IN PARTNERSHIP WITH:
**Institut national des sciences appliquées de Lyon**

# Activity Report 2014

# 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

*Creation of the Team:* 2012 January 01*, updated into Project-Team:* 2013 July 01.

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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).

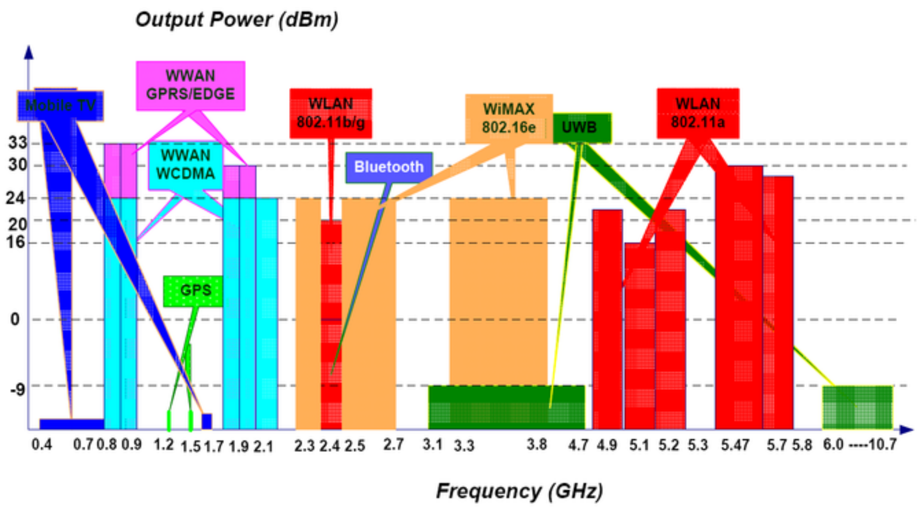


*Figure 1. The most recent standards for wireless communications are developed in the UHF and VHF bands. These bands are mostly saturated (source: WPAN/WLAN/WWAN Multi-Radio Coexistence, IEEE 802 Plenary, Atlanta, USA, Nov.2007)*

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.* [55]

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 [54], 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 [47]. 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 [51], [52]. 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 [47]. 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 [51], [48].

### *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 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:

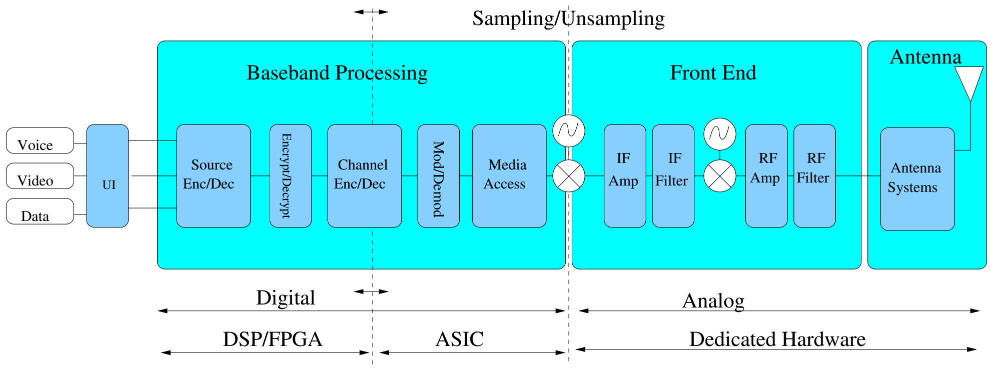


*Figure 2. Radio Block Diagram, highlighting separation between digital and analog parts, as well as programmable, configurable and fixed hardware parts.*

- *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” [53]. 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 [49].

## 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 [50] 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 and RF Front-Ends:* This is a key issue for reducing interference, increasing capacity and reusing frequency. Hot topics such as wake-up radio or multi protocol parallel radio receivers 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.

# 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 3 illustrates the three regions of a transceiver corresponding to the three Socrate axes.

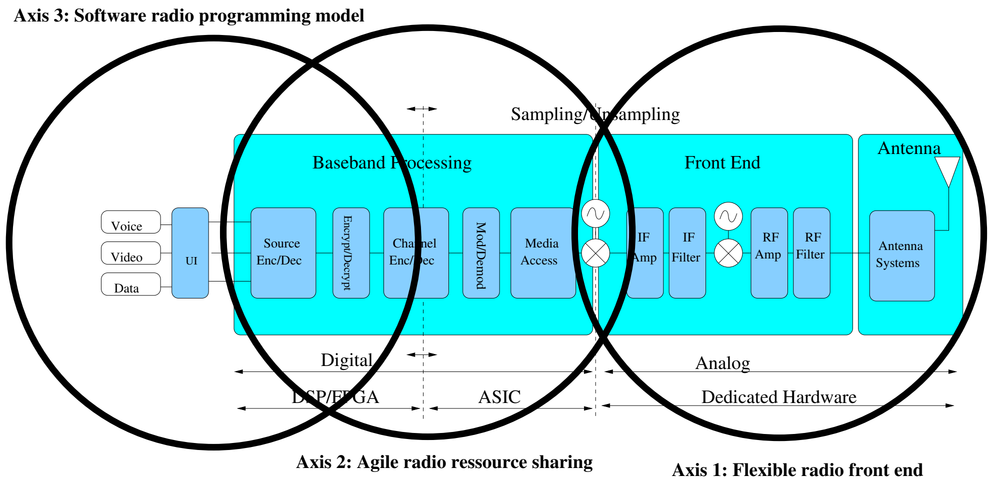


*Figure 3. Center of interest for each of the three Socrate research axes with respect to a generic software radio terminal.*

## 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 3). 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, Perlaza Samir, Leonardo Sampaio-Cardoso.

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 3), 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.

The second research axis is dealing with multi-user communications focusing on resource sharing between uncoordinated nodes but using the same spectral resources. The agility relies on the nodes capability to adapt their transmission protocol to the actual radio environment. Centralized and decentralized approaches are investigated and the group is targeting fundamental limits as well as feasible and even practical implementations.

To make agile radio resource sharing a reality, two research directions are investigated. The first one aims at increasing the signal processing capabilities of software radio devices (middle circle in Fig 3), including modulation, coding, interference cancelation, sensing. The objective is to broaden the set of available processing capabilities thus offering more degrees of freedom. Note how this aspect relies on the two other research axes: radio front-end and radio programming.

Processing capabilities is not enough for agility. The second research direction concerns 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. In some cases, centralized solutions are possible but distributed algorithms are often required. Therefore, the target is to find distributed solutions ensuring stability, efficiency and fairness. 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 challenging. The corresponding paradigm is referred to as opportunistic cooperative transmissions. We structure our research into three directions:

- Establishing theoretical limits of cooperative wireless networks in the network information theory framework.
- Designing coding and signal processing techniques for optimal transmissions (e.g. interference alignment).
- Developing distributed mechanisms for distributed decision at layer 1 and 2, using game theory, consensus and graph modeling.

## 3.4. Software Radio Programming Model

**Participants:** Tanguy Risset, Kevin Marquet, Guillaume Salagnac, Florent de Dinechin.

Finally the third research axis is concerned with software aspect of the software radio terminal (left of Fig 3). 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

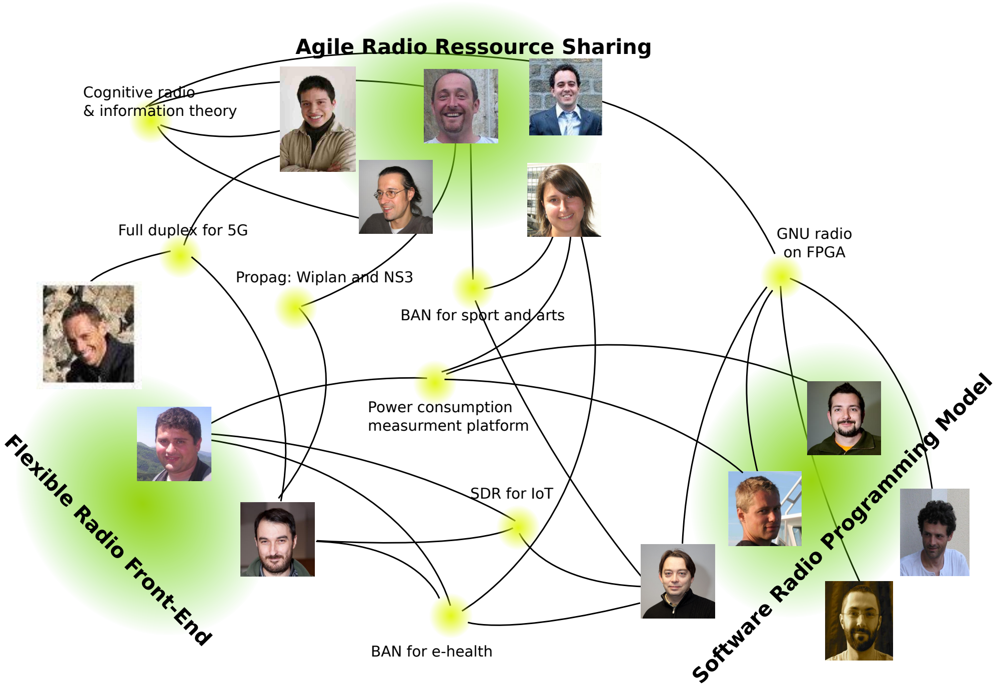


*Figure 4. Inter-Axis Collaboration in Socrate: we expect innovative results to come from this pluri-disciplinary research*

Innovative results come from collaborations between the 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 4.

- *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), respectively.
- *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).
- *CorteXlab*. The 3 axes also collaborate on the design and the development of CorteXlab.
- *body area networks applications*. Axis 2 and axis 3 collaborate on the development of body area networks applications in the framework of the FUI Smacs project. Jean-Marie Gorce and Tanguy Risset co-advised Matthieu Lauzier.
- *Wiplan and NS3*. The MobiSim ADT involves Guillaume Villemaud (axis 1) and Jean-Marie Gorce (axis 2).

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

- *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). 1 Phd started in 2011.
- *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

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 terminal, 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 enables 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 huge venue 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 includes $i$) 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 future 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 developpement of the FIT plateform [49] 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 [50].

Recent natural disasters have brought considerable attention to the need of enhanced public safety communication abroad [48]. 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 leaded recently to the creation of a start-up company, leaded 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 on going. 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 direction 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 have 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 to the standardization group 802.15.6. Recently, Inria has been added as a partner the FET flagship untitled *Guardian Angels* (http://www.fet-f.eu/), an important european initiative to develop the BANs of the futur.

We consider that BANs will probably play an important role in the future of Internet as the multiple objects connected on body could also be connected to Internet by the mobile phone hosted 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 Socrate team.

# 5. New 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), proposed by JM Gorce in 2001 and further extended. 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 computational load to be restricted to a pre-processing phase. Extensive works have been done to make predictions more realistic. The development of the wiplan software has been a part of the european project iPlan (IAPP-FP7 project) and has been integrated in NS-3 simulator.

## 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. 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.

In 2014, FloPoCo was enhanced with a generator of FIR filters accurate to the last bit [19] and several variants of the Atan2 function [46].

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

## 5.4. FIT/CorteXlab software

During the setting up of the FIT/CorteXlab platform, important software tools have been developped for the platform. The main tools is Minus which is used to deploy software programs on SDR hardware, it is developped in Python and is able to deploy complete configuration of NI USRP or Nutaq PicoSDR platforms. A seconf tools is DAS (*Automatic deployement system*) which is used to create the complete software environment of the servers of FIT/CorteXlab. This software could be use to create another testbed based on the same principle: hardware SDR nodes programmed from internet. These softwarea are currently used on the deployement testbed and on the production testbed.

# 6. New Results

## 6.1. Highlights of the Year

### *6.1.1. FIT/CortexLab Inauguration*

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 is be composed of four main parts: a Network Operations Center (NOC), a set of Embedded Communicating Object (ECO) test-beds, a set of wireless OneLab test-beds, and a cognitive radio test-bed (CorteXlab) deployed by the Socrate team in the Citi lab. In 2014 the construction of the room was finished see Figure 5. SDR nodes have installed in the room, 42 industrial PCs (Aplus Nuvo-3000E/P), 22 NI radio boards (USRP) and 18 Nutaq boards (PicoSDR, 2x2 and 4X4) can be programmed from internet now.

A very successfully inauguration took place on the 28th October 2014 [2], with the noticable venue of Vincent Poor, Dean of School of Engineering and Applied Science of Princeton University.

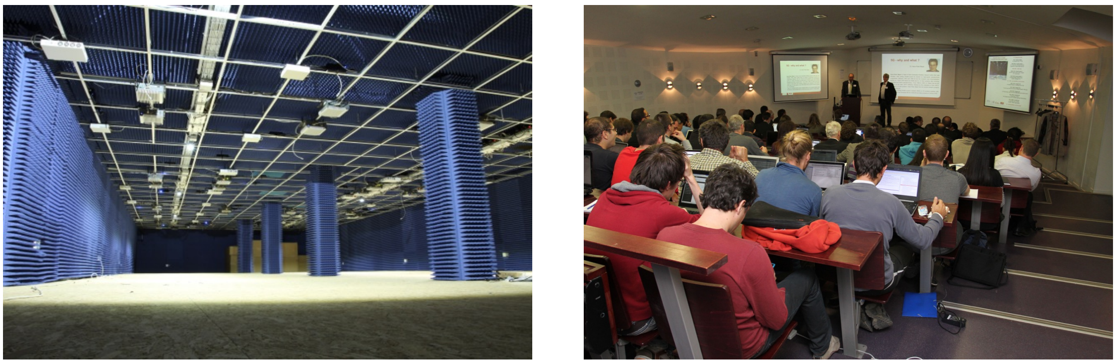

*Figure 5. Photo of the FIT/CortexLab experimentation room installed and a snaptshot of the inauguration meeting*

[2] http://www.inria.fr/centre/grenoble/actualites/inauguration-reussie-de-la-plateforme-cortexlab-equipex-fit

## 6.2. Flexible Radio Front-End

The innovative Wake-Up radio architecture proposed by the Socrate team, based on a classical WiFi standard with a specific OFDM pattern, has been deeply studied in theory and simulations [1], [25], [24]. Great enhancements on the sensitivity study, the choice of identifiers and the comparison of the energy consumption relative to classical systems have led to the development of a first prototype (ongoing work).

### *6.2.1. Wake-Up Radios*

The innovative Wake-Up radio architecture proposed by the Socrate team, based on a classical WiFi standard with a specific OFDM pattern, has been deeply studied in theory and simulations [HUTU-JWCN][KHOUMERI-ECUMICT][HUTU-RWS]. Great enhancements on the sensitivity study, the choice of identifiers and the comparison of the energy consumption relative to classical systems have led to the development of a first prototype (ongoing work).

### *6.2.2. Full-Duplex systems*

In the development of wideband OFDM Full-Duplex systems, [33] proposes an analysis of the impact of the thermal noise on the quality of the self-interference cancellation in such systems. A method is proposed to reduce the impact on the bit-error-rate by increasing the level of certain parts of the preamble in each frame. [35] add to the analog RF cancellation proposed previously a stage of digital cancellation enabling to increase more the performance of Full-Duplex terminals.

Furthermore, [34] extend the study to a dualband Full-Duplex systems, enabling the very promising combination of Full-Duplex and carrier aggregation. The proposed structure being sensitive to IQ impairments, a digital mitigation algorithm is also designed.

### *6.2.3. SDR for SRD*

In collaboration with Orange labs, [32] analyses the requirements of an SDR gateway for urban networks collecting SRD (short range devices) information. This study is particularly focused on the ADC resolution, showing that the required resolution in realistic scenarios is too high, therefore emphasizing the need to develop specific hardware techniques.

### *6.2.4. Experimental Facilities*

For the development of the CorteXlab testbed, lots of radio hardware and propagation constraints had to be taken into account [15], [14]. Moreover,[36] had proposed a first implementation of Full-Duplex on USRPs which is expected to be deployed on this tesbed.

Another testbed dedicated to the measurement of the energy consumption of radio devices was also designed and implemented.

## 6.3. Agile Radio Resource Sharing

This axis addresses the challenges relative to the network perspective of software radio. While the two other axes work on the design of the software radio nodes, we focus herein on their coexistence in a multi-user communications perspective. We are first interested in theoretical limits of some reference scenarios where trade-offs between spectral efficiency, energy efficiency, stability and/or fairness are analyzed. Our research activities are further driven by applicative frameworks. We focused on radio access networks with new results on energy efficiency-spectral efficiency trade-off in LTE networks and multi-band CSMA strategies in Wifi networks. We also studied pure random access and success probabilities for the challenging ultra-narrow band (UNB) technology of SigFox. Lot of efforts has been put on body area networks [8] with deep studies on positioning strategies and distributed decisions and information gathering. As mentioned above, our research follows three objectives:

- Establishing theoretical limits of cooperative wireless networks in the network information theory framework.

- Designing MAC procedures, coding and signal processing techniques for optimal transmissions (e.g. interference alignment).
- Developing distributed mechanisms for distributed decision at layer 1 and 2, using game theory, consensus and graph modeling.

### 6.3.1. Theoretical limits from information theory

The group strengthened his activities from a formal perspective in the framework of network information theory as initiated with the recruitment of Samir Perlaza and the sabbatical of Jean-Marie Gorce at Princeton University in the group of Prof. H. Vincent Poor. The first scenario is devoted to cellular networks with a random distribution on base stations. The main contribution concerns the broadcast channel (BC) generalized to a continuum of users. The second scenario concerns the interference channel (IC) and the main contribution is relative to the characterization of the Nash stable region for the interference channel with noisy feedback.

#### 6.3.1.1. Broadcast channel with a continuum of users in a typical cell

The theoretical Energy efficiency-Spectral efficiency Pareto optimal front in a typical cell has been evaluated by associating stochastic geometry (Poisson point processes, PPP) and information theory.[21], the broadcast channel is extended to a continuum of users. We derived the theoretical uniform achievable rate with superposition coding principles. We show the potential gain of superposition coding techniques compared to the conventional time sharing. These results are however limited to Gaussian channels and the extension to the vector Gaussian channel is still under investigation. The PPP modeling for multi-cells has been also introduced as well as the price of interference management.

#### 6.3.1.2. Interference Channel with feedback

The decentralized interference channel (DIC) with noisy feedback has been analyzed. In [31], all the rate-pairs that are achievable at a Nash equilibrium (NE) in the two-user linear deterministic symmetric decentralized interference channel (LD-S-DIC) with noisy feedback are identified. A second result provides closed form expressions for the PoA, which allows the full characterization of the reduction of the sum rate due to the anarchic behavior of all transmitter-receiver pairs. The price of anarchy (PoA) and the price of stability (PoS) of the game in which transmit-receiver pairs seek an optimal individual transmission rate are fully characterized in [9]. In particular, it is shown that in all interference regimes, there always exists at least one Pareto optimal Nash equilibrium (NE).

### 6.3.2. Coding, signal processing and MAC procedures for optimal transmissions

#### 6.3.2.1. Implementation

While theoretical studies provide interesting insights about potential gain and limits of cognitive networks, the achievable efficiency may depend on practical issues related to quantization, synchronization and real-time processing limits. We developed the CortexLab facility offering a reproducible environment for fostering the validation of cooperative communication schemes. The first demo has been presented at the Infocom conference [28] and also at the Melbourne Greentouch meeting. We also contributed to the implementation and analysis of a cognitive transceiver for opportunistic networks [ref Maso JWCN]. The work first focused on a previously introduced dynamic spectrum access (DSA) - cognitive radio (CR) solution for primary-secondary coexistence in opportunistic orthogonal frequency division multiplexing (OFDM) networks, called cognitive interference alignment (CIA). The implementation is based on software-defined radio (SDR) and uses GNU Radio and the universal software radio peripheral (USRP) as the implementation toolkit. The proposed flexible transceiver architecture allows efficient on-the-fly reconfigurations of the physical layer into OFDM, CIA or a combination of both.

#### 6.3.2.2. Interference alignment

In the framework of Greentouch, we studied interference alignment as a mean for improving the EE-SE tradeoff in cellular networks [43]. We combined theoretical studies with stochastic geometry and simulations to show the potential interest. We are also developing a demo with CorteXlab enhancing the IA capability from a real perspective.

#### 6.3.2.3. Multiband MAC

In collaboration with CEA-Leti, we studied MAC strategies for multiband systems. The main idea is based on exploiting the multiband system as a slotted Aloha channel for the RTS/CTS initiation but keeping the total band as a whole for data transmission. We proved that this strategy outperforms classical approaches [39], [40], [30].

#### 6.3.2.4. MAC for localization

In the context of the ANR Cormoran project, we account for radiolocation experiments aiming at both indoor navigation and mobility detection applications for Wireless Body Area Networks (WBAN) [7]. We also studied the relation between the MAC protocol and ranging techniques for localization. The impact of mobility on the distance estimation between 2 nodes of a Wireless Body Area Network (WBAN) by comparing the Two-Way Ranging (2WR) and Three-Way Ranging (3WR) protocols has been proposed in [23]. We also investigated the impact of mobility on the Motion Capture applications [22].

#### 6.3.2.5. random access in Ultra-narrow band networks

Ultra narrow band (UNB) transmission is a very promising technology for low-throughput wireless sensor networks. This technology has already been deployed and has proved to be ultra-efficient for point-to-point communications in terms of power-efficiency, and coverage area. We studied the scalability of UNB for a multi-point to point network. In particular, we proposed a new multiple access scheme: random frequency division multiple access (R-FDMA) and studied the impact of the induced interference on the system performance in terms of bit error rate and outage probability [20]. We also analyzed the system performance in terms of bit error rate and outage probability [37].

### 6.3.3. Distributed decision mechanisms

Distributed decisions appear in many situations in the wireless world. Resource allocation, power management or relaying techniques are all expecting distributed decisions. To avoid strong coordination, distributed mechanisms inspired e.g. by game theory or consensus algorithms are appealing. Some of the results obtained below also rely on information theory but with a more important focus on algorithms and decision processes when several pairs of wireless transceivers are willing to simultaneously transmit in the same environment.

#### 6.3.3.1. Cognitive radio networks

The problem of joint channel selection and power control is analyzed in the context of multiple-channel clustered ad-hoc networks in[ref Rose [3], i.e., decentralized networks in which radio devices are arranged into groups (clusters) and each cluster is managed by a central controller (CC). The problem is modeled by a game in normal form in which the corresponding utility functions are designed for making some of the Nash equilibria (NE) to coincide with the solutions to a global network optimization problem. A second scenario has been considered where multiple source-destination pairs communicate with each other via an energy harvesting relay [5]. The focus was put on the relay's strategies to distribute the harvested energy among the multiple users and their impact on the system performance. Specifically, a non-cooperative strategy that uses the energy harvested from the i-th source as the relay transmission power to the i-th destination is considered first. An auction based power allocation scheme is also proposed to achieve a better tradeoff between system performance and complexity.

#### 6.3.3.2. Distributed decisions and consensus in MANETs

In the large research area of wireless body area networks, cooperative applications involving several users is attracting strong interests. This cooperation may target a simple information exchange or even some cooperative decision such as swarm coordination. We considered in [26]such a swarm of users moving in a common direction and we are interested in the mechanisms allowing to propagate and share some common information. We extend and improve a previous algorithm derived as a max-consensus approach. We describe a complete experimental setup deployed during a real bike race with 200 runners.

## 6.4. Software Radio Programming Model

### *6.4.1. Data Flow Programming*

Software defined radio (SDR) technology has evolved rapidly and is now reaching market maturity. However, no standard has emerged for programming the new type of machine that will manage the access to the radio channel. Mickaël Dardaillon, Kevin Marquet, Tanguy Risset have been working in collaboration with the CEA LETI on compiling waveform for heterogeneous Multi-processor SoCs . This research leaded to a prototype compiler for the Magali MP-SoC developped in Mickael Dardaillon' PhD thesis (passed in November 2014) which was the first attempt to compile the SPDF format to a real architecture [18], [16], [17]. This study highlighted in particular the fact that SPDF was a good computation model for waveform description langage, easier to compile than dynamic dataflow format.

### *6.4.2. Non-volatile memory management for ultra low power systems*

To enable non-trivial computation on very resource-constrained platforms powered by energy harvested from RF communications, an embedded OS has to save and restore program state to and from non-volatile memory. By doing so, the application program does not lose all progress when power is lost, which happens very often in environmentally-powered systems. This can be achieved [13] thanks to an incremental checkpointing scheme which aims at minimizing the amount of data written to non-volatile memory, while keeping the execution overhead as low as possible.

### *6.4.3. FPGA-based Implementation of physical Layers for SDR*

A VHDL implementation of the three available options of the IEEE 802.15.4 physical layer was developed [29] in the context of FIT/CorteXlab. This parametrized design was validated on a Nutaq platform which combines Xilinx Virtex-6 FPGA and tunable Radio420x RF transceiver. This work participates to the building of an open source hardware SDR library similar to GNU radio but targeted to FPGA-based platforms.

### *6.4.4. Towards filters and functions computing just right*

A FIR filter is specified by its coefficients (real numbers) and its input and output formats. The implementation of a FIR should be as accurate as its output format allows, but no more. This very simple specification enables the automatic construction of FIR filter implementations that are provably accurate at a minimal hardware cost [19]. The corresponding FIR generator is available in FloPoCo.

The fixed-point Atan2 function is very useful to recover the phase of a complex signal. A careful study of three implementation techniques (including a novel one based on two-variable quadratic approximation) shows that, on current FPGAs, the good old CORDIC technique is more efficient than multiplier-based techniques [46].

# 7. Bilateral Contracts and Grants with Industry

## 7.1. Bilateral Contracts with Industry

Socrate has strong collaboration 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 french young 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 with Bosch on arithmetic for automotive embedded platforms involves Florent de Dinechin and members of the AriC team.

# 8. Partnerships and Cooperations

## 8.1. National Initiatives

### 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 should 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)

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 - MetalibM - "Automatic generation of function and filters" (2014-2017, 200 keuros)

The goal of the Metalibm project is to provide a tool for the automatic implementation of mathematical (libm) functions. A function $f$ is automatically transformed into machine-proven $C$ code implementing an polynomial approximation in a given domain with given accuracy. This project is led by Inria, with researchers from Socrate and AriC; PEQUAN team of Laboratoire d'Informatique de Paris 6 (LIP6) at Université Pierre et Marie Curie, Paris; DALI team from Université de Perpignan Via Domitia and Laboratoire d'Informatique, Robotique et Microélectronique de Montpellier (LIRMM); and SFT group from Centre Européen de Recherche Nucléaire (CERN).

### 8.1.4. 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.

### 8.1.5. 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 technologie enabling real-time localization of mobile targets (like cyclist for instance), at a low energy (more generaly low cost). The technology will be demonstrated at real cycling races (Tour de France 2013 and 2014). One of the goal 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. European Initiatives

### *8.2.1. 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.

## 8.3. International Initiatives

### *8.3.1. Inria International Partners*

Socrate has strong collaborations with several international partners.

- **Princeton University**, School of Applied Science, Department of Electrical Engineering, NJ. USA. This cooperation with Prof. H. Vincent Poor is on topics related to decentralized wireless networks. Samir Perlaza has been appointed as Visiting Research Collaborator at the EE Department. Jean-Marie Gorce spent his Sabatical year at the EE Department. Scientific-Leader at Inria: Jean-Marie Gorce.
- **University of Sheffield**, Department of Automatic Control and Systems Engineering, Sheffield, UK. This cooperation with Prof. Inaki Esnaola is on topics related to information-driven energy systems. Scientific-in-charge at Inria: Samir Perlaza.
- **Virginia Tech**, Discovery Analytics Center, Department of Computer Science, Blacksburg, VA, USA. This cooperation with Prof. Ravi Tandon is on topics related to channel-output feedback in wireless networks. Scientific-Leader at Inria: Samir Perlaza.
- **University of Cyprus**, Department of Electrical and Computer Engineering, University of Cyprus (ECE), Nicosia, Cyprus. This cooperation with Prof. Ioannis Krikidis is on topics related to energy-harvesting and wireless communications systems. Scientific-Leader at Inria: Guillaume Villemaud.

#### *8.3.1.1. Informal International Partners*

- **Universidade Federal do Ceará**, Department of Tele-informatics, GTEL lab. A formal cooperation is currently under preparation but, exchange of researchers for seminars and courses already took place between 2012 and 2014. Mutual topics of interests include interference management and massive MIMO.

## 8.4. International Research Visitors

### *8.4.1. Visits of International Scientists*

#### *8.4.1.1. Sabbatical programme*

Gorce Jean-Marie

Princeton University (USA). September 2013 - July 2014. CMIRA regional council Scholarship Programme.

#### *8.4.1.2. Research stays abroad*

Samir Perlaza spent few months visiting the following academic partners:

University of Sheffield (UK), May 2014 and October 2014.

Princeton University (UK), June - July 2014.

# 9. Dissemination

## 9.1. Promoting Scientific Activities

### *9.1.1. Scientific events organisation*

The inauguration of the experimentation room of FIT/CortexLab took place in October 2014, see Figure 5 [3], with the noticeable venue of Prof. H. Vincent Poor, Dean of School of Engineering and Applied Science of Princeton University.

[3] http://www.inria.fr/centre/grenoble/actualites/inauguration-reussie-de-la-plateforme-cortexlab-equipex-fit

*9.1.1.1. general chair, scientific chair*

- Samir Perlaza was a co-chair the Eight IEEE Sensor Array and Multichannel Signal Processing (SAM 2014). Special Session on Estimation in Cyber-Physical Energy Systems. June 22-25, 2014, La Coruna, Spain.

*9.1.1.2. member of the conference program committee*

- Florent de Dinechin was a member of the following program committees:
  - IEEE International Conference on Application-specific Systems, Architectures and Processors (ASAP)
  - IEEE International Conference on Field Programmable Logic and Applications (FPL)
  - IEEE International Conference on Field Programmable Technologies (FPT)
  - IEEE International Conference on Reconfigurable Computing and FPGAs (ReConFig)
  - International Symposium on Highly Efficient Reconfigurable Accelerator Technologies (HEART)
  - Conférence d'informatique en Parallélisme, Architecture et Système (CompAS)
- Jean-Marie Gorce was a member of the following program committees:
  - IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) 2014
  - IEEE International Conference on Ultra-Wideband (ICUWB) 2014
- Tanguy Risset was a member of the following program committees:
  - IEEE Computer Society Annual Symposium on VLSI (ISVLSI) 2014.
  - Design Automation and Test in Europe (DATE) 2014.
- Samir Perlaza was a member of the following program committees:
  - IEEE Global Conference on Signal and Information Processing (GLOBALSIP) 2014.
  - Conference on Decision and Game Theory for Security (GameSec) 2014.
  - International Workshop on Wireless Networks: Communication, Cooperation and Competition (WNC3) 2014.
  - IEEE INFOCOM Workshop on Communications and Control for Smart Energy Systems (CCSES) 2014.
  - IEEE ICC Workshop on Small Cell and 5G Networks (SmallNets) 2014.
  - International WDN Workshop on Cooperative and Heterogeneous Cellular Networks (WDN-CN) 2014.
- Guillaume Villemaud was a member of the following program committees:
  - IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) 2014
  - International Telecommunications Symposium (ITS) 2014

*9.1.1.3. member of the editorial board*

- Florent de Dinechin is an associate editor of IEEE Transactions on Computers
- Jean-Marie Gorce is an associate editor of Telecommunications Systems (Springer) and Journal of Wireless communications and Networking (Springer).

## 9.2. Teaching - Supervision - Juries

### *9.2.1. Teaching*

Tanguy Risset and Jean-Marie Gorce and 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.

Leonardo Sampaio Cardoso is associate professor at Insa Lyon (Premier Cycle).

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

Guillaume Villemaud and Florin Hutu are associate professor 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 départemeent of Insa Lyon

### 9.2.2. Supervision

Phd: **Nicolas Brunie**: *Contributions to computer arithmetic and applications to embedded systems*, École Normale Supérieure de Lyon, Kalray CIFRE grant, 16 May 2014.

Phd: **Mickael Dardaillon**: *Compilation d'applications flot de données paramétriques pour MPSoC dédiés à la radio logicielle*, nom de l'Université, Rhones-Alpes Grant, 19 Nov. 2014.

PhD in progress **Coralie Saysset**: *Compilation de programme data-flow pour architecture multi-coeur*, nom de l'Université, MENRT, since 09/2014.

PhD in progress **Victor Quintero**: *Fundamental Limits of Decentralized Cognitive Radio Networks*, Ecole Doctoral EEA de Lyon, funded by Colciencias since 02/2014.

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

PhD in progress : **Matei Istoan**: *High-performance coarse operators for FPGA-based computing*, ANR Metalibm grant, since 01/2014.

PhD in progress : **Matthieu 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.

PhD in progress **Aissa Khoumeri**: "*Study and Development of Wake-Up Radio Receivers*", FUI ECONHOME since 11/2011.

Jean-Marie Gorce is a member of the Comité National des Universities (CNU) in section 61 signal processing.

### *9.2.3. Juries*

Florent de Dinechin

PhD: **Manish Kumar Jaiswal**, *Configurable Architectures for Mixed High Precision Floating Point Arithmetic*, City University, Hong Kong (as a reviewer).

PhD: **Nicolas Brunie**, *Contributions to computer arithmetic and applications to embedded systems*, École Normale Supérieure de Lyon.

PhD: **Mohamed Amine Najahi**, *Synthesis of certified programs in fixed-point arithmetic, and its application to linear algebra basic blocks*, Université de Perpignan Via Domitia (as a reviewer).

PhD: **Benoît Lopez**, *Implémentation optimale de filtre linéaire en arithmétique virgule fixe*, Université Pierre et Marie Curie, Paris.

Jean-Marie Gorce

HDR: **Jean-Yves Baudais**, *Systèmes à porteuses multiples précodés*, IETR, INSA Rennes.

HDR: **Marceau Coupechoux**, *Ingénierie des réseaux radio*, Telecom Paris Tech, Paris.

PhD: **Ramona Rosini**, *From radio channel modeling to a system level perspective in body-centric communications*, Univ. of Bologna,Italy.

PhD:, INSA Toulouse

PhD:, IETR, INSA Rennes

PhD:, Gipsa-lab Université Joseph Fourier, Grenoble

PhD: Zhaowu Zhan, INSA Lyon.

Tanguy Risset

PhD: **Mickael Dardaillon**, *Compilation d'applications flot de données paramétriques pour MPSoC dédiés à la radio logicielle*, Insa-Lyon.

PhD: **Ganda Stéphane Ouedraogo**, *Automatic Synthesis of Hardware Accelerators from High-Level Specifications of Physical Layers for Flexible*

# 10. Bibliography

## Publications of the year

### Articles in International Peer-Reviewed Journals

[1] F. D. Hutu, A. Khoumeri, G. Villemaud, J.-M. Gorce. *A new wake-up radio architecture for wireless sensor networks*, in "EURASIP Journal on Wireless Communications and Networking", October 2014, 10 p. [*DOI :* 10.1186/1687-1499-2014-177], https://hal.archives-ouvertes.fr/hal-01078406

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