RESEARCH CENTRE

Grenoble - Rhône-Alpes

IN PARTNERSHIP WITH:

Institut national des sciences appliquées de Lyon

2020

ACTIVITY REPORT

Project-Team

MARACAS

Models and Algorithms for Reliable Communication Systems

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

DOMAIN

Networks, Systems and Services, Distributed Computing

THEME

Networks and Telecommunications

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Computer sciences and digital sciences

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2 Overall objectives

2.1 Motivation

During the last century, the industry of communications was devoted to improving human connectivity, leading to a seamless worldwide coverage to cope with increasing data rate demands and mobility requirements. The Internet revolution drew on a robust and efficient multi-layer architecture ensuring end-to-end services. In a classical network architecture, the different protocol layers are compartmentalized and cannot easily interact. For instance, source coding is performed at the application layer while channel coding is performed at the physical (PHY) layer. This multi-layer architecture blocked any attempt to exploit low level cooperation mechanisms such as relaying, phy-layer network coding or joint estimation. During the last decade, a major shift, often referred to as *the Internet of Things (IoT)*, was initiated toward a machine-to-machine (M2M) communication paradigm, which is in sharp contrast with classical centralized network architectures. The IoT enables machine-based services exploiting a massive quantity of data virtually spread over a complex, redundant and distributed architecture.

This new paradigm makes the aforementioned classical network architecture based on a centralized approach out-of-date.

The era of *Internet of Everything* deeply modifies the paradigm of communication systems. They have to transmute into reactive and adaptive intelligent systems, under stringent QoS constraints (latency, reliability) where the networking service is intertwined in an information-centric network. The associated challenges are linked to the intimate connections between communication, computation, control and storage. Actors, nodes or agents in a network can be viewed as forming a distributed system of computations—a *computing network*.

2.2 Scientific methodology

It is worth noting that working on these new architectures can be tackled from different perspectives, e.g. data management, protocol design, middleware, algorithmic design... Our main objective in Maracas is to address this problem from a communication theory perspective. Our background in communication theory includes information theory, estimation theory, learning and signal processing. Our strategy relies on three fundamental and complementary research axes:

- Mathematical modeling: information theory is a powerful framework suitable to evaluate the limits of complex systems and relies on probability theory. We will explore new bounds for complex networks (multi-objective optimization, large scale, complex channels,...) in association with other tools (stochastic geometry, queuing theory, learning,...)
- Algorithmic design: a number of theoretical results obtained in communication theory, despite their high potential are still far from a practical use. We will thus work on exploiting new algorithmic techniques. Back and forth efforts between theory and practice is necessary to identify the most promising opportunities. The key elements are related to the exploitation of feedbacks, signaling and decentralized decisions. Machine learning algorithms will be explored.
- Experimentation and cross-layer approach: theoretical results and simulation are not enough to provide proofs of concept. We will continue to put efforts on experimental works either on our own (e.g. FIT/CorteXlab and SILECS) or in collaboration with industries (Nokia, Orange, Thalès,...) and other research groups.

While our expertise is mostly related to the optimization of wireless networks from a communication perspective, the project of Maracas is to broaden our scope in the context of *Computing Networks*, where a challenging issue is to optimize jointly architectures and applications, and to break the classical network/data processing separation. This will drive us to change our initial positioning and to really think in terms of information-centric networks following, e.g. [51, 49, 56].

To summarize, *Computing Networks* can be described as highly distributed and dynamic systems, where information streams consist in a huge number of transient data flows from a huge number of nodes (sensors, routers, actuators, etc...) with computing capabilities at the nodes. These *Computing Networks* are nothing but the invisible nonetheless necessary skeleton of cloud and fog-computing based services.

Our research strategy is to describe these *Computing Networks* as complex large scale systems in an information theory framework, but in association with other tools, such as stochastic geometry, stochastic network calculus, game theory [19] or machine learning.

The multi-user communication capability is a central feature, to be tackled in association with other concepts and to assess a large variety of constraints related to the data (storage, secrecy,...) or related to the network (energy, self-healing,...).

The information theory literature or more generally the communication theory literature is rich of appealing techniques dedicated to efficient multi-user communications: e.g. physical layer network coding, amplify-and-forward, full-duplexing, coded caching at the edge, superposition coding. But despite their promising performance, none of these technologies play a central role in current protocols. The reasons are two-fold : i) these techniques are usually studied in an oversimplified theoretical framework which neglect many practical aspects (feedback, quantization,...), and that is not able to tackle large scale networks and ii) the proposed algorithms are of a high complexity and are not compatible with the classical multi-layer network architecture.

Maracas addresses these questions, leveraging on its past outstanding experience from wireless network design.

The aim of Maracas is to push from theory to practice a fully cross-layer design of *Computing Networks*, based on multi-user communication principles relying mostly on information theory, signal processing, estimation theory, game theory and optimization. We refer to all these tools under the umbrella of *communication theory*.

As such, Maracas project goes much beyond wireless networks. The *Computing Networks* paradigm applies to a wide variety or architectures including wired networks, smart grids, nanotechnology based networks. One Maracas research axis will be devoted to the identification of new research topics or scenarios where our algorithms and mathematical models could be useful.

3 Research program

3.1 General description

As presented in the first section, *Computing Networks* is a concept generalizing the study of multi-user systems under the communication perspective. This problematic is partly addressed in the aforementioned references. Optimizing *Computing Networks* relies on exploiting simultaneously multi-user communication capabilities, in the one hand, and storage and computing resources in the other hand. Such optimization needs to cope with various constraints such as energy efficiency or energy harvesting, delays, reliability or network load.

The notion of reliability (used in MARACAS acronym) is central when considered in the most general sense : ultimately, the reliability of a *Computing Network* measures its capability to perform its intended role under some confidence interval. Figure 1 represents the most important performance criteria to be considered to achieve reliable communications. These metrics fit with those considered in 5G and beyond technologies [53].

On the theoretical side, multi-user information theory is a keystone element. It is worth noting that classical information theory focuses on the power-bandwith tradeoff usually referred as Energy Efficiency-Spectral Efficiency (EE-SE) tradeoff (green arrow on 1). However, the other constraints can be efficiently introduced by using a non-asymptotic formulation of the fundamental limits [52, 54] and in association with other tools devoted to the analysis of random processes (queuing theory, ...).

Maracas aims at studying *Computing Networks* from a communication point of view, using the

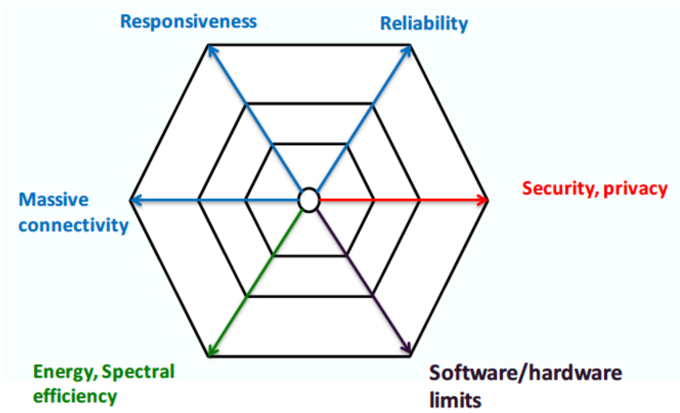

Figure 1: Main metrics for future networks (5G and beyond)

foundations of information theory in association with other theoretical tools related to estimation theory and probability theory.

In particular, Maracas combines techniques from communication and information theory with statistical signal processing, control theory, and game theory. Wireless networks is the emblematic application for Maracas, but other scenarios are appealing for us, such as molecular communications, smart grids or smart buildings.

Several teams at Inria are addressing computing networks, but working on this problem with an emphasis on communication aspects is unique within Inria.

The complexity of *Computing Networks* comes first from the high dimensionality of the problem: i) thousands of nodes, each with up to tens setting parameters and ii) tens variable objective functions to be minimized/maximized.

In addition, the necessary decentralization of the decision process, the non stationary behavior of the network itself (mobility, ON/OFF Switching) and of the data flows, and the necessary reduction of costly feedback and signaling (channel estimation, topology discovering, medium access policies...) are additional features that increase the problem complexity.

The original positioning of Maracas holds in his capability to address three complementary challenges :

1. **to develop a sound mathematical framework inspired by information theory.**
2. **to design algorithms, achieving performance close to these limits.**
3. **to test and validate these algorithms on experimental testbeds.**

3.2 Research program

Our research is organized in 4 research axes:

- **Axis** 1 **- Fundamental Limits of Reliable Communication Systems**: Information theory is revisited to integrate reliability in the wide sense. The non-asymptotic theory which made progress recently and attracted a lot of interest in the information theory community is a good starting point. But for addressing computing network in a wide sense, it is necessary to go back to the foundation of communication theory and to derive new results, e.g. for non Gaussian channels [8] of for multi-constrained systems [18].

  This also means revisiting the fundamental estimation-detection problem [55] in a general multi-criteria, multi-user framework to derive tractable and meaningful bounds.

  As mentioned in the introduction, *Computing Networks* also relies on a data-centric vision, where transmission, storage and processing are jointly optimized. The strategy of *caching at the edge* [48] proposed for cellular networks shows the high potential of considering simultaneously data and

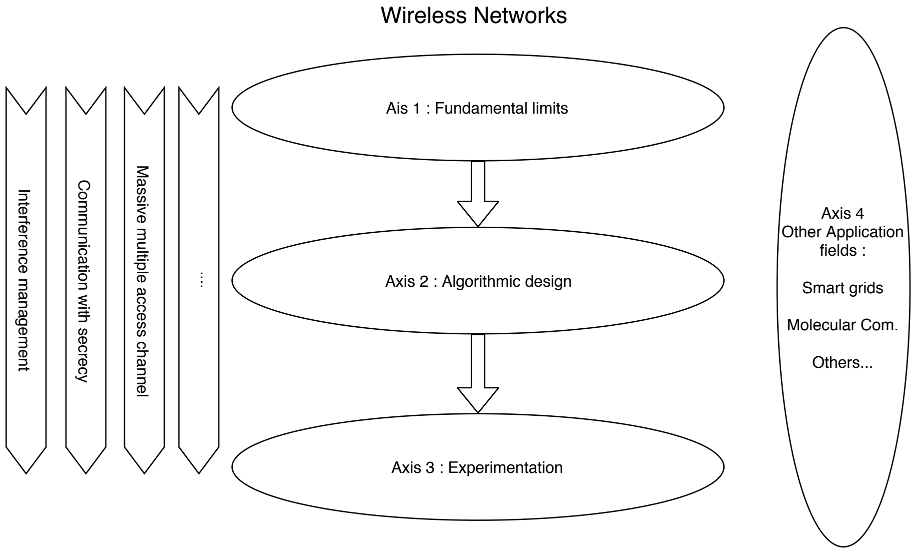

Figure 2: Maracas organization

network properties. Maracas is willing to extend his skills on source coding aspects to tackle with a data-oriented modeling of *Computing Networks.*

- **Axis** 2 **- Algorithms and protocols**: Our second objective is to elaborate new algorithms and protocols able to achieve or at least to approach the aforementioned fundamental limits. While the exploration of fundamental limits is helpful to determine the most promising strategies (e.g. relaying, cooperation, interference alignment) to increase system performance, the transformation of these degrees of freedom into real protocols is a non trivial issue. One reason is the exponentially growing complexity of multi-user communication strategies, with the number of users, due to the necessity of some coordination, feedback and signaling. The general problem is a decentralized and dynamic multi-agents multi-criteria optimization problem and the general formulation is a non-linear and non-convex large scale problem.

  The conventional research direction aims at reducing the complexity by relaxing some constraints or by reducing the number of degrees of freedom. For instance, topology interference management is a seducing model used to reduce feedback needs in decentralized wireless networks leading to original and efficient algorithms [57, 50].

  Another emerging research direction relies on using machine learning techniques [45] as a natural evolution of cognitive radio based approaches. Machine learning in the wide sense is not new in radio networks, but the most important works in the past were devoted to reinforcement learning approaches. The use of deep learning (DL) is much more recent, with two important issues : i) identifying the right problems that really need DL algorithms and ii) providing extensive data sets from simulation and real experiments. Our group started to work on this topic in association with Nokia in the joint research lab. As we are not currently expert in deep learning, our primary objective is to identify the strategic problems and to collaborate in the future with Inria experts in DL, and in the long term to contribute not only to the application of these techniques, but also to improve their design according to the constraints of computing networks.

- **Axis** 3 **- Experimental validation** : With the rapid evolution of network technologies, and their increasing complexity, experimental validation is necessary for two reasons: to get data, and to validate new algorithms on real systems.

  Maracas activity leverages on the FIT/CorteXlab platform (`http://www.cortexlab.fr/`), and our strong partnerships with leading industry including Nokia Bell Labs, Orange labs, Sigfox or Sequans. Beyond the platform itself which offers a worldwide unique and remotely accessible testbed , Maracas also develops original experimentations exploiting the reproducibility, the remote accessibility, and the deployment facilities to produce original results at the interface of academic and industrial research [1, 10]. FIT/CorteXlab uses the GNU Radio environment to evaluate new multi-user communication systems.

Our experimental work is developed in collaboration with other Inria teams especially in the Rhone-Alpes centre but also in the context of the future SILECS project `https://www.silecs.net/` which will implement the convergence between FIT and Grid'5000 infrastructures in France, in cooperation with European partners and infrastructures. SILECS is a unique framework which will allow us to test our algorithms, to generate data, as required to develop a data-centric approach for computing networks.

Last but not least, software radio technologies are leaving the confidentiality of research laboratories and are made available to a wide public market with cheap (few euros) programmable equipment, allowing to setup non standard radio systems. The existence of home-made and non official radio systems with legacy ones could prejudice the deployment of Internet of things. Developing efficient algorithms able to detect, analyse and control the spectrum usage is an important issue. Our research on FIT/CorteXlab will contribute to this know-how.

- **Axis** 4 **- Other application fields** : Even if the wireless network context is still challenging and provides interesting problems, Maracas targets to broaden its exploratory playground from an application perspective. We are looking for new communication systems, or simply other multi-user decentralized systems, for which the theory developed in the context of wireless networks can be useful. Basically, Maracas might address any problem where multi-agents are trying to optimize their common behavior and where the communication performance is critical (e.g. vehicular communications, multi-robots systems, cyberphysical systems). Following this objective, we already studied the problem of missing data recovery in smart grids [11] and the original paradigm of molecular communications [6].

  Of course, the objective of this axis is not to address random topics but to exploit our scientific background on new problems, in collaboration with other academic teams or industry. This is a winning strategy to develop new partnerships, in collaboration with other Inria teams.

4 Application domains

4.1 5G, 6G, and beyond

The fifth generation (5G) broadens the usage of cellular networks but requires new features, typically very high rates, high reliability, ultra low latency, for immersive applications, tactile internet, M2M communications.

From the technical side, new elements such as millimeter waves, massive MIMO, massive access are under evaluation. The initial 5G standard validated in 2019, is finally not really disruptive with respect to the 4G and the clear breakthrough is not there yet. The ideal network architecture for billions of devices in the general context of Internet of Things, is not well established and the debate still exists between several proposals such as NB-IoT, Sigfox, Lora. We are developing a deep understanding of these techniques, in collaboration with major actors (Orange Labs, Nokia Bell Labs, Sequans, Sigfox) and we want to be able to evaluate, to compare and to propose evolutions of these standards with an independent point of view.

This is why we are interested in developing partnerships with major industries, access providers but also with service providers to position our research in a joint optimization of the network infrastructure and the data services, from a theoretical perspective as well as from experimentation.

4.2 Energy sustainability

The energy footprint and from a more general perspective, the sustainability of wireless cellular networks and wireless connectivity is somehow questionable.

We develop our models and analysis with a careful consideration of the energy footprint : sleeping modes, power adaptation, interference reduction, energy gathering, ... many techniques can be optimized to reduce the energetic impact of wireless connectivity. In a *computing networks* approach, considering simultaneously transmission, storage and computation constraints may help to reduce drastically the overall energy footprint.

4.3 Smart building, smart cities, smart environments

Smart environments rely on the deployment of many sensors and actuators allowing to create interactions between the twinned virtual and real worlds. These smart environments (e.g. smart building) are for us an ideal playground to develop new models based on information theory and estimation theory to optimize the network architecture including storage, transmission, computation at the right place.

Our work can be seen as the invisible side of cloud/edge computing. In collaboration with other teams expert in distributed computing or middleware (typically at CITIlab, with the team Dynamid of Frédéric Le Mouel) and in the framework of the chaire SPIE/ICS-INSA Lyon, we want to optimize the mechanisms associated to these technologies : in a multi-constrained approach, we want to design new distributed algorithms appropriate for large scale smart environments.

From a larger persective we are interested on various applications where the communication aspects play an important role in multi-agent systems and target to process large sets of data. Our contribution to the development of TousAntiCovid falls into this area.

4.4 Machine learning based radio

During the first 6G wireless meeting which was held in Lapland, Finland in March 2019, machine learning (ML) was clearly identified as one of the most promising breakthroughs for future 6G wireless systems expected to be in use around 2030 (https://www.6gsummit.com/). The research community is entirely leveraging the international ML tsunami. We strongly believe that the paradigm of wireless networks is moving toward to a new era. Our view is supported by the fact that artificial Intelligence (AI) in wireless communications is not new at all. The telecommunications industry has been seeking for 20 years to reduce the operational complexity of communication networks in order to simplify constraints and to reduce costs on deployments. This obviously relies on data-driven techniques allowing the network to self-tune its own parameters. Over the successive 3GPP standard releases, more and more sophisticated network control has been introduced. This has supported increasing flexibility and further self-optimization capabilities for radio resource management (RRM) as well as for network parameters optimization.

We target the following key elements :

- Obtaining data from experimental scenarios, at the lowest level (baseband I/Q signals) in multi-user scenarios (based upon FIT/CorteXlab).
- Developing a framework and algorithms for deep learning based radio.
- Developing new reinforcement learning techniques in high dimensional state-action spaces.
- Embedding NN structures on radio devices (FPGA or m-controllers) and in FIT/CorteXlab.
- Evaluating the gap between these algorithms and fundamental limits from information theory.
- Building an application scenario in a smart environment to experiment a fully cross-layer design (e.g. within a smart-building context, how could a set of object could learn their protocols efficiently ?)

4.5 Molecular communications

Many communication mechanisms are based on acoustic or electromagnetic propagation; however, the general theory of communication is much more widely applicable. One recent proposal is molecular communication, where information is encoded in the type, quantity, or time or release of molecules. This perspective has interesting implications for the understanding of biochemical processes and also chemical-based communication where other signaling schemes are not easy to use (e.g., in mines). Our work in this area focuses on two aspects: (i) the fundamental limits of communication (i.e., how much data can be transmitted within a given period of time); and (ii) signal processing strategies which can be implemented by circuits built from chemical reaction-diffusion systems.

A novel perspective introduced within our work is the incorporation of coexistence constraints. That is, we consider molecular communication in a crowded biochemical environment where communication should not impact pre-existing behavior of the environment. This has lead to new connections with communication subject to security constraints as well as the stability theory of stochastic chemical reaction-diffusion systems and systems of partial differential equations which provide deterministic approximations.

5 Social and environmental responsibility

5.1 Footprint of research activities

Considering our research activities, most of our works are based on theoretical works or simulations. We may be concerned with the following aspects :

- Experimental works : To reduce the energy footprint of CorteXlab, all equipments are connected on Electronic Power Switches (EPS) with remote access. Then, the equipments can be turned on only when an experiment is launched.

- Computer sustainability : We use to keep the computers for at least 4 years, to avoid a fast turn-over.

- Travelling represents an important part of our CO2 footprint. For 2020, most of travels have been cancelled. In the future we believe that international events remain important for young researchers, but we will start a reflexion on this question.

5.2 Impact of research results

Our research may impact the energy consumption of the digital world even if the current debate on 5G is ill-posed. It is worth that the rebound effect associated to any technology should be thought carrefully.

Typially, the desing of former wireless protocols focused on high rates and high quality of service, with a lack of considering energy and CO_2 footprint.

In the future, we will contribute to better understanding large scale impact of new communication technologies, and to investigate how innovation can help reducing the energy footprint, and may help to build a greener world.

6 Highlights of the year

- Malcolm Egan and Bayram Akdeniz got important achievements about molecular communication channel modeling. As a matter of recognition, they have several papers accepted, and M. Egan has bee invited for lectures on this topic.

- Maracas contributed to the design of TousAntiCovid. The contact tracing protocol (Robert) designed by the team Privatics, is the core of the final solution. Our contribution concerns the algorithm which computes the exposure score based on the BLE RSSI measures. The main contribution is summarized in [40]. We also contributed to explore solutions to compensate for system gains, to trade between false alarm and misdetections and we contributed to the experimental evaluation that was held in April 2020, in collaboration with many other researchers. The algorithm is now running over more than 12 million devices.

7 New software and platforms

7.1 New software

7.1.1 cortexlab-fftweb

Keywords: Experimentation, Data visualization, SDR (Software Defined Radio)

Functional Description: fftweb is a real-time spectral (FFT) visualization of one or several signal, embedded in a web page. The FFT is computed in a GNURadio block, then sent to a gateway server, which serves the web page, associated javascripts, and signal websockets. The end user only has to use the GNURadio block and and the web page, and doesn't need to bother about the internal details of the system. fftweb has been developped specially for the CorteXlab testbed but with minor adaptations, it can be used in other contexts, and also can be used to draw more generic real-time graphs, not only FFTs. Technologies: GNURadio, python, python-gevent, Javascript, D3JS

Contact: Matthieu Imbert

7.1.2 cortexlab-minus

Keywords: Experimentation, SDR (Software Defined Radio)

Functional Description: Minus is an experiment control system able to control, the whole lifecycle of a radio experiment in CorteXlab or any other testbed inspired by it. Minus controls and automates the whole experiment process starting from node power cycling, experiment deployment, experiment start and stop, and results collection and transfer. Minus is also capable of managing multiple queues of experiments which are executed simultaneously in the testbed.

Contacts: Matthieu Imbert, Leonardo Sampaio, Tanguy Risset

7.1.3 cortexlab-webapp

Keywords: Experimentation, SDR (Software Defined Radio)

Functional Description: User management module, which aims at easing platform usage and improving the metadata that we can associate with each experimenter and experiment. This metadata aims at improving the metrics we can gather about the platform's usage

Contacts: Pascal Girard, Matthieu Imbert

Partner: Insa de Lyon

7.1.4 CorteXlab-IoT Framework

Name: Framework for PHY-MAC layers Prototyping in Dense IoT Networks using CorteXlab Testbed

Keywords: SDR (Software Defined Radio), Iot, CorteXlab, GNU Radio

Functional Description: This framework was developed in the project "Enhanced Physical Layer for Cellular IoT" (EPHYL). It provides a customizable and open source design for IoT networks prototyping in a massive multi-user, synchronized and reproducible environment thanks to the hardware and software capabilities of the testbed.

URL: `https://github.com/CorteXlab/gr-ephyl`

Publication: hal-02150687

Author: Othmane Oubejja

Contact: Othmane Oubejja

Figure 3: FIT/CorteXlab facility

7.2 New platforms

7.2.1 FIT/CorteXlab

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 (FIT NOC), a set of IoT test-beds (FIT IoT-Lab), a set of wireless test-beds (FIT-Wireless) which includes the FIT/CorteXlab platform deployed previoulsy by the Socrate team and now managed by Maracas team in the Citi lab, and finally a set of Cloud test-beds (FIT-Cloud). In 2014 the construction of the room was done and SDR nodes have been 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 remotely, from internet now.

In spite of the global Covid pandemic, the year of 2020 has seen several key developments in CorteXlab:

- Faradization repairs in the experimentation room due to a flood in 2018. This required a service interruption of about 2 months with a partial disassembling of the experiementation room and re-assembling. The room is now fully operational and back in (before flood) working order.
- The establishment of a new and complementary experimentation paradigm based on Docker virtualization and direct access to nodes. While its development started in 2019, final developments made it more usable allowing it to enter mainstream, as of 2020. This new experimentation paradigm allows for more control on the part of the user than ever before, while retaining the level of security and manageability expected from the general usage of such a kind of platform. This development also allows for more flexible experiments, easing the use of non GNU Radio experiments with other kinds of SDR frameworks, like for example, OpenAir Interface. Eventually, the old Minus-based experimentation system will be seamlessly migrated into hidden Docker style experiment.
- The usage of robots in experiments has been further developed with a fully functional turtle bot equipped with LIDAR ranging and mapping and an USRP B210, able to roam the experimentation room under different and programmable mobility patterns. The usage of robot based experiments have also started with the Deep Learning Based Transmitter Identification works of Cyrille Morin et al. The robot usage will be integrated into the experimental software tools to automate the launching and stopping of the robot for each experiment.

- The web user interface was greatly developed during 2020 (went into production January 2021) as the first web interface elements of several to come to help ease the usage of CorteXlab and lower the entry ticket to the platform. This web interface allows for users to manage their own accounts, freeing engineer time to other more important developmental tasks, as well as increasing the security to social hacker attacks. The next web interface elements will greatly profit from the web frameworks developed and include a reservation tool, experiment monitoring tool and service aggregation portal.

For the next years, we will pursue the following objectives for CorteXlab:

1. Gradually, but surely, dephase old rarely used radio hardware and replace it with new, more useful, and updated hardware. While the USRPs N2932 are still good options for many kinds of experiments, they present certain limitations with respect to frequency ranges, bandwidth and communication speeds with the computer interface, meaning that they are becoming less and less relevant as time passes. The PicoSDRs have not presented a great usage profile since they are hard to use, in either pure GNU Radio mode as well as FPGA mode. They demand a great investment of tools and time from the user side and are less well documented and supported by the manufacturer. The ideal scenario would be to replace all PicoSDRs with dual transceiver USRPs N2944R and co-equip all USRP N2932 nodes with dual channel N2900 (B210 equivalents) to offer more flexibility to the users and allow for other SDR systems, like Eurecom's Openair Interface, to be easily deployed in CorteXlab.

2. Update all controlling node PCs with new and more capable machines, able to increase the complexity of the GNU Radio chains running in these machines. With the rise in popularity of Deep Learning systems for radio, some of these machines could also be equipped with a GPU unit to aid with in loco — on line Deep Learning systems.

3. Update the support equipment, increasing the networking bandwidth between the nodes themselves and also the server, which would allow for more relevant distributed (auto-coordination, distributed learning, etc...) and/or centralized (Deep Learning aggregation, cloud RAN, etc...) techniques to be studied.

4. The massive multi-user scenarios, one of the main targets of CorteXlab, are still a challenging problem do deal with both from the theoretical and experimentation fronts. We aim at providing several tools to ease with the experimentation of such scenarios, such as a) ready-made, usable multi-user frameworks with pluggable parts that allow for fast experimentation; b) extensive datasets as well as the tools used to create them, for users working with Deep Learning; c) more realistic (and close to standard compliance) physical layer systems, that will either be created from scratch or adapted from open source systems, will allow users to get closer to real life systems while remaining in the stable environment of CorteXlab's experimentation room.

5. Nodes outside the experimentation room for real-life, real interference profile communications tests in the ISM band (and other bands we might be able to get licensing deals), under regulated norms. This objective requires tests to restrain the nodes' transmission frequencies and powers to the ones allowed as to avoid harmful interference to other systems.

8 New results

In 2020, as for many teams, some collaborative projects have been delayed due to the pandemia. For instance, the implementation of our two PhC european fundings, one with Serbia and the other with Austria have been delayed. Also the context made difficult the realization of experimental tests especially with CorteXlab. In addition, we have been strongly involved in the design of the TousAntiCovid application, since March 2020, with the consequence of postponing some ongoing works. In average, the work of our PhD students has been impacted with an average delay of about 6 months.

Despite this complexe situation, the team continue to work with weekly virtual meetings, writings and readings. We have been able to contribute significantly along with the four research axes. The scenarios related to wireless networks studied in the 3 first research axes have been addressed from complementary perspectives (fundamental limits, algorithms and experimentation) and are of three kinds:

- Point-to-point transmissions: fundamental limits in [23, 30, 37] (axis 1).
- NOMA for IoT : fundamental limits of massive access [27] (axis 1), performance evaluation of Lora networks [28] (axis 2),ML based identification of active nodes [34] and ML based receveirs for MIMO-OFDM [41] (axis 2).
- Interference networks : non Gaussian interference models [25, 32, 44, 35] (axes 1 and 2), topological interference management [33] (axis 1), and transmitter identification with contributions in axes 2 and 3 [42].

In parallel, as planned in the Maracas project, we conduct research activities in axis 4, based on our triptic theoreric/algorithmic/experimental evaluation of multi-user communications, but addressing original scenarios non directly connected to our usual wireless network setup. This year we investigated on :

- Molecular communications: Modeling, capacity and bounds of molecular channels [26, 22, 24, 29, 31].
- StopCovid/TousAntiCovid : development of a scoring algorithm to assess a measure of exposure of people from RSSI BLE messages [40].
- Quantum algorithms : We started the investigation on exploiting quantum algorithms to solve complex problem in multi-user communications.

In the following subsections, these contributions are detailed. They are classified by research axis, and for each contribution, we indicate the corresponding scenario. When one contribution is at the interesection of two axes, the details are provided in the most significant one, and a link is indicated in the other research axis.

8.1 Results of axis 1: fundamental limits

The main contributions in this axis are [23, 30, 37, 27, 32, 44, 33].

The contributors in this section are Dadja Anade (PhD stud), Hassan Kallam (PhD stud), Léonardo Cardoso, Malcolm Egan, Jean-Marie Gorce. The main partners are Samir Perlaza from NEO team, Inria Sophia, Chris Zheng (PhD stud.) and Laurent Clavier from Ircica Lille, Philippe Mary from INSA Rennes, Jean-Marc Kélif from Orange Labs. These contributions have been mostly funded by the ANR project Arburst, the Nokia Bell Labs - Inria common lab and the Fed4PMR project (PIA3).

In this axis, our work explores the limits of information theory, in the non standard regime, with additional tools such as stochastic geometry, probability measure approximations, copulas and α-stable distributions. The objective is to deal with short packets, transient regimes and massive access that represent the characteristics of our playground.

- Point-to-point transmission: while the fundamental limit in terms of rate-power tradeoff has been established by C. Shannon more than 50 years ago, the fundamental limits of a point-to-point transmission in the non asymptotic regime is not perfectly known despite many contributions since the early time of information theory. More specifically, when the number of channel uses is below few hundreds, error free transmissions are not possible and a packet error probability is unavoidable. The fundamental limit in this regime may be evaluated at the second order with the error exponent or through the achievable tradeoff between codebook size M, number of channel uses n and error probability ϵ. In this context, our work [23, 30] introduces an upper bound on the absolute difference between: (a) the cumulative distribution function (CDF) of the sum of a finite number of independent and identically distributed random variables with finite absolute third moment; and (b) a saddlepoint approximation of such CDF. This upper bound, which is particularly precise in the regime of large deviations, is used to study the dependence testing (DT) bound and the meta converse (MC) bound on the decoding error probability (DEP) in point-to-point memoryless channels.

- Massive access: One of the main figures of merit in an IoT cell is the capability to support a massive access from distributed nodes, but with very small information quantity. We formalised this problem in [12] where we derived the capacity of a massive access cell, exploiting stochastic geometry results. This bound is a capacity and its achievability relies on a doubly asymptotic regime (classical asymptot with n and an a complementary asymptot with the number of transmitters). In [27], we introduce a finite time transmission constraint and we evaluate the achievability in a downlink scenario, in the finite block-length regime. We show that the gain of non orthogonal multiple access shrinks for small packets and with the best known coding schemes. In some regimes, orthogonal multiple access (OMA) outperforms NOMA schemes with SIC.

- Interference management and resource management is a very complex problem in wireless environment (e.g. [46]). The capacity region is only known for some specific scenarios under some specific channel conditions. But the optimal performance relies on perfect feedback mechanisms, to get channel state information at the transmitters and to coordinate them. As proposed by Jafar et al, topological interference management (TIM) [47] is a seducing framework to balance performance with feedback complexity. However, the actual definition of the graph associated to a wireless network introduced by Jafar does not fit with the properties of the physical network when the power scales up. We propose in [33] a new model which is able to adapt the graph with the SNR levels. This work is the core contribution of the PhD of Hassan Kallam to be defended in 2021, first semester.

- Non-Gaussian interference : A key question in IoT-based wireless networks is interference management, due to the large number of devices and a limited ability of coordination. In a collaboration between MARACAS, University of Lille, and Heriot-Watt, we have studied the interference statistics in this setting where devices randomly access multiple time or frequency resources. This results in interference represented by a heavy-tailed random vector with non-trivial statistical dependence, which we have given a detailed characterisation and methods for parameter estimation. Additionally with the University of Aalborg, we have performed a statistical analysis of real experimental data, which provides an initial confirmation of the theoretical analysis [25]. This work has been published in IEEE Communications Letters[32] and IEEE ICC [44], with a further journal paper submitted. This work also led to the successful completion of a PhD by Ce Zheng (co-supervised by MARACAS).

8.2 Results of axis 2: algorithms

The main contributions in this axis are [41, 28, 34, 42, 35]

The activities in this research axis have been done by Lelio Chetot (PhD), Diane Duchemin (PhD), Mathieu Goutay (PhD), Cyrille Morin (PhD), Jean-Marie Gorce, Malcolm Egan, Claire Goursaud. This work has been funded by the ANR projects EPHYL and ARBURST, and is strongly supported by the Nokia Bell Labs - Inria common lab. The PHD of MAzteus Mota is funded by the European project Windmill.

Almost all our contributions are relative to the Massive multi-user access in the uplink in a cellular network, either for IoT or high-rate regimes, that are strategic for 5G and beyond research.

- NOMA uplink coded access : Active user detection is a standard problem that concerns many applications using random access channels in cellular or ad-hoc networks. Despite being known for a long time, such a detection problem is complex, and standard algorithms for blind detection have to trade between high computational complexity and detection error probability. Traditional algorithms rely on various theoretical frameworks, including compressive sensing and bayesian detection, and lead to iterative algorithms, e.g. orthogonal matching pursuit (OMP). However, none of these algorithms have been proven to achieve optimal performance.In [34], we proposed a deep learning based algorithm (NN-MAP) able to improve on the performance of state-of-the-art algorithms while reducing detection time, with a codebook known at training time. This work is a joint contribution of Diane Duchemin and Cyrille Morin.

- NOMA uplink with LORA : We explored this massive access problem with the LORA technology in [28]. This is an output of the EPHYL project in colloboration with Yi Yu, Lina Mroueh, Michel

Terré from ISEP Paris and Guillaume Vivier from Sequans, Paris. We considered an IoT dedicated network corresponding to a non licensed LoRa Low Power Wide Area Network. To efficiently mitigate this high level of interference, LoRa network essentially relies on a Chirp Spread Spectrum (CSS) modulation and on repetition diversity mechanisms. Although the CSS modulation protects edge-cell's devices from the high level of interference induced by nodes in the proximity of the gateway, it fails to protect nodes at the edge of a given SF region and several trials are required to recover the packet. We proposed an adaptive multi-channels allocation policy that attributes multiple adjacent channels of 125 kHz for nodes situated at the edge of SF zones. We study the impact of this adaptive sub-band allocation on the gateways'intensities, the rate distribution and the power consumption. Our results are based on a statistical characterization of the interference in the network as well as the outage probability in a typical cell.

- Transmitter identification in interfering networks : An essential part of most wireless com-munications systems is the identification of a transmitter by a receiver. Being able to identify a transmitter at the physical layer gives context to the communication itself, but is also an important building block for more advanced techniques such as physical layer security. It can also be used to reduce over heading the transmission of small packets. Our contribution focused on reducing the impact of channel effects on identification performance and generalisation to changing conditions, something that has been little addressed in the literature, and show that increasing channel variations in the data used to train a neural network can increase its resiliency to channel modifications, leading to a gain of up to 21.3% in accuracy compared to the naive approach found in the literature. The data sets collected for this paper are available online, as well as the tools to collect new ones, in the hope that they can be reused by the community.

- ML based Multi-User MIMO receiver : in [41], we propose an ML-enhanced MU-MIMO receiver that builds on top of a conventional linear minimum mean squared error (LMMSE) architecture. It preserves the interpretability and scalability of the LMMSE receiver, while improving its accuracy in two ways. First, convolutional neural networks (CNNs) are used to compute an approximation of the second-order statistics of the channel estimation error which are required for accurate equalization. Second, a CNN-based demapper jointly processes a large number of orthogonal frequency-division multiplexing (OFDM) symbols andsubcarriers, which allows it to compute better log likelihood ratios (LLRs) by compensating for channel aging. The resulting architecture can be used in the up- and downlink and is trained in an end-to-end manner, removing the need for hard-to-get perfect channel state information (CSI) during the training phase. Simulation results demonstrate consistent performance improvements over the baseline which are especially pronounced in high mobility scenarios. This work is an important contribution of the PhD of Mathieu Goutay.

- Transmission in IoT interference. Recently, there has been a proliferation of wireless communication technologies in unlicensed bands for IoT. A key question is whether these networks can coexist given that they have different power levels, symbol periods, and access protocols. The main challenge is to characterize the impact of mutual interference arising from distinct unco-ordinated networks. As described in reseach axis 1, interference is well-modeled by the heavy-tailed α-stable distribution. In [35], we focus on the scenario where interferers transmit on multiple subbands. Under a policy where each interferer independently accesses each band with probability p, we provide an exact characterization of the interference random vector. Exploiting this characterization, we derive optimal linear combining weights and an analytical approximation for the bit error rate (BER), accurate for large transmit power.

8.3 Results of axis 3: experimental assessment

The main publications in this axis are [34, 42, 25].

The activities in this research axis are driven by Léonardo Cardoso. Cyrille Morin (PhD), Mathieu Imbert (eng.), Yasser Fadlallah (external collaborator), Amaury Paris (eng.), Othmane Oubejja (eng.), Jean-Marie Gorce, Malcolm Egan are the main contributors. This axis is funded by the ANR (SILECS EquipEx, Ephyl and Arburst projects) and supported by the Nokia Bell Labs - Inria framework.

During 2020, our experimental work was mostly devoted to the development of new functions of FIT/CorteXlab as described in section 7.2. Due to the pandamia and the repairment of CorteXlab, experimental works have been limited.

The following activities have been nevertheless developed :

- Othmane Oubejja has been recruited (CDD) in the team of prof. Michele Wigger (IMT Paris) to work on the implementation of distributed polar codes under the supervision of Yasser Fadlallah, on CorteXlab. The work is still ongoing.
- Cyrille Morin extended the experimental dataset for transmitter identification (described in section 8.2, see [42]).
- Malcolm Egan collaborated with the research groups of Laurent Clavier and Petar Popovski to validate the non Gaussian interference model in ioT [25].
- Amaury Paris, recruted as a young engineer on the ADT worked on the implementation of the LORA PHY layer developed by EPFL.The objective is to have a full Lorawan implementation on CorteXlab. This work is done in collaboration with ass.prof. Oana Iova (team AGORA, Inria).

8.4 Results of axis 4: other application fields

The topic on Molecular communications was investigated by Malcolm Egan, with Bayram Akdeniz. The work relative to TousAntiCovid is done by Jean-Marie Gorce with Malcolm Egan and Jihad Hamié. The Quantum algorithm topic is investigated by Claire Goursaud, with Yoan Clot, Idham Habibie and Jihad Hamié.

- Molecular communications : Molecular communications is an emerging field on the interface between communication theory and biology, inspired by natural mechanisms such has quorum sensing in bacteria colonies. Within MARACAS, principally Malcolm Egan, we have been developing information theoretic limits of molecular communication and also signal processing techniques. A key motivating application is the design of microfluidic lab-on-a-chip devices supporting distributed spectroscopy. The work involves a combination of information theory, statistical signal processing, analysis of stochastic reaction-diffusion models, and engineering aspects of microfluidic systems. A main contribution has been the development of "equilibrium signaling", which provides a robust framework for reliable communication even when there is a great deal of uncertainty in fluid characteristics and container geometry. This work has been supported by an INRIA PRE (2018-2020), funding a postdoc Bayram Akdeniz, and a PHC Amadeus project with the Institute of Mathematics and Scientific Computing in the University of Graz (contact Dr Bao Quoc Tang). This work has been published in three journals in 2020 (including IEEE Trans. Commun.) [26, 22, 24], and published in two conference proceedings [31, 29]. As a consequence of this work, Malcolm Egan has been invited to give a two hour lecture in the International Symposium on Molecular and Biological Communications, hosted by VNIT India.
- TousAntiCovid : When the Covid pendemia shuffled the daily-life of citizens, Inria engaged in many projects to sustain the national strategy to fight the pendemia. We have been sollicitated to contribute on the design of TousAntiCovid (previsouly named StopCovid). The initial idea and the general protocol (Robert) has been designed by the team Privatics in a large european collaboration. Our group has been sollicited to evaluate the feasibility of estimating an exposure risk from RSSI BLuetooth Low Energy (BLE) received informations between standard phones. We contributed in the following elements as reported in [40] :
  - We warned the consortium about the non callibrated nature of the devices, and we proposed an approach to compensate the measures by static gains associated to the devices (sometimes more than 30dB).
  - We developed a precise algorithm to process the RSSI traces to reduce fading impact, thus reducing the variability and to compute a local scoring from these traces. This study was based on the data acquired with the German bundeswehr under the guidance of the Fraunhoffer institute made at our disposal through the PEPP-PT European project.

  - We participated to the preparation of the real test experiments conducted at Roquencourt (Inria) and in the Subway, in April, 2020.
  - We performed a deep analysis of the results, we produced a report showing that a balance of 80% of detection and 20% of false alarm was achievable in real conditions.
  - We ensure a role of expertise in the running phase to ensure that the implemented algorithm corresponds to the proposed algorithm.

  TousAntiCovid is funded by Inria in support to the national strategy against the pandemia. The proposed algorithm has been developed in collaboration with Rémi Gribonval (ENS Lyon, INRIA team Dante) and with direct collaboration with researchers and engineers from the consortium (Inria, Orange, ...).

- Quantum algorithms : the activity in this exploratory field has speed up during 2020 thanks to the recruitment of Yoan Clot (5 months master internship), and Idham Habibie (PhD student, started in October 2020). During the master internship, very simple algorithms based on Grover approach have been implemented to find a known value in a list. Then, Muhamad has improved this algorithm to extend it to the case where we are searching for the solution x such that $f(x) = y$, where f is not easy to invert. We are now focusing on adding random parameters in the problem to be able to address wireless communications systems. Besides, Jihad Hamie has also started working with us and will supervise Idham during his PhD. We are currently working on a survey paper to present an up to date state of the art regarding quantum algorithms applied to communications systems. The objective is now to pursue the definition of quantum algorithms for decoding multiple users wireless communications in the IoT context. To this aim, we will jointly define the coding strategy and the decoding algorithm that permits to benefit from the quantum acceleration with highest efficiency.

9 Bilateral contracts and grants with industry

9.1 Bilateral contracts with industry

We have currently the following partnerships

1. Inria-Nokia Bell Labs common lab (600k€) : we are involved in two research actions (Analytics, and Network Information Theory), with the funding of two PhDs and 1 postdoc (to be hired) for Maracas.

2. SPIE-ICS (1Meuros, 2017-2021) : The Insa-Spie IoT Chair `http://www.citi-lab.fr/chairs/iot-chair/` relies on the expertise of the CITI Lab. The skills developed within the different teams of the lab integrate the study, modelling, conception and evaluation of technologies for communicating objects and dedicated network architectures. It deals with network, telecom and software matters as well as societal issues such as privacy. The chair will also lean on the skills developed at INSA Lyon or in IMU LabEx. The SPIE-ICS / Insa Lyon chaire on IoT has been setup in 2017 by JM Gorce for the benefit of the CITIlab. JM Gorce was the head of this chair from 2016 to 2019 and is now vice-head (Frédéric Le Mouel is heading the chair since sept 2019). The remaining budget for Maracas corresponds to one postdoc to be hired and overhead costs.

9.2 Bilateral grants with industry

1. Inria-Nokia Bell Labs (2019-2022): the PhD of Mathieu Goutay is supported by a CIFRE contract.

10 Partnerships and cooperations

10.1 International initiatives

Informal international partners Our main international collaborators in 2020 were:

- Ass. Prof. Troels Pedersen, University of Aalborg, Danemark.
- Prof. Dejan Vukobratovic, Department of Power, Electronic and Communication Engineering, University of Novi Sad, Serbia.
- Dr Bao Quoc Tang, Institute of Mathematics and Scientific Computing, University of Graz.
- Prof. Gareth W. Peters, School of Mathematical and Computer Sciences, Heriot Watt University, UK.

10.1.1 Participation in other international programs

We setup two PhC collaboration programs (PhC) :

- PhC Pavle Savis 2020, with Novi Saad (Serbia) : Massive IoT Radio Access (MITRA).
- PhC with U. Of Graaz, Austria :

These programs that mostly cover travel costs have been postponed due to the Covid pandemia.

10.2 European initiatives

10.2.1 FP7 & H2020 Projects

SLICES `http://slices-ri.eu/` SLICES is a flexible platform designed to support large-scale, experimental research focused on networking protocols, radio technologies, services, data collection, parallel and distributed computing and in particular cloud and edge-based computing architectures and services.

We participate as the host of one of the facilities offered to the research community.

WindMill `https://windmill-itn.eu/` We are involved as a non funded partner institution (as INSA-Lyon) and we collaborate with Nokia Bell Labs which is the funded partner (PhD of Mateus Mota, co-advised). The research in WindMill is about the integration of two research fields: wireless communications and machine learning. The overall research objective is the development of new methodologies based on machine learning in the design of wireless systems, while also contributing to the advancement of applied ML science. The achievement of the ultimate scientific objectives of the WindMill project will be pursued by the accomplishment of the following, more specific goals: Advancing the field of ML for wireless communications, Prediction schemes and anticipatory optimisation for fast-varying processes, Data-driven optimisation schemes for radio access management and System-wide "cognitive" optimisation schemes.

10.2.2 Collaborations with major European organizations

Maracas participated to the COST Action CA15104 on Inclusive Radio Communications (IRACON). Start date: 22/03/2016 – End date: 21/03/2020.

10.3 National initiatives

10.3.1 ANR

- ANR U-Wake *Ultra-Low Power Wake-up Radio* (2020-2024, 150 keuros, leader : IETR Lille) : The scientific motivation of U-Wake is to achieve a fully self-powered wake-up receiver prototype. This is made possible through the adjunction of ultra-low powerelectronic subparts (RF demodulator, neuro-inspired detector and SNN) and RF energy harvesting. Moreover, this object will be realized in standard industrial CMOS technology to allow low cost andwide scale deployment.
- ANR EPHYL *Enhanced PHY for Cellular Low Power Communication IoT* (2016-2019, 183 keuros, leader : Sequans). This project aims to investigate coming and future LPWA technologies with the aim to improve coverage, data rate and connectivity while keeping similar level of complexity and power consumption at the node for the access. New waveforms enablers will be investigated and

trialled in order to increase the efficiency of future systems and to provide efficient and fair access to the radio resource. The proposed new waveforms should comply with system constraints and with the coexistence of multiple communications.

- ANR ARBURST *Acheivable region of bursty wireless networks* (2016-2021, 195 KEuros, leader : Maracas, INSA-Lyon). In this project, we propose an original approach complementary to other existing projects, devoted to the study of IoT networks fundamental limits. Instead of proposing one specific technical solution, our objective is to define a unified theoretical framework. We aim at establishing the fundamental limits for a decentralized system in a bursty regime which includes short packets of information and impulsive interference regime. We are targeting the fundamental limits, their mathematical expression (according to the usual information theory framework capturing the capacity region by establishing a converse and achievability theorems). We will use the recent results relative to finite block-length information theory and we will evaluate the margin for improvement between existing approaches and these limits and we will identify the scientific breakthrough that may bring significant improvements for IoT/M2M communications. This project will contribute to draw the roadmap for the development of IoT/M2M networks and will constitute a unified framework to compare existing techniques, and to identify the breakthrough concepts that may afford the industry the leverage to deploy IoT/M2M technical solutions.

- ANR EquipEx FIT/CorteXlab (2009-2020, 1M€, leader : UPMC). The FIT projet is a national equipex headed by the Lip6 laboratory. As a member of Inria, Maracas is in charge of the development of the Experimental Cognitive Radio platform (CorteXlab) that is used as a testbed for SDR terminals and cognitive radio experiments. This has been operational since 2014 and is maintained 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). Thid plateform is part of the European initiative "Slices".

10.3.2 Prospective projects

- SILECS is a research infrastructure being built to gather the efforts of several testbeds, relying on the success of Grid'5000 and FIT `https://www.silecs.net/`.

11 Dissemination

11.1 Promoting scientific activities

11.1.1 Scientific events: organisation

General chair, scientific chair

- Malcolm Egan was session Chair at ACM NanoCom.

- Jean-Marie Gorce is co-chair of the track Operational and Experimental Insights (OPE), at EuCNC and 6G summit, 8-11 June, 2021.

Member of the organizing committees

- Leonardo Cardoso is co-organizer of the European GNU Radio Days (`https://gnuradio-eu-20.sciencesconf.org/`) planed to be held in Poitiers, France on 22-23 June, 2020, but has been postponed to 2021, due to the Covid pandemia.

- Malcolm Egan was co-organizer (with Bao Quoc Tang, Univ. Graz) of a workshop on "Reaction, Diffusion and Molecular Communication" (Online).

Member of the conference program committees Maracas researchers have been members of the following conference program committees: IEEE Global Communications Conference (Globecom), IEEE International Conference on Communications (ICC), IEEE International Conference on Computing, Networking and Communications (ICNC), IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), 5G-World Wide Forum.

Reviewer Maracas members have been reviewers for the following conferences : Asia-Pacific Conference on Communications (APCC); European Conference on Networkd and Communications (EuCNC); IEEE Global Communications Conference (Globecom); IEEE International Conference on Acoustic, Speech and Signal Processing (ICASSP); ACM NanoCommunications Conference; IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC); IEEE International Conference on Communications (ICC); International Conference on Computing, Networking and Communications (ICNC); IEEE International Symposium on Information Theory (ISIT); IEEE Wireless Communications and Networking Conference (WCNC)

11.1.2 Journal

Member of the editorial boards

- Malcolm Egan is an associate editor of IEEE Communication letters and guest editor of IEEE Acces Special Issue.
- Jean-Marie Gorce is ans associate editor of Entropy (MDPI) and Journal of Wireless Communications and Networking (JWCN, Springer).
- Claire Goursaud is an associate editor of European Transactions on Telecommunications (ETT) and of Internet Technol. Letters (ITL).

Reviewer - reviewing activities Maracas members are regular reviewers of the main journals in our fields : IEEE Communications Letters, IEEE Wireless Communication Letters, IEEE Journal on Selected Areas in Communications, IEEE Journal on Selected Topics in Signal Processing, IEEE Sensors, IEEE Internet of Things Journal, IEEE Trans on Communications, IEEE Trans on Information Theory, IEEE Trans. on Mobile Computing, IEEE Trans on Molecular Biological, IEEE Trans on NanoBioscience, IEEE Trans on Signal Processing, IEEE Trans on Vehicular Technologies, IEEE Trans on Wireless Communications and Multi-Scale Communications, EURASIP Journal on Advances in Signal Processing, EURASIP Journal on Wireless Communications and Networking.

11.1.3 Invited talks

- M. Egan gave an invited lecture (2 hours) at International Symposium on Molecular and Biological Communications, hosted by VNIT India.
- M. Egan had an invited paper in ACM International Workshop of Nanoscale Computing, Communications, and Applications (2020).

11.1.4 Leadership within the scientific community

11.1.5 Scientific expertise

- JM Gorce is a member of the Commission d'évaluation (CE), Inria.
- C. Goursaud is a member of the commission nationale des universités (CNU), in section 61.

11.1.6 Research administration

- JM Gorce is vice head for research at the Inria Grenoble Rhone-Alpes centre.
- JM Gorce is a member of the Groupe Académique de l'Université de Lyon.
- M Egan is a member of the scientific committee of CITIlab.
- C Goursaud is vice-director of CITIlab (starting on January 2021).

11.2 Teaching - Supervision - Juries

11.2.1 Teaching

Maracas members are teaching regularly at the telecommunications department of INSA Lyon. We deliver courses with strong connections with our research ativity.

- Bachelor : L Cardoso, Electromagnetism and Wave Physics, 104 eqTD, L2, First Cycle Dept, INSA Lyon, France.
- Bachelor : L Cardoso, Mathematics for Engineering, 60h eqTD, L1, First Cycle Dept, INSA Lyon, France.
- Bachelor : L Cardoso, C Goursaud, Digital Communications, 80h eqTD, L3, Telecommunications dept, INSA Lyon, France.
- Bachelor : L Cardoso, C Goursaud, Research projetcs, 32h eqTD, L3, Telecommunications dept, INSA Lyon, France.
- Master : JM Gorce, M Egan, L Chetot - Advanced Digital Communications, M1, Telecommunications dept, INSA Lyon, France.
- Master : JM Gorce, D Duchemin - Radio Access Networks, 32h eqTD, M1, Telecommunications dept, INSA Lyon, France.
- Master : L Cardoso, C Morin, Software Radio, 32h eqTD, M2, Telecommunications dept, INSA Lyon, France.
- Master : C Goursaud, Communications Systems, 32h eqTD, M1, Telecommunications dept, INSA Lyon, France.

In addition, this year, we taught a master (M2) course at ENS Lyon:

- Master : S Perlaza, JM Gorce, Selected Topics in Information Theory, 32h eqTD, M2, Compute sciences dept, ENS Lyon, France.

11.2.2 Supervision

PhDs defended in 2020:

- Nizar Khalfet (,Insa Lyon), Study of stochastique energy sources to power communication system. sup. Samir Perlaza and Jean-Marie Gorce.
- Ce Zheng (, IRCICA Lille), Statistical models for IoT interference. sup Malcolm Egan, Jean-Marie Gorce and Laurent Clavier (IRCICA, Lille).

PhDs in progress:

- Diane Duchemin (start 01 Oct. 2016, defense under preparation) : Distributed coding for dense IoT networks. sup. Claire Goursaud and Jean-Marie Gorce.
- Hassan Kallam (start 01 Feb 2017, defense under preparation) : Topology aided Multi-User Interference Management in Wireless Networks. sup. Loonardo S. Cardoso and Jean-Marie Gorce.

- Dadja Anade (start 01 Oct 2017, defense under preparation) : Non-asymptotic fundamental limits of impulsive radio communications. sup. Philippe Mary, Samir Perlaza (NEO, Inria, Sophia), Jean-Marie Gorce.
- José Rugelles (start 01 Jan 2017): Deep Learning for Security in GSM Based IoT Systems. sup. Loonardo S. Cardoso and Edward Guillén (U. of Colombia).
- Lélio Chetot (start 01 Oct. 2018) : From finite blocklength information theory to multi-user M2M communication protocols. sup. Malcolm Egan and Jean-Marie Gorce.
- Cyrille Morin (start 20 Feb 2018): Deep learning for next generation communication systems. sup. Leonardo S. Cardoso, Jakob Hoydis (Nokia Bell Labs) and Jean-Marie Gorce.
- Mathieu Goutay (start 01 Feb. 2019) : Prédistortion digitale profonde. sup Jakob Hoydis (Nokia Bell Labs) and Jean-Marie Gorce.

Masters and interns

- Antoine Dejonghe (Machine learning,L. Cardoso).
- Yohann Clot (Quantum algorithms, C. Goursaud).
- Xuan Thang Tran (Molecular communications, M. Egan).

11.2.3 Juries

1. Malcolm Egan
   - Examiner for the PhD of Homa Nikbakht (Télécom Paris, Institut Polytechnique, 15/12/2020), "Networks with Mixed-Delay Constraints".
   - Examiner and co-adviser for the PhD of Ce Zheng (IRCICA, U. of Lille, 08/12/2020), "Impulsive and Dependent Interference in IoT Networks".
2. Jean-Marie Gorce
   - Reviewer for the HdR of Damien Roque (Supaéro, INP Toulouse, 29/06/2020), "Gestion de l'interférence dans les systèmes à haute efficacité spectrale".
   - Examiner and co-adviser for the PhD of Ce Zheng (IRCICA, U. of Lille, 08/12/2020), "Impulsive and Dependent Interference in IoT Networks".
   - Examiner and co-adviser for the PhD of Nizar Khalfet (CITI, INSA Lyon, /2020), "Simultaneous Information and Energy Transmission".
   - Reviewer for the PhD of Homa Nikbakht (Télécom Paris, Institut Polytechnique, 15/12/2020), "Networks with Mixed-Delay Constraints".
   - Reviewer for the PhD of Matthieu Roy (IETR, Insa Rennes, 23/11/2020), "A ray-based Approach for Massive MIMO Systems".
   - Reviewer for the PhD of Marie-Josepha Youssef (Ecole Mines-Telecom, IMT-Atlantique, 19/11/2020), "New approaches for resource allocation in future communication networks using NOMA and UAV".
   - Reviewer for the PhD of Simon Bicaïs (CEA Leti, Université Grenoble-Alpes (UGA), 12/11/2020), "Design of the Physical Layer for future sub-TeraHertz Communication Systems".
   - Chair for the PhD of Guillaume Celosia (CITI, INSA Lyon, 22/09/2020), "Privacy Challenges in Wireless Communications of the Internet of Things".
   - Reviewer for the PhD of Chhayarith Heng Uy (CEA Leti, Université Grenoble-Alpes (UGA), 25/06/2020), "Analyse automatique du canal de propagation pour l'adaptation des liens radiofréquence ultra-faiblevconsommation dédiés aux applications à très grande autonomie".

- Reviewer for the PhD of Apostolos Avranas (Télécom Paris, Institut Polytechnique, 04/06/2020), "Resource Allocation for Latency Sensitive Wireless Systems".
- member of the thesis monitoring committee of Gurvan Priem (Biosency and University of Rennes).
- member of the thesis monitoring committee of Mohammadreza Mardani (IETR, Rennes).

3. Claire Goursaud

- Reviewer for the PhD of Ivan Marino MARTINEZ (Université Bretagne Sud/Lorient Lab-STIC, 12/01/2021), "Jamming in LPWAN : Modelisation and study of the impact on LoRaWAN network and counter-measures".
- Reviewer for the PhD of Cédric Bérenger (Laboratoire d'Informatique et Systèmes d'Aix-Marseille Université, 14/01/2021), "Grands Réseaux Maillés Basse Énergie : Protocoles minimalistes pour la Synchronisation, la mesure de Distance et le Partitionnement".
- member of the thesis monitoring committee of Wissal Ben Ameur (IETR, Rennes).

11.3 Popularization

11.3.1 Articles and contents

JM Gorce, in the context of the chaire IoT between SPIE-ICS/INRIA gave a talk at an industrial event. He also copublished an article related to the popularization of IoT access techniques [43].

12 Scientific production

12.1 Major publications

[1] G. C. Alexandropoulos, P. Ferrand, J.-M. Gorce and C. B. Papadias. 'Advanced coordinated beamforming for the downlink of future LTE cellular networks'. In: *IEEE Communications Magazine* 54.7 (July 2016). Arxiv: 16 pages, 6 figures, accepted to IEEE Communications Magazine, pp. 54–60. DOI: 10.1109/MCOM.2016.7509379. URL: https://hal.inria.fr/hal-01395615.

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12.2 Publications of the year

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