not currently implied in any military or public safety research programs but is aware of the potential importance this domain may take in Europe in a near future.

4.4. Ambient Intelligence: WSN and IoT

Sensor networks have been investigated and deployed for decades already; their wireless extension, however, has witnessed a tremendous growth in recent years. This is mainly attributed to the development of wireless sensor networks (WSNs): a large number of sensor nodes, reliably operating under energy constraints. It is anticipated that within a few years, sensors will be deployed in a variety of scenarios, ranging from environmental monitoring to health care, from the public to the private sector. Prior to large-scale deployment, however, many problems have to be solved, such as the extraction of application scenarios, design of suitable software and hardware architectures, development of communication and organization protocols, validation and first steps of prototyping, etc. The Citi laboratory has a long experience in WSN which led recently to the creation of a start-up company, led by two former Citi members: HIKOB(http://openlab.hikob.com).

The Internet of Things (IoT) paradigm is defined as a very large set of systems interconnected to provide a virtual twin world interacting with the real world. In our work we will mostly focus on wireless systems since the wireless link is the single media able to provide a full mobility and ubiquitous access. Wireless IoT is not a reality yet but will probably result from the convergence between mobile radio access networks and wireless sensor networks. If radio access networks are able to connect almost all humans, they would fail to connect a potential of several billions of objects. Nevertheless, the mutation of cellular systems toward more adaptive and autonomous systems is ongoing. This is why Socrate develops a strong activity in this applicative area, with its major industrial partners: Orange Labs and Alcatel-Lucent Bell labs.

For instance, the definition of a *smart node* intermediate between a WSN and a complex SDR terminal is one of the research directions followed in Socrate, explicitly stated in the ADT Snow project. Other important contributions are made in the collaboration with SigFox and Euromedia and in the EconHome project.

4.5. Body Area Networks

Body Area Network is a relatively new paradigm which aims at promoting the development or wireless systems in, on and around the human body. Wireless Body Area Networks (BAN) is now a well known acronym which encompasses scenarios in which several sensors and actuators are located on or inside the human body to sense different data, e.g. physiological information, and transfer them wirelessly towards a remote coordination unit which processes, forwards, takes decisions, alerts, records, etc. The use of BAN spans a wide area, from medical and health care to sport through leisure applications, which definitely makes the definition of a standard air interface and protocol highly challenging. Since it is expected that such devices and networks would have a growing place in the society and become more stringent in terms of quality of service, coexistence issues will be critical. Indeed, the radio resource is known to be scarce. The recent regulation difficulties of UWB systems as well as the growing interest for opportunistic radios show that any new system has to make an efficient use of the spectrum. This also applies to short range personal and body area network systems which are subject to huge market penetrations.

Socrate was involved in the Banet ANR project (2008-2010), in which we contributed to the development of a complete PHY/MAC standard in cooperation with Orange Labs and CEA Leti, who participated in the standardization group 802.15.6. Recently, Inria has been added as a partner in the FET flagship entitled *Guardian Angels* (http://www.fet-f.eu/), an important european initiative to develop the BANs of the future. Socrate is currently involved in the Cormoran ANR project (2012-2015), in which we contribute to the definition of a MAC standard dedicated to localization based on UWB PHY layer.

We consider that BANs will probably play an important role in the future of Internet as the multiple objects connected on the body could also be connected to the Internet by the mobile phone owned by each human. Therefore the BAN success really depends on the convergence of WSN and radio access networks, which makes it a very interesting applicative framework for the Socrate team.

5. Software and Platforms

5.1. WSnet

Socrate is an active contributor to WSnet (http://wsnet.gforge.inria.fr/) a multi-hop wireless network discrete event simulator. WSnet was created in the ARES team and it is now supported by the D-NET team of Inria Rhône-Alpes.

5.2. Wiplan

Wiplan is a software including an Indoor propagation engine and a wireless LAN optimization suite, which has been registered by INSA-Lyon. The heart of this software is the propagation simulation core relying on an original method, MR-FDPF (multi-resolution frequency domain ParFlow). The discrete ParFlow equations are translated in the Fourier domain providing a large linear system, solved in two steps taking advantage of a multi- resolution approach. The first step computes a cell-based tree structure referred to as the pyramid. In the second phase, a radiating source is simulated, taking advantage of the pre-processed pyramidal structure. Using of a full-space discrete simulator instead of classical ray-tracing techniques is a challenge due to the inherent high computation requests. However, we have shown that the use of a multi-resolution approach allows the main computation load to be restricted to a pre-processing phase. Extensive works have been done to make predictions more realistic. The network planning and optimization suite is based on a multi-criteria model relying on a Tabu solver. The development of the wiplan software is a part of the european project iPlan (IAPP-FP7 project).

5.3. FloPoCo

The purpose of the open-source FloPoCo project is to explore the many ways in which the flexibility of the FPGA target can be exploited in the arithmetic realm. FloPoCo is a generator of operators written in C++ and outputting synthesizable VHDL automatically pipelined to an arbitrary frequency. In 2013, a CORDIC-based arctangent was written in Socrate.

Among the known users of FloPoCo are U. Bristol,U. Cape Town, U.T. Cluj-Napoca, Imperial College, U. Essex, U. Madrid, U. P. Milano, T.U. Muenchen, T. U. Kaiserslautern, U. Paderborn, CalTech, U. Pernambuco, U. Perpignan, U. Tohoku, U. Tokyo, Virginia Tech U. and several companies.

Web page: http://flopoco.gforge.inria.fr/

6. New Results

6.1. Flexible Radio Front-End

The contributions on hardware design are twofold. First, the development of a Full-Duplex architecture for OFDM systems. Second, a proposal of a Wake-Up scheme for home networking with reduced power consumption.

6.1.1. Full-Duplex systems

Zhan et al. [23] focused on the study of active analog self-interference cancellation (AASIC) techniques in full-duplex OFDM systems. This original approach aims at proposing a cancellation technique at RF level for wideband systems. A theoretical study confronted to simulations was proposed with a particular emphasis on the channel estimation of the interfering signal. This study was completed with an analysis on the phase noise and the thermal noise impact.

6.1.2. Wake-Up Architectures

Khoumeri et al. [28] proposed radio architectures for allowing energy savings by letting devices to switch off part of the transmission components when they are not in use. Based on classical WiFi systems, the proposed architecture offers the ability to use a conventional emitter, using only a particular subcarrier fingerprint to identify the node to wake-up, hence avoiding a high level of false wake-up.

6.2. Agile Radio Resource Sharing

The contributions of the axis in *agile radio resource sharing* can be gathered in three groups: (a) green communications; (b) performance analysis; and (c) scheduling and power allocation techniques.

6.2.1. Green Communications

The main contributions in the subject of green communications focus on the problem of increasing the energy efficiency of Orthogonal Frequency-Division Multiple Access (OFDMA) wireless networks. In particular, Tsilimantos et al. in [21] and Hasan et al. in [15] studied different techniques to strategically switch off some of the base stations in cellular systems while guaranteeing a given quality of service (QoS). In [21], the authors use methods from stochastic geometry to determine the number of active cells that can be switched off while the outage probability, or equivalently the signal to interference plus noise ratio (SINR), remains the same. In [15], this problem is studied from a decentralized point of view using methods from coalitional game theory.

6.2.2. Performance Analysis

The contributions in performance analysis are mainly oriented to the field of body area networks (BANs), [17] indoor adaptive OFDM wireless networks and relay channels.

In [17], Lauzier et al. presented the results of a measurement campaign whose primary objective was to characterize the complete mesh of a BAN and analyze the quality of every radio link between the different nodes. In [18], [19], the Multi-Resolution Frequency Domain ParFlow (MRFDPF) model is used to calculate the bit error rate (BER) and study the feasibility of adaptive modulation in OFDM systems.

In the context of relay channels, Ferrand et al. [32] studied the asymptotic *coding gain* of the packet error rate of relay channels in which the radio links are subject to both fading and log-normal shadowing effects simultaneously.

6.2.3. Scheduling and Power Allocation Techniques

Power allocation techniques and scheduling were studied by Ferrand et al. [33] and Wang et al. [9]. More specifically, advances in the study of the achievable rate region of relay channels in the case of global power constraints were reported in [33]. Cooperative scheduling techniques in the context of BAN were proposed in [9] to reduce inter-BAN interference using tools from game theory.

6.3. Software Radio Programming Model

Software defined radio (SDR) technology has evolved rapidly and is now reaching market maturity. Still, a lot of issues have yet to be studied. Mickaël Dardaillon, Kevin Marquet, Tanguy Risset and others highlighted the constraints imposed by recent radio protocols and presented current architectures, solutions, and challenges for programming SDR [31].

6.3.1. Dataflow programming

To enable dynamic adaptation of computation intensive multimedia dataflow applications, Lionel Morel, Kevin Marquet and others have studied language extensions, together with the corresponding run-time support. They show that this approach can be used to monitor and control throughput [20] and offer quality of service [29], with a low impact on the overall performance.

6.3.2. Energy-efficient Localization

Guillaume Salagnac and others address the tradeoff between energy consumption and localization performance in a mobile sensor network application [7]. The focus is on augmenting GPS location with more energy-efficient location sensors to bound position estimate uncertainty while GPS is off. Such combined strategies can cut node energy consumption by one third while still meeting application-specific positioning criteria.

6.3.3. Swap Fairness for Thrashing Mitigation

In the context of shared hosting or virtualization, where multiple users run uncoordinated and selfish workloads, François Goichon, Guillaume Salagnac and Stéphane Frénot introduced an accounting layer that forces swap fairness among processes competing for main memory [13]. It ensures that a process cannot monopolize the swap subsystem by delaying the swap operations of abusive processes, reducing the number of system-wide page faults while maximizing memory utilization.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

Socrate has strong collaborations with Orange Labs (point to point collaboration) and Alcatel Lucent through the Inria-ALU common lab and the Green Touch initiative. Socrate also works in collaboration with Siradel, a french worldwide company working on wireless system simulations, Sigfox a young french compagny deploying the first cellular network operator dedicated to M2M and IoT, and HIKOB a start-up originated from the Citi laboratory providing sensor networks solutions. A bilateral cooperation supports the PhD of Laurent Maviel, and Siradel is a member of the Ecoscell ANR project in which Socrate is involved.

Socrate started in September 2011 a strong bilateral cooperation with the Euromedia group about Body Area Networks in which Tanguy Risset, Guillaume Villemaud and Jean-Marie Gorce are involved and the project supports the thesis of Matthieu Lauzier.

A collaboration started in 2013 with Bosch on arithmetic for automotive embedded platforms. It involves Florent de Dinechin and members of the AriC team.

Florent de Dinechin received a donation of two ZedBoard platforms from the Xilinx University Program.

8. Partnerships and Cooperations

8.1. National Actions

8.1.1. Equipex FIT- Future Internet of Things (2011-..., 1.064 k€)

The FIT projet is a national equipex (*equipement d'excellence*), headed by the Lip6 laboratory. As a member of Inria, Socrate is in charge of the development of an Experimental Cognitive Radio platform that should be used as test-bed for SDR terminals and cognitive radio experiments. This platform will be operational in 2013 for a duration of 7 years. To give a quick view, the user will have a way to configure and program through Internet several SDR platforms (MIMO, SISO, and baseband processing nodes).

8.1.2. ANR - Cormoran - "Cooperative and Mobile Wireless Body Area Networks for Group Navigation" (2012-2015, 150 keuros)

The Cormoran project targets to figure out innovative communication functionalities and radiolocation algorithms that could benefit from inter/intra-BAN cooperation. More precisely, the idea is to enable accurate nodes/body location, as well as Quality of Service management and communications reliability (from the protocol point of view), while coping with inter-BAN coexistence, low power constraints and complying with the IEEE 802.15.6 standard. The proposed solutions will be evaluated in realistic applicative scenarios, hence necessitating the development of adapted simulation tools and real-life experiments based on hardware platforms. For this sake, Cormoran will follow an original approach, mixing theoretical work (e.g. modelling activities, algorithms and cross-layer PHY/MAC/NWK design) with more practical aspects (e.g. channel and antennas measurement campaigns, algorithms interfacing with real platforms, demonstrations).

8.1.3. ANR - Idefix - "Intelligent DEsign of Future mobile Internet for enhanced eXperience" (2013-2016, 55 keuros)

The aim of IDEFIX project is to radically revisit the way technologies are evaluated and benchmarked by proposing novel performance evaluation tools, based on the latest developments in queuing theory, that are able to tackle the complexity of traffic profiles in future mobile networks. These tools are to be carefully adapted to the different technologies discussed within 3GPP, and then used to benchmark these technologies and perform pertinent choices among them. Furthermore, IDEFIX will not adopt a passive behavior limited to performance evaluation of technologies. It will, on the contrary, propose service and network control mechanisms that enforce Quality of Service (QoS) and Quality of Experience (QoE) of users of different services. For this aim, this project puts together experts on performance evaluation tools and traffic engineering, whose world class research results are recognized in the telecommunication community. This expertise is complemented by another internationally recognized expertise on service and network control mechanisms and, for the first time in this field, by an expertise on network economy and decision-making in strategic investments. These academic and industrial experts will help two top actors in the world telecommunications industry, Alcatel Lucent and Orange, in their perpetual quest for producing the most efficient technologies and deploying networks with the best QoS.

8.1.4. ADR Green - "Green Networking" (2013-2015, 70 keuros)

This action is a part of the common lab of Inria and Alcatel Lucent Bell Labs. This action groups Urbanet and Socrate teams of Inria with the Bell Labs Vx team and adresses different aspects of Green Networking. Socrate works on the 'virtual cell concept' which deals with mobile centric cells in dense small cells networks.

8.1.5. Greentouch GTT project- "Interference Alignment" (2013-2014, 63 keuros)

The Greentouch GTT (Green transmission technology) project aims at proposiing new energy efficient transmission techniques, and focus specifically on the Energy efficiency - spectral efficiency (EE-SE) trade-off. Interference management is a critical issue and socrate aims at designing a dynamic and distributed approach allowing to cancel strong interfers by combining control theory and interference alignment principles.

8.1.6. FUI ECONHOME - "Energy efficient home networking" (2010-2014, 309 keuros)

The project aims at reducing the energy consumption of the home (multimedia) data networks, while maintaining the quality requirements for heterogeneous services and flows, and preserving, or even enhancing the overall system performance. the equipments under concern are residential gateways, set-top-boxes , PLC modules, Wifi extenders, NAS. The user equipment, such as smartphones, tablets or PCs are not concerned. The approach relies on combining both individual equipments IC and system level protocols that have to be eco-designed.

8.1.7. FUI SMACS - "SMart And Connected Sensors" (2013-2016, 267 keuros)

The SMACS projet targets the deployement of an innovating wireless sensor network dedicated to many domains sport, health and digital cities. The projet involves Socrate (Insavalor), HIKOB and wireless broadcasting company Euro Media France. The main goal is to develop a robust technology enabling real-time localization of mobile targets (like cyclists for instance), at a low energy (more generally low cost). The technology will be demonstrated at real cycling races (Tour de France 2013 and 2014). One of the goals is to include localisation information with new radio technology. Another subject of study is distributed wireless consensus algorithms for maintaining a neighborhood knowledge with a low energy budget that scales (more than 200 cycles together)

8.2. International Research Visitors

Jean-Marie Gorce is currently spending a sabbatical year at Vincent Poor's lab in Princeton university. Following the Post-Doc of Samir Perlaza, Socrate is developping a regular collaboration with Princeton on network information theory and distributed radio resource allocation algorithms.

9. Dissemination

9.1. Scientific Animation

- Jean-Marie Gorce is an associate editor of Telecommunications Systems (Springer) and Journal of Wireless communications and Networking (Springer). He was a member of the Program Committees of the conferences : IEEE PIMRC 2013, ICUWB 2013, ICT 2013, VTC 2013 (Las Vegas, USA) IEEE 24th Int. Symposium on Personal, Indoor and Mobile radio Communications (PIMRC2013) 8-11 September 2013, London, UK. IEEE 78th Vehicular Technology Conference (VTC2013-Fall) 2-5 September 2013, Las Vegas, USA. IEEE Int Conference on Ultra-Wideband (ICUWB2013) 15-18 September 2013, Sidney, Australia. 20th International Conference on Telecommunications (ICT 2013) 6-8 Mai 2013, Casablanca, Morocco.
- Florent de Dinechin is an associate editor of the journal *IEEE Transactions on Computers*. He was a member of the Program Committees of the conferences CompAs (Grenoble, Januar 2013), Applied Reconfigurable Computing (Los Angeles, March 2013), Highly Efficient Accelerators and Reconfigurable Technologies (Edimburgh, June 2013), Field-Programmable Logic (Porto, September 2013), Field-Programmable Technology (Kyoto, December 2013), ReConfig 2013 (Cancun, December 2013).
- Tanguy Risset is in the Program Comittee of conferences IEEE SIES 2013, ISVLSI 2013.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Tanguy Risset and Jean-Marie Gorce are professors in the Telecommunications department of Insa Lyon.

Florent de Dinechin is professor in the Computer Science department of Insa Lyon.

Claire Goursaud is associate professor in the Telecommunications department of Insa Lyon.

Guillaume Salagnac and Kevin Marquet are associate professors in the Computer Science department of Insa Lyon.

Guillaume Villemaud and Florin Hutu are associate professors in the Electrical Engineering department of Insa Lyon.

Nikolai Lebedev is associate professor in the engineering school in Chemistry, Physics and Electronics, Lyon.

Tanguy Risset has been the vice-head of the Telecommunications department of Insa Lyon until september 2012.

Tanguy Risset is the responsible for the Networking program of the Master Mastria from University of Lyon.

Jean-Marie Gorce is the responsible for the Telecommunications program of the future Master EEAP from University of Lyon.

Guillaume Villemaud is responsible for international relations in the Electrical engineering départemement of Insa Lyon

9.2.2. Supervision

HdR: **Guillaume Villemaud**, *Les communications multi-* : contribution au développement d'architectures radio flexibles pour les réseaux sans fil hétérogènes*, Insa Lyon, 9 december 2013

PhD: **Laurent Maviel**, *Modélisation et simulation des réseaux sans fil hétérogènes et non-stationnaires. Application aux topologies de petites cellules*, CIFRE grant with SIRADEL, defended 27 may 2013.

PhD: **Meiling Luo**: *Indoor Radio Propagation Modeling For System performance prediction* MENRT grant, 17 july 2013.

PhD: **Cengis Hasan**, *Optimization of resource allocation for small cells networks*", Orange labs grant, 29 august 2013.

PhD: **Francois Goichon**, *Equité d'accès aux ressources dans les systèmes partagés best-effort*, 16 december 2013.

PhD: **Paul Ferrand**: *Cooperative communications in BANET*, MENRT, defended 21 june 2013.

PhD in progress: **Mickael Dardaillon**, *Virtual machine for the cognitive radio*, Rhône-Alpes grant, since 10/2011.

PhD in progress: **Arturo Jimenez Guizar**: *Cooperative communications in Body Area Networks*, ANR Cormoran grant, since 09/2012.

PhD in progress: **Mathieu Lauzier**: "*Design and evaluation of information gathering systems for dense mobile wireless sensor networks*", CIFRE/Euromedia, since 09/2011.

PhD in progress: **Baher Mawlawi**: CEA grant, since 09/2012.

PhD in progress: **Matthieu Vallerian**: "*Radio Logicielle pour réseau de capteurs*", CIFRE/Orange, since 09/2012.

PhD in progress: **Zhaowu Zhan**: "*Full-Duplex Multimode MIMO wireless communications*", CSC/China grant with , since 9/2012.

9.2.3. Participation in thesis Committees

Claire Goursaud Jury member for the PhD defense of Nicolas BARBOT " Codage de canal pour les communications optiques sans fils" , 22 nov. 2013 (U. Limoges)

Tanguy Risset:

- reviewer for the Phd of Muhammad Mahtab ALAM " Power Aware Adaptive Techniques for Wireless Sensor Networks" , 27 feb. 2013 (U. Rennes 1)
- reviewer for the Phd Djamel Benferhat " Conception d'un syst'eme de communication tol´erant la connectivit´e intermittente pour capteurs mobiles biom´etriques" , 2 oct. 2013 (U. Bretagne Sud)
- reviewer for the Phd Jair Gonzalez-Pina "Application modelling and software architectures for the software defined radio" , 14 may 2013 (Telecom-ParisTech, Nice)
- Jury president for the PhD of Antoine Morvan "ASIP processor instruction set extension", 28 jun. 2013 (U. Rennes 1)
- Jury president for the PhD of Maria Isabel Vergara Gallego "Smarter Radios for Energy Efficiency in Wireless Sensor Networks" , 3 oct. 2013 (U. Grenoble)
- Jury president for the PhD of Hervé Yviquel "From Dataflow-based video Coding Tools to dedicated embedded Multi-core platforms ", 25 jun. 2013 (U. Rennes 1)
- Jury members of Habilitation à Diriger les recherches of Guillaume Villemaud, 9 dec. 2013 (U Lyon1/Insa-Lyon)

Jean-Marie Gorce has been reviewer of Phd theses:

- reviewer for the HdR of Benoit Escrig: "Communications coopératives"; 5 Juillet 2013 (INP Toulouse);
- Ziaf Khalaf: "Contribution à l'étude de détection des bandes libres dans le contexte de la radio intelligente"; 7 Février 2013 (Supelec Rennes);
- Sébastien Marcille: " Resource Allocation for HARQ based Mobile Ad hoc Networks"; 21 Février 2013 (Telecom Paris Tech);
- Aymen Ayari: "Mécanismes d'ingénieries pour la planification des réseaux de 3ème et 4ème génération"; 29 Mars 2013 (Supcom Tunis);
- Salma Bourbia: "Algorithmes de prise de décision pour la Cognitive Radio et optimisation du mapping de reconfigurabilité de l'architecture de l'implémentation numérique"; 27 Nov. 2013 (Supcom Tunis et Supélec Rennes);

Florent de Dinechin

- reviewer for the PhD of thèse de Mourad Gouicem "Conception et implantation d'algorithmes efficaces pour la résolution du dilemme du fabricant de tables sur architectures parallèles." , 14 oct. 2013 (U. Paris VI)

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