RESEARCH CENTRE

Inria Lyon Center

IN PARTNERSHIP WITH:

Institut national des sciences appliquées de Lyon

2022
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

Contents

Project-Team MARACAS

Creation of the Project-Team: 2020 January 01

Keywords

Computer sciences and digital sciences

A1.2.5. – Internet of things

A1.2.6. – Sensor networks

A1.2.7. – Cyber-physical systems

A1.5.2. – Communicating systems

A3.4.1. – Supervised learning

A3.4.3. – Reinforcement learning

A3.4.8. – Deep learning

A5.9. – Signal processing

A5.9.2. – Estimation, modeling

A5.9.6. – Optimization tools

A7.1.4. – Quantum algorithms

A8.6. – Information theory

A8.7. – Graph theory

A8.8. – Network science

A8.11. – Game Theory

A9.2. – Machine learning

A9.3. – Signal analysis

A9.9. – Distributed AI, Multi-agent

Other research topics and application domains

B1.1.10. – Systems and synthetic biology

B4.5.1. – Green computing

B6.2.2. – Radio technology

B6.4. – Internet of things

B6.6. – Embedded systems

B8.1. – Smart building/home

B8.2. – Connected city

1 Team members, visitors, external collaborators

Research Scientist

- Malcolm Egan [INRIA, Researcher]

Faculty Members

- Jean-Marie Gorce [Team leader, INSA LYON, Professor, HDR]
- Lelio Chetot [INSA LYON, Associate Professor, from Sep 2022]
- Claire Goursaud [INSA LYON, Associate Professor, HDR]
- Jihad Hamié [INSA Lyon, until Jun 2022]
- Leonardo Sampaio Cardoso [INSA LYON, Associate Professor]

Post-Doctoral Fellows

- Naveed Ahmad [INSA Lyon, until Nov 2022]
- Homa Nikbakht [Inria, until Jun 2022]

PhD Students

- Lelio Chetot [INSA LYON, until Jul 2022]
- Fabrice Dupuy [ORANGE, CIFRE]
- Mathieu Goutay [Nokia Bell Labs, CIFRE, until Jan 2022]
- Muhammad Idham Habibie [INRIA]
- Alix Jeannerot [UDL]
- Guillaume Marthe [INSA LYON]
- Shashwat Mishra [NOKIA BELL LABS, CIFRE]
- Mateus Pontes Mota [NOKIA BELL LABS]
- Shanglin Yang [ORANGE, CIFRE, from Sep 2022]

Technical Staff

- Pascal Girard [INSA LYON, Engineer]
- Matthieu Imbert [INRIA]
- Amaury Paris [INRIA, until Nov 2022, Engineer]

Interns and Apprentices

- Thomas Beligné [Insa Lyon, Intern, from Mar 2022 until Aug 2022]
- Romain Berthomieu [Insa Lyon, Intern]
- Christian Da Cruz [Insa Lyon, Intern, from Mar 2022 until Aug 2022]
- Chetanveer Gobin [INSA Lyon, from Sep 2022]
- Alexandre Rodriguez [INSA Lyon, Intern, from Feb 2022]
- Enzo Zattarin [INSA Lyon, Intern, from Sep 2022]

Administrative Assistant

- Claire Sauer [INRIA]

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. [48, 46, 53].

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 [23] 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 [50].

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 [49, 51] 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 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

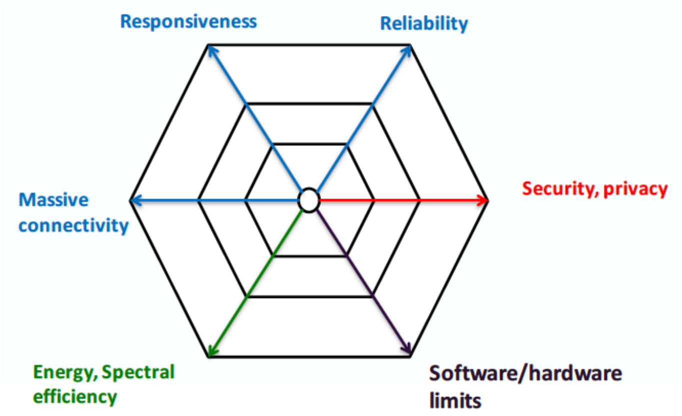

Figure 1: Main metrics for future networks (5G and beyond)

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 [10] of for multi-constrained systems [22].

  This also means revisiting the fundamental estimation-detection problem [52] 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* [45] proposed for cellular networks shows the high potential of considering simultaneously data and network properties. Maracas is willing to extend his skills on source coding aspects to tackle with a data-oriented modeling of *Computing Networks*.

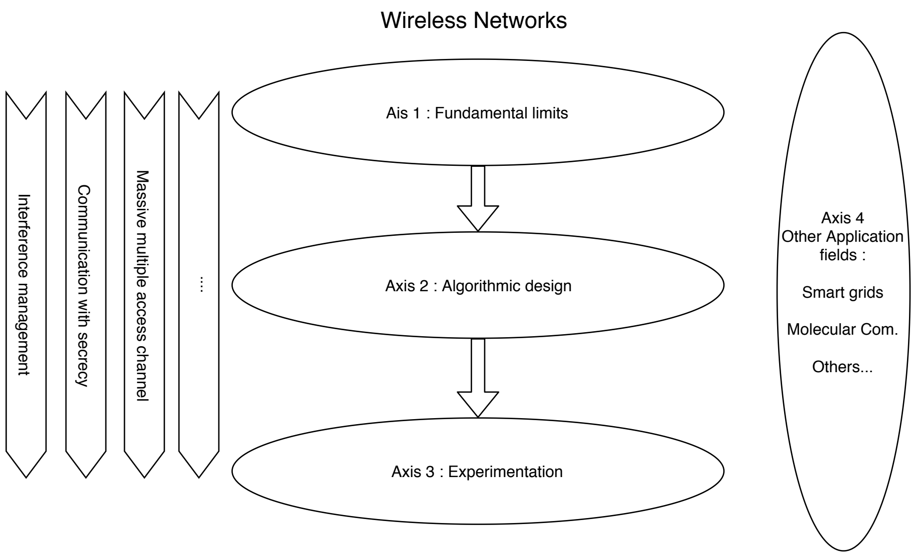

Figure 2: Maracas organization

- **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 [54, 47].

  Another emerging research direction relies on using machine learning techniques [44] 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 (), 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 [2, 13]. 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 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 [14] and the original paradigm of molecular communications [8].

  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 perspective 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 (SNS 6G IA Horizon Europe). 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

6.1 Awards

Two PhDS have been defended :

- Mathieu Goutay developed ML based transmission chains. This is a joint work between Maracas and Nokia.
- Lélio Chetot developped new algorithms for MU detectors, using Gaussian approximate message passing theory and he integrated non homogeneous and correlated ativities in the model.

7 New software and platforms

7.1 New software

7.1.1 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.

Contact: Matthieu Imbert

7.1.2 cortexlab-webapp

Keywords: Experimentation, SDR (Software Defined Radio)

Functional Description: The cortexlab web application, 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 The cortexlab web application provides several modules and workflows : - a user management module that allows users to manage their account with a graphical interface. This module also contains two administrator workflows: one to import several user accounts, at the same time, from a json file, which is useful for many use cases, and one to request users to re-validate their accounts, if, for example, the expiration date is outdated, - a booking module: it allows users to book the test bed with a user-friendly graphical interface, instead of the command line. It also allows the user to manage their reservations, - a security module.

Contact: Pascal Girard

Partner: Insa de Lyon

7.1.3 Cortexlab_LORA_PHY

Name: Multi nodes LORA in GNU radio

Keywords: CorteXlab, GNU Radio, LoRaWAN

Functional Description: Dynamic and customizable LoRa physical layer, derived from the original EPFL LoRa implementation in GNU Radio. More information on this implementation can be found in "Dynamic LoRa PHY layer for MAC experimentation using FIT/CorteXlab testbed", written by Amaury Paris, Leonardo S. Cardoso and Jean-Marie Gorce.

This adaptation allows end-users to connect any existing upper layer to the physical layer through an easy to use interface using the JSON format, without having to implement the upper layer in GNU Radio.

URL: https://github.com/AmauryPARIS/LoRa_PHY_Cxlb/

Contact: Leonardo Sampaio

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. The framework has been extended in 2022, to improve modularity, with the project ADT 3D-SIP.

Release Contributions: Extension to improve synchronization problems, and to support modularity. Independent optimization and development of the PHY layer, the MAC layer and the radio resource management algorithms.

URL: https://github.com/AmauryPARIS/gr-ephyl

Publication: hal-02150687

Author: Othmane Oubejja

Contact: Jean-Marie Gorce

Figure 3: FIT/CorteXlab facility

7.2 New platforms

Participants: Pascal Girard, Jean-Marie Gorce, Mathieu Imbert, Cyrille Morin, Amaury Paris, Léonardo Sampaio Cardoso.

7.2.1 FIT/CorteXlab

FIT (Future Internet of Things) was a french Equipex (Équipement d'excellence) built to develop an experimental facility, a federated and competitive infrastructure with international visibility and a broad panel of customers. FIT is 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 managed by Maracas team, 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.

As the FIT project development phase ended in 2019 , CorteXlab has seen continued usage as well as further developments. FIT/CorteXlab has been used by both INSA and the European GNU Radio Days (Gnu radio days) for both lectures and tutorials. Several scientific measurements campaigns have taken place in the FIT/CorteXlab experimentation room and are under works at the moment.

In 2022 the following work has bee done:

- The usage of docker containers as the unit of experimentation has been further developed, with the addition and maintenance of new reference docker images, with the improvement of the overall system reliability, and with the improvement of the feedback provided to users through detailed logs collected during experiment runs.

- Automatic shutdown of unused nodes has been added, providing several benefits such as reduction of power consumption (both of the nodes and also the climate control, because the platforms produces less heat), and increase of the lifetime of experimental equipments (especially SDR nodes).

- 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. It provides a user friendly graphical interface so that users can book the platform and manage their reservations It also allows administrators to import several user accounts at the same time and to request revalidation of user accounts.
- Repair of the remotelly controlled Electric Power Switches (EPS). The EPSs are essential elements of the CorteXlab platform as it allows for remote control of the nodes' computers as well as maintenance. Many EPSs have experienced failure in the years since CorteXlab's inauguration. This hindered the full usage of the testbed. They have been fixed by the platform engineers and have had their life-time extended. However, a more realiable solution for electrically controlling the nodes must be sought.
- A reservation tool has seen its development start in 2021 and was delivered in production early 2022. It allows fast and easy reservations of the CorteXlab resources, which will potentially increase the pool of potential CorteXlab users, as well as free engineer more time. Experiment monitoring tool and service aggregation portal are some functionalities developped in 2022.
- As the radio hardware in the CorteXlab experimentation room gets old and outdated, its replacement by newer and more capable radios has become an important step to maintain CorteXlab a state of the art platform. These new USRPs will enable to experiment with demanding 5G systems as well as more refined measurement capabilities due to its high bandwidth. It will be paramount for new Deep Learning based experiments, such as radio localization and identification.
- The develoment of a LoRa basis for experimentation in CorteXlab has also seen the light of day during 2021 (described above as an independent software: Cortexlab_LORA_PHY). A new LoRa starting point for experimenting has been created, based from an existing EPFL implementation, with the adition of dynamic features as well as a simplified MAC layer. This was the work of both an Inria engineer as well as an intern. A deliverable from this project is a tutorial, hosted at the CorteXlab wiki page (tutorial Lora on CorteXlab) and presented in [43].
- The framework CorteXlab-IoT Framework has been renewed and transformed in a more flexible framework by Amaury Paris, to foster the use of multi-user access tests by other teams. This framework has been presented at the international GNU radio conference () and at the workshop on AFF3CT organized by Inria Bordeaux (.
- The construction of a dataset for radio signal detection and identification has been built in collaboration with L2S, Supelec.

In the coming years, we will pursue the following objectives for CorteXlab:

1. Continued update of old and 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.

CorteXlab will be part of the SLICES/FR node of the European project SLICES, and will be integrated in the set of plateform for 5G and beyond in the framework of the PEPR 5G. We also expect to collaborate in the future SNS-IA program of Horizon Europe. More specifically, CorteXlab can be used to explore machine learning based radio, resource management and also tu evaluate joint sensing and communication concepts for twinning real and virtual worlds.

8 New results

In 2022, we were able to restart dome collaborative projects, and to attend some conferences. For instance, the implementation of our two PhC European funding, one with Serbia (Novi Saad) and the other with Austria have been run out.

We summarize our contributions along four main lines : fundamental results, multi-user network scenarios, experimentation and cross-roads exploration.

An important reference scenario that is common for all our works is a mono-cellular system with either downlink or uplink access with guaranties (reliability or delay).

Fundamental limits: Many applied problems in communication can be evaluated under the light of applied probabilities, at the root of information theory and estimation theory. A part of our work in axis 1 contributes in this area. In 2022 we obtained 4 important results:

- The fundamental limits in the finite block-length (FBL) have been used to evaluate joint channel coding of consecutive messages with heterogeneous decoding deadlines [36, 42].
- Optimal strategies to superpose URLLC and eMBB traffics has been established [37, 29].
- In a different setting, we evaluated physical layer security (PLS) by considering correlated fading channels and side information at the transmitter, exploiting the copula technique [30].
- We also considered a large scale scenario with random spatial fields of interferers over multiple carriers. We derived a novel tractable characterization of the interference probability distribution based on an application of Sklar's theorem to develop a combination of α-stable and t-copula dependence models [31]

Algorithms in multi-user environments: Multi-user network scenarios constitute the natural playground for our research, for instance considering an isolated cell in the downlink, or a LORA random access topology, etc... For each scenario, we may explore it under three perspectives: fundamental limits (axis 1), efficient algorithms (axis 2) and experimental evaluation (axis 3). Before going deeper in these contributions, we herein summarize the scenario studied this year

- **Point-to-point transmissions**: despite its long history and well-established results, the basic scenario made of one transmitter and one receiver still represents challenges: Typically, to adapt the transmission to new propagation channels (e.g. THz, VLC) with non classical properties, but also to support new QoS requirements (URLLC), which occurs especially in the context of machine to machine communications. Last but not least, revisiting the P2P communication problem under the light of machine learning may bring new breakthrough in terms of encoder/decoder complexity and adaptability.
  Our contributions this year concern first the evaluation of the optimal receiver in the context of an impulsive noise, which occur in random access large scale networks when the interference is considered as noise. We evaluated a new technique for log-likelihood ratio (LLR) estimation. This is an important output of the ANR Arburst, prepared in collaboration with INSA Rennes and IEMN Lille [33].

  In the PhD of Mathieu Goutay, we worked with Nokia Bell Labs on the design of ML aided PHY layer to enhance the end-to-end performance, to suppress the need of pilots, and to optmize the tradeoff between rates and bandwidth [41]

- **Multiple access channel**: in this setup, individual nodes randomly send packets to a unique BS. In the IoT context, one isolated cell may serve thousand of nodes with low transmission probability. The design of an optimal setting for such scenario requires to consider as a whole the PHY and the MAC layers either in the downlink or the uplink. In this area, we proposed 3 new contribution. In the first one, we collaborated with Nokia and with the university of Adelaide (Australia) to elaborate a MAC protocol for visible light communications [27]. We also proposed in collaboration with IMT Lille and Aalborg University, a new random access strategy considering the acitivity correlation between the sensors activity [38]. This question has been also in the core of the PHD of Lelio Chetot where the impact of this correlation has been considered to elaborate a new Hybride Gaussian Approximate Message Passing (HGAMP) algorithm for user detection and channel estimation problems in multi-user setting [40]. Last but not least, we also enhanced the IoT framework developed for CorteXlab to foster the evaluation of multiple access techniques [43]. We also explored communication learning strategies [35].

- **NOMA in the Downlink**: In the downlink, we explored the use of a graph matching technique to maximise the density of connected devices using multiple-resources NOMA [34].

Crossroad studies: The objective of axis 4 is either to explore new setups not directly related to the wireless context, or to explore new techniques or models that could be useful for wireless. In the past, we started to evaluate ML techniques, which are now part of our classical tools. We also worked extensively on the molecular communication problem. This year the focus was on :

- Quantum algorithms: the fundamental question we are addressing is on the use of quantum algorithms to improve hard problems, such as the active users detection in the multiple access framework [32, 39]. This is the objective of Idham Habibie' PhD.

- Smart building, industry4.0: an important aspect for industrial processes is to limit exposure to system malfunction. We proposed in [28] the development of new algorithms based on modifier adaptation and reinforcement learning, which efficiently manage the tradeoff between cost minimization and identification.

8.1 Axis 1: fundamental limits

8.1.1 Contributions in Information Theory in the FBL

Participants: Malcolm Egan, Jean-Marie Gorce, Homa Nikbakht.

A standard assumption in the design of ultra-reliable low-latency (URLLC) communication systems is that the duration between message arrivals is larger than the number of channel uses before the decoding deadline. Nevertheless, this assumption fails when messages rapidly arrive and reliability constraints require that the number of channel uses exceeds the time between arrivals. In this paper, we study channel coding in this setting by jointly encoding messages as they arrive while decoding the messages separately, allowing for heterogeneous decoding deadlines. For a scheme based on power sharing, we analyze the probability of error in the finite block-length regime. We show that significant performance improvements can be obtained for short packets by using our scheme instead of standard approaches based on time sharing [36]. While the former scheme was based on superposition coding, we later proposed an evaluation of a dirty paper coding (DPC) based approach [42].

8.1.2 Contributions in mixed traffic conditions

Participants: Malcolm Egan, Jean-Marie Gorce, Homa Nikbakht, Michèle Wigger* (IMT Paris), Shlomo Shamai* (Technion - Israel Institute of Technology), H. Vincent Poor* (Princeton U.).

Following the work developed by Homa Nikbakht in her PhD, we review and extended the different strategies to mix URLLC traffic with eMBB traffic. The superposition og both traffic exploit SIC and SC, in the asymptotic, or n the FBL regime [29]. In [37], Wyner's soft-handoff network is considered where transmitters simultaneously send messages of enhanced mobile broadband (eMBB) and ultra-reliable low-latency communication (URLLC) services. Due to the low-latency requirements, the URLLC messages are transmitted over fewer channel uses compared to the eMBB messages. To improve the reliability of the URLLC transmissions, we propose a coding scheme with finite block-length codewords that exploits dirty-paper coding (DPC) to precancel the interference from eMBB transmissions. Rigorous bounds are derived for the error probabilities of eMBB and URLLC transmissions achieved by our scheme. Numerical results illustrate that they are lower than for standard time-sharing.

8.1.3 Contributions to physical layer security

Participants: Jean-Marie Gorce, Farshad Rostami Ghadi* (U. of Malaga, Spain), F.J. Lopez-Martinez* (U. of Malaga, Spain), Wei-Ping Zhu* (Concordia U., Canada).

We collaborated to the work of Farshad Rostami Ghadi who investigated the impact of side information (SI) on the performance of physical layer security (PLS) under correlated fading channels. Considering non-causally known SI at the transmitter and exploiting the copula technique to describe the fading correlation, we derive closed-form expressions for the average secrecy capacity (ASC) and secrecy outage probability (SOP) under positive/negative dependence conditions. We indicate that considering such knowledge at the transmitter is beneficial for system performance and ensures reliable communication with higher rates, as it improves the SOP and brings higher values of the ASC.

8.1.4 Contributions to communication limits in non Gaussian interference

Participants: Malcolm Egan, Jean-Marie Gorce, Ce Zhang* (IMT Lille Douai), Laurent Clavier* (IMT Lille Douai), Gareth Peters* (Heriott Watt U.).

This work was done with the PhD of Chris Zheng, who was co-supervised by L. Clavier from IEMN and Malcolm Egan from Inria Lyon. Effective symbol detection, channel estimation and decoding of channel codes require an accurate characterization of the noise probability distribution. In many systems, notably the internet of things, noise is largely in the form of interference, arising from a massive number of simultaneous transmissions from uncoordinated devices. Obtaining the probability distribution of the interference is a challenging problem due to the use of non-orthogonal multiple access schemes over several sub-carriers (leading to multivariate statistical models) and the heavy-tailed nature of the interference due to the random locations of devices. In this work, a novel tractable characterization of the interference probability distribution is established based on an application of Sklar's theorem to develop a combination of α-stable and t-copula dependence models. We demonstrate that this formulation produces an accurate statistical modeling framework that admits efcient parameter estimation methods. As an illustration of the utility of our models, we develop a simple-to-implement nonlinear receiver when a binary signal is transmitted over all subcarriers by the desired transmitter, which is efective in a range of scenarios and can signifcantly outperform existing approaches [31].

8.2 Axis 2: algorithms

8.2.1 Optimal receiver in non Gaussian interference

Participants: Dadja Anade, Malcolm Egan, Jean-Marie Gorce, Laurent Clavier* (IMT Lille Douai), Anne Savard* (IMT Lille Douai), Alban Goupil* (CReSTIC, Reims), Philippe Mary* (Insa Rennes), Yasser Mesrah* (Insa Rennes).

Complementarily to the work presented in section8.1.4, we evaluated optimal receivers for non gaussian interference in the framework of the ARBURST project [33]. A challenge in coping with impulsive noise, particularly alphastable models, is that tractable expressions for the log-likelihood ratio (LLR) are not available, which bas a large impact on softinput decoding schemes, e.g., low-density parity-check (LDPC) packets. On the other band, constraints on packet length also mean that pilot signais are not available resulting in nontrivial approximation and parameter estimation problems for the LLR. In this paper, a new unsupervised parameter estimation algorithm is proposed for LLR approximation. In terms of the frame error rate (FER), this algorithm is shown to significantly outperform existing unsupervised estimation methods for short LDPC packets (on the order of 500 symbols), with nearly the same performance as when the parameters are perfectly known. The performance is also compared with an upper bound on the information-theoretic limit for the FER, which suggests that in impulsive noise further improvements require the use of an alternative code structure other than LDPC.

8.2.2 Deep learning in wireless

Participants: Jean-Marie Gorce, Mathieu Goutay, Fayçal Ait Aoudia* (Nokia Bell Labs), Jakob Hoydis* (Nokia Bell Labs).

The PhD of Mathieu Goutay [41] developed new machine learning based transmission techniques by learning from the data. These systems can be trained to embrace the undesired effects of practical hardware and channels instead of trying to cancel them. Mathieu Goutay's thesis compared different approaches to unlock the full potential of DL in the physical layer. First, he described a neural network (NN)-based block strategy, where an NN is optimized to replace one or multiple block(s) in a communication system. He applied this strategy to introduce a multi-user multiple-input multiple-output (MU-MIMO) detector that builds on top of an existing DL-based architecture. The key motivation is to replace the need for retraining on each new channel realization by a hypernetwork that generates optimized sets of parameters for the underlying DL detector. Second, he detailed an end-to-end strategy, in which the transmitter and receiver are modeled as NNs that are jointly trained to maximize an achievable information rate. This approach allows for deeper optimizations, as illustrated with the design of waveforms that achieve high throughputs while satisfying peak-to-average power ratio (PAPR) and adjacent channel leakage ratio (ACLR) constraints. Lastly, he proposed a hybrid strategy, where multiple DL components are inserted into a traditional architecture but trained to optimize the end-to-end performance. To demonstrate its benefits, he proposed a DL-enhanced MU-MIMO receiver that both enable lower bit error rates (BERs) compared to a conventional receiver and remains scalable to any number of users. Each approach has its own strengths and shortcomings. While the first one is the easiest to implement, its individual block optimization does not ensure the overall system optimality. On the other hand, systems designed with the second approach are computationally complex and do not comply with current standards, but allow the emergence of new opportunities such as high-dimensional constellations and pilotless transmissions. Finally, even if the block-based architecture of the third approach prevents deeper optimizations, the combined flexibility and end-to-end performance gains motivate its use for short-term practical implementations

8.2.3 Algorithms for multiple access channel for IoT

Participants: Lélio Chetot, Malcolm Egan, Jean-Marie Gorce, Shashwat Mishra, Mateus Mota, Abdullah A. Saed* (U. of Adelaide), Siu Wei Ho* (U. of Adelaide), Ce Zhang* (IMT Lille Douai), Laurent Clavier* (IMT Lille Douai), Anders E Kalør* (Aalborg U), Petar Popovski* (Aalborg U), Chung Sue Chen* (Noka Bell Labs), Lou Salaun* (Nokia Bell Labs), Alvaro Valcarce* (Nokia Bell Labs).

Visible Light Decentralized Asynchronous Systems: With Nokai and Adelaide University, we elaborated a strategy dedicated for Visible Light Decentralized Asynchronous Systems [27]. In some visible light communication (VLC) systems, transmitters are light sources which support not only illumination but also information broadcast and positioning. Since transmit signals in these systems inevitably interfere with each other at the receiver side, extra devices may be added to synchronize the transmitters, but this impairs an appealing advantage in VLC systems that existing lighting infrastructure can be simply reused. In this work, we proposed a novel multiple access scheme to realize decentralized asynchronous VLC systems such that both the transmitters and receivers are asynchronous. For a system with N transmitters, two unique codewords of L chips are allocated to each transmitter where L is a prime number larger than $4N$. Those codewords are designed to help maintain a constant transmitted average power and enhance channel estimation, as well as conveying data. Our scheme enables the receiver to obtain one channel estimate and one data symbol per L chips. Simulation results show that the proposed scheme significantly outperforms other schemes in the literature in terms of bit error rate and system throughput.

Random access under correlated sources: This work was done by Ce Zhang in his PhD (supervised at IEMN and Inria) was done in collaboration with Aalborg U and focused on random access under correlated sources [38]. This is the first paper at the best of our knowledge, that do not consider i.i.d. sources. A key challenge for random access communications arising in the monitoring of physical phenomena is optimizing the access policy. This is particularly the case when the activity of each sensor is correlated, contrasting with the independence assumption underpinning standard slotted ALOHA schemes. In this work, we proposed a stochastic resource allocation algorithm to reduce outages via maximization of the expected number of sensors that are able to reliably communicate with an access point. Allowing for devices to transmit data over multiple consecutive frames, we show that the proposed algorithm converges with probability one to a locally optimal solution. Moreover, our algorithm significantly outperforms existing methods in terms of the average number of successful transmissions when utilizing successive interference cancellation.

AUDaCE - activity user detection and channel estimation: The PhD of Lelio Chetot, funded by the common lab Inria-Nokia, worked on the AUDaCE problem (activity user detecton and channel estimation) which is the first work the BS performs in a random access channel.In this thesis, the focus is on grant-free RA (GFRA) as an enabler of uRLLC and mMTC. GFRA is a new protocol introduced in 5G new radio (5G-NR) for reducing the data overhead of the random access (RA) procedure. This results in a significant reduction in the latencies of the user equipments (UEs) access to a connected medium via an access point (AP). Achieving efficient GFRA is of key importance for many 5G applications, e.g. for large scale internet of things (IoT) wireless networks. The study of new non-orthogonal multiple access (NOMA) signal processing techniques is then considered. Using tools from the theory of Bayesian compressed sensing (CS), algorithms within the family of approximate message passing (AMP) are developed to address the joint active user detection and channel estimation (AUDaCE) problem. It is crucial to properly identify transmitting UEs and guarantee that an AP can reliably transmit back data to the detected UEs. In contrast to existing work on this topic, the AUDaCE is studied for wireless networks where the activity of the UEs is correlated. To this end, two activity models are introduced. The first one models the activity of the UEs in the network with group-homogeneous activity (GHomA). The second model accounts for more general dependence structure via group-heterogeneous activity (GHetA). Approximate message passing algorithms within the hybrid GAMP (HGAMP) framework are developed for each of the models. With the aid of latent variables associated to each group for modeling the activity probabilities of the UEs, the GHomA-HGAMP algorithm can perform AUDaCE for GFRA leveraging such a group homogeneity. When the activity is heterogenous, it is possible to develop GHetA-HGAMP using the copula theory. Extensive numerical studies are performed, which highlight significant performance improvements of GHomA-HGAMP and GHetA-HGAMP over existing algorithms which do not properly account for correlated activity. In particular, the channel estimation and active user detection capability are enhanced in many scenarios with up to a 4dB improvement with twice less user errors. As a whole, this thesis provides a systematic approach to AUDaCE for wireless networks with correlated activities using Bayesian CS.

NOMA in the Dowlink: maximising the connected devices density: The PhD of Shashwat Mishra, a CIFRE with Nokia Bell Labs focuses on ML aided algorithms for the optimization of resource allocation. In this work [34], we developed a framework for maximizing the number of transmitted packets for devices in a Narrowband Internet of Things (NB-IoT) network using non-orthogonal multiple access (NOMA) in the downlink. The base station (BS) chooses one of the multiple available physical resource blocks (PRBs) that are well separated in frequency for a device, giving them the advantage of exploiting frequency diversity. The scheduling strategy focuses on the twofold problem involving efficient device clustering and optimum power allocation. This problem is a mixed-integer non-convex problem. We propose a bipartite graph matching approach, termed minimum weight full matching with pruning (MWFMP), to address the problem over multiple PRBs and solve it under the quality-of-service (QoS), allowable PRB, power budget, and interference constraints. Additionally, we provide a comparison with a greedy heuristic, the multi-PRB stratified device allocation (MPSDA), where we extend our previous work for a single PRB connectivity problem. Furthermore, we compare our algorithms to orthogonal multiple access (OMA) scheduling, which is prevalent in legacy LTE networks. We show that our algorithms steadily outperform the connectivity performance offered by OMA.

Communication learning: This work [35] is the core of the PhD of Mateus Pontes Mota funded by the European ITN project Windmill and developed in collaboration by Inria and Nokia Bell Labs. The objective is to apply a multi-agent reinforcement learning (MARL) framework to let a base station (BS) and the user equipments (UEs) to jointly learn a channel access policy and its signaling in a wireless multiple access scenario. In this framework, the BS and UEs are reinforcement learning (RL) agents that need to cooperate in order to deliver data. The comparison with a contention-free and a contention-based baselines shows that our framework achieves a superior performance in terms of goodput even in high traffic situations while maintaining a low collision rate. The scalability of the proposed method is studied, since it is a major problem in MARL and this paper provides the first results in order to address it.

8.3 Axis 3: experimental assessment

8.3.1 Experimenting with Cortexlab

Participants: Thomas Beligné, Christian Da Cruz, Jean-Marie Gorce, Matthieu Imbert, Cyrille Morin, Amaury Paris, Léonardo Sampaio Cardoso.

The work described in this section is complementary to the work described in section 7 and gives the scientific rational of the software developed in Maracas. CorteXlab provides a unique worldwide testbed with free access to develop and tests new radio waveforms and MAC protocols without any standard limitation. The hardware is the unique limitation. Everything is software after I/Q signals processing.

Our objetive is to develop collaborations to position CorteXlab as a necessary passage for reproducible research, especially with the growing interest in machine learning based approaches.

The contributions of the year are :

Lora multi-user framework : The complete GNU Radio, dynamic and customizable physical (PHY) layer for long range (LoRa) transceiver, usable with the FIT/CorteXlab radio testbed and derived from the original EPFL LoRa implementation has been completed. The created adaptation, through a standardized interface, allows end-users an easy connection to an external medium access control (MAC)/upper layer to experiment scenarios in a fully reproducible and isolated environment. It also provides several PHY layer key performance indicators and metrics such as signal to noise ratio (SNR), received signal energy, binary error rate (BER) and other, that can be used to gauge the performance of the ongoing communications as well as construct MAC layers able to use this information. Finally, the interface allows our plug&play PHY solution to be used with any existing or newly adapted MAC layer, without having to implement it in GNU Radio. A new software (Cortexlab_LORA_PHY) has been built.

S3-CAP : a new extension of CorteXlab-IoT In [43], we present the extension of the CorteXlab-IoT Framework to a more adaptable, and user friendly framework called S3-CAP: Slotted and Synchronized multi-Sources experimental framework for the evaluation of new Channel Access Policies. This new framework creates a tunable interface between radio and PHY layers in one hand, and MAC algorithms in the other hand. In this work, we proposed a Slotted and Synchronized multi-Sources experimental framework for the evaluation of new Channel Access Policies (S3-CAP). Each node transmission to the base station is made in a shared slotted time-frame where a decentralized access policy determines which slot to use. Then, a modular and replaceable physical (PHY) layer is used to create the transmitted signal. The IoT network can be either emulated on a local computer with a simulated channel or deployed in the FIT/CorteXlab testbed where slot synchronisation between all nodes is provided by a clock distribution module. This open-source framework, designed in a GNU Radio environment, opens perspectives to design, evaluate and compare decentralised random access strategies for M2M communications.

ML based radio identification : Following the PhD of Cyrille Morin finished in 2021, we extended the dataset for radio signals identification an we worked with Supelec Paris (Prof. Raul de la Cerda) to elaborate an efficient strategy to label data. New datasets will be released soon on our wiki page.

8.4 Axis 4 : side roads exploration

In this *open-mind* research area, we developed two research axes.

8.4.1 Quantum algorithms

Participants: Claire Goursaud, Muhammad Habibie, Jihad (Alex) Hamié, Fabrice Dupuy.

On going work: The field of quantum information science may revolutionize numerous information processing applications. Indeed, quantum information may lead to fast algorithms for complex computational problems and may help to design new communication protocols. Our research direction is to evaluate the potential of quantum information in the core of wireless communication protocols.

We started by exploring the use of quantum algorithms for the grant-free massive access in IoT explored in axis 2.

Quantum algorithms for multi-user detection in massive access : The strong growth in the number of connected mobile devices has imposed new challenges in efficiently exploiting the available networks resources. Code Domain Non-Orthogonal Multiple Access (NOMA) technique appears as a tremendous efficient solution. Each device uses its assigned code to simultaneously transmit its data along with the user identifier, without any resource reservation exchange, saving precious wireless resources. However, this requires a receiver capable of blindly detecting the active users, which is highly complex. Driven by the promising superposition property of quantum architecture, the goal of this work [39, 32] is to adapt and apply the quantum Grover algorithm for Active User Detection (AUD) purpose in the context of NOMA, to alleviate the search complexity. This adapted Grover's algorithm is compared with the optimal classical Maximum Likelihood (ML) AUD receivers, as well as with the basic classical Conventional Correlation Receiver (CCR). A benchmark on the probability of AUD is assessed as a function of the Signal to Noise Ratio (SNR) of the received signal. We show that our adapted Grover's algorithm is very promising in high SNR regime.

8.4.2 Beyond communications

Participants: Malcolm Egan , José Matias* (NTNU, Norway) , Vyacheslav Kungurtsev* (CTU, Prague).

A key problem for many industrial processes is to limit exposure to system malfunction. However, it is often the case that control cost minimization is prioritized over model identification. Indeed, model identification is typically not considered in production optimization, which can lead to delayed awareness and alerting of malfunction. In this paper, we address the problem of simultaneous production optimization and system identification. We develop new algorithms based on modifier adaptation and reinforcement learning, which efficiently manage the tradeoff between cost minimization and identification. For two case studies based on a chemical reactor and subsea oil and gas exploration, we show that our algorithms yield control costs comparable to existing methods while yielding rapid identification of system degradation [28].

9 Bilateral contracts and grants with industry

9.1 Bilateral contracts with industry

Participants: Naveed Ahmad, Lelio Chetot, Fabrice Dupuis, Malcolm Egan, Jean-Marie Gorce, Claire Goursaud, Alix Jeannerot, Homa Nikbakht, Léonardo Sampaio Cardoso, Shanglin Yang
.

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. They cover the funding of two PhDs (Cyrille Morin and Lelio Chetot), a partial funding of another PhD (Alix Jeannerot) and 1 postdoc (Homa Nikbakht) for Maracas.

2. SPIE-ICS (1Meuros, 2017-2021) : The Insa-Spie IoT Chair IoT chair relies on the expertise of the CITI Lab. The skills developed within the different teams of the lab integrate study, modeling, 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. This project supported the postdoc of Naveed Ahmad supervised by Malcolm Egan. 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. Frédéric Le Mouel is heading the chair since sept 2019. The remaining budget for Maracas corresponds to one postdoc (Naveed Ahmad).

9.2 Bilateral grants with industry

1. CIFRE Nokia Bell Labs (2019-2022): PhD of Mathieu Goutay.

2. CIFRE Nokia Bell Labs (2021-2024): PhD of Shashwat Mishra.
3. CIFRE Nokia Bell Labs (2022-2025): PhD of Shanglin Yang.
4. CIFRE Orange Labs (2022-2025): PhD of Fabrice Dupuis.

10 Partnerships and cooperations

10.1 International initiatives

10.1.1 Inria associate team not involved in an IIL or an international program

FedAutoMoDL

Title: Federated Automated Deep Learning

Duration: 2022 ->

Coordinator: Bapi Chatterjee (bapi@iiitd.ac.in)

Partners:

- Indian Institute of Technology Delhi New Delhi (Inde)

Inria contact: Malcolm Egan

Summary: While DNNs have had a huge impact on algorithm design for image and signal processing, it is well-known that the results are heavily dependent on the selected architecture. Typically, the architecture is tailored to a particular application by hand, which is susceptible to significant performance losses. Moreover, DNN architecture design has mostly been investigated in the context of image processing and natural language processing [Elsken 2019]. For generic time-series data beyond speech and music signals (e.g., most sensor data), DNN architecture design remains in its infancy.

In federated settings, where data is not centralized due to privacy or communication constraints, high-performance design of DNN architectures is even less well-understood. This is now becoming a critical issue due to the widespread development of the IoT and edge computing.

The main goal of FedAutoMoDL is to develop algorithms for the systematic design of federated DNN architectures with a focus on scenarios with time-series data, such as that which often arises in the IoT and ranges from traffic management to data analytics [Liu 2021,Ghosh 2019,Tian 2018, Ramakrishnan 2018,Tshilongamulenzhe 2020]. This will be achieved using tools from the emerging area of neural architecture search (NAS) [Zhu 2020], and in particular the recently developed approach of differentiable neural architecture search.

10.1.2 Participation in other International Programs

PhC PAVLE SAVIC 2020

Participants: Léonardo Cardoso, Malcolm Egan, Jean-Marie Gorce, Claire Goursaud, Alix Jeannerot, Lélio Chetot.

MASSIVE IOT RADIO ACCESS (MITRA)

Partner Institution(s):

- ICONIC centre, Novi Saad University, Serbia

2020-2022

Additionnal info/keywords: massive MIMO, signal processing, ML aided radio

10.2 International research visitors

10.2.1 Visits of international scientists

- Dejan Vukobranovic, Professor; Novi Sad University, Serbia, 4-7 July.
- Vyacheslav Kungurtsev, Senior Researcher; Czech Technical University in Prague, 1st April. Research collaboration on stochastic optimization.
- Bao Quoc Tang, Assistant Professor, University of Graz, 6-9 November. Research collaboration on stochastic approximation for reaction-diffusion systems
- Dr. Gul Muhammad, Center of Intelligent System and Network Research, Pakistan, University of Engineering and Technology, 14-16, November.
- Yuri Carvalho Barbosa Silva and Walter Freitas Jr., Prof. Dr. Researcher; Wireless Telecom Research Group (GTEL), Federal University of Ceará (UFC), Fortaleza-CE, Brazil 18, November.

10.2.2 Visits to international teams

Research stays abroad

Jean-Marie Gorce,Alix Jeannerot,Lélio Chetot

Visited institution: U. of Novi Saad

Country: Serbia

Dates: 16-18 Nov

Context of the visit: PhC MITRA

Mobility program/type of mobility: short visit

Malcolm Egan

Visited institution: Michael Barros (Lecturer, University of Essex)

Country : UK

Dates: 20th-21st April

Context : collaboration on molecular communications

10.3 European initiatives

10.3.1 Horizon Europe

Windmill - ITN We are non-funded partner to this project, but we collaborate to the PhD of MAteus Pontes Mota who is funded by this project and paid by Nokia Bell Labs. his lateste contribution is here ().

As wireless communication networks evolve towards 5G and beyond, we are entering an era of massive connectivity, massive data, and extreme service demands. However, it is challenging to handle such complexity and data volume successfully. A promising approach to this issue is to develop new network management and optimization tools based on machine learning. This presents a major shift in the design and operation of wireless networks. At the same time, the approach demands a new type of expertise: a combination of engineering, mathematics and computer science disciplines. The ITN project WindMill addresses this issue by providing relevant interdisciplinary training. In the course of the project, 16 Early Stage Researchers (ESRs) will be trained in integrating wireless communications and machine learning. The trainings will be provided by a consortium of leading international research institutes and companies with experts in wireless communications and machine learning. In this way, project will also nurture the sense of responsibility of the ESRs and the other participants through personal engagement in the training program and by promoting teamwork through collaborative joint projects.

10.3.2 H2020 projects

TESTBED2 This project is managed by Samir Perlaza who moved to NEO team (Sophia centre). We didn't contribute in 2022 to this project.

TESTBED2 project on cordis.europa.eu

Title: Testing and Evaluating Sophisticated information and communication Technologies for enaBling scalablE smart griD Deployment

Duration: From February 1, 2020 to July 31, 2025

Partners:

- INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET AUTOMATIQUE (INRIA), France
- INSTITUTE OF ELECTRICAL ENGINEERING CHINESE ACADEMY OF SCIENCES (IEECAS), China
- JINAN UNIVERSITY (JNU), China
- UNIVERSITY OF NEBRASKA (UN), United States
- UNIVERSITY OF DURHAM (UNIVERSITY OF DURHAM), United Kingdom
- BEIA CONSULT INTERNATIONAL SRL (BEIA), Romania
- DOTX CONTROL SOLUTIONS BV (DOTX CONTROL SOLUTIONS), Netherlands
- UNIVERSITY OF NORTHUMBRIA AT NEWCASTLE (Northumbria University), United Kingdom
- TRUSTEES OF PRINCETON UNIVERSITY (PRINCETON), United States
- ORGANISMOS TILEPIKOINONION TIS ELLADOS OTE AE (HELENIC TELECOMMUNICATIONS ORGANIZATION SA), Greece
- HERIOT-WATT UNIVERSITY (HWU), United Kingdom
- CHINA ELECTRIC POWER RESEARCH INSTITUTE (SEAL) SOE (CEPRI), China
- DEPSYS SA (DEPSYS), Switzerland
- THE REGENTS OF THE UNIVERSITY OF CALIFORNIA (LOS ANGELES UCLA SANTA BARBARA UCSB DAVIS UCD RIVERSIDE UCR SAN DIEGO UCSD SANTA CRUZ UCSC IRVIN), United States
- UNIVERSITAET KLAGENFURT (UNI-KLU), Austria
- EBERHARD KARLS UNIVERSITAET TUEBINGEN (UT), Germany
- SOUTHEAST UNIVERSITY (SEU), China
- STICHTING NEDERLANDSE WETENSCHAPPELIJK ONDERZOEK INSTITUTEN (NWO-I), Netherlands

Inria contact: Samir PERLAZA

Coordinator:

Summary: Smart grids represent an electricity network that can intelligently integrate generators, consumers and energy storage in order to efficiently deliver electricity. There is a clear consensus that smart grids can provide many innovative services – to date the EC has devoted €360,413 million to support 527 projects on developing smart grid services. Decision-making plays a vital role in these services. But the computational complexity of decision-makings could grow explosively with the size of smart grid infrastructure, the number of devices/users, or the amount of data; If this scalability issue was underestimated, smart grid services can end up with poor performance or limited function, making these services impractical to meet the needs of real-life or industrial-scale deployment. Hence, there is an urgent need to solve the research problem: to what extent the performance and function of smart grids can be maintained without having significant increase of the computational complexity when its scale is changed in terms of smart grid infrastructure size or the number of devices/users? TESTBED2 is a major interdisciplinary project that combines wisdoms in three academic disciplines - Electronic & Electrical Engineering, Computing Sciences and Macroeconomics, to address the aforesaid problem. The main focus is on developing new techniques to improve the scalability of smart grid services, particularly considering the joint evolution of decarbonised power, heat and transport systems. Moreover, new experimental testbeds will be created to evaluate scalable smart grid solutions. Overall, the main objective of this project is to coordinate the action of 13 Universities (7 in EU, 3 in US, and 3 in China) and 5 enterprises (3 SMEs and 2 large enterprises) with complementary expertise to develop and test various promising strategies for ensuring the scalability of smart grid services, thereby facilitating successful deployment and full roll-out of smart grid technologies.

10.4 National initiatives

10.4.1 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. The project supports the PhD of Guillaume Marthe.

- ANR ARBURST *Acheivable region of bursty wireless networks* (2016-2022, 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. This project supported the PhD of Dadja Anade and Chris Zhang.

10.4.2 Prospective projects

- SILECS is the French node of the European initiative SLICES, 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.

- BPI – France Relance – 5G Events Labs [Consortium: CEA – Centre de Saclay, Ericsson, Inria, Orange] [2021–23]. The 5G Events Labs project aims to boost the economic activity of the events, culture and sports sectors, around ten major sites in France where Orange and its partners will offer 5G coverage, technological platforms and adapted support enabling companies to leverage these technologies and incubate innovations in the areas of services for attendees and organizers. Maracas contributes in grant-free access solutions for IoT, in collaborative and decentralized estimation algorithms

11 Dissemination

11.1 Promoting scientific activities

11.1.1 Scientific events: organisation

General chair, scientific chair

- Jean-Marie Gorce was a co-organizer of the COST INTERACT Meeting Lyon, 13-15 June, 2022 ()

Member of the organizing committees

- Malcolm Egan, Claire Goursaud, Léonardo Cardoso, Lélio Chetot, Alix Jeannerot, Guillaume Marthe, Idham Habibie were members of the organization committee of the COST INTERACT Meeting Lyon, 13-15 June, 2022 ()
- Leonardo S. Cardoso was organizer and member of the scientific commitee of the European GNU Radio Days 2022, whose 2022 edition was exceptionally paired with the Software Defined Radio Academy (SDRA) 2022 ()

11.1.2 Scientific events: selection

Member of the conference program committees

- JM Gorce was TPC member of GRETSI 2022, the premium French conference in signal processing.
- L. Cardoso was TPC of both the IEEE WCNC 2023 and the IEEE ICC 2023 (Machine Learning and Communications Track).

11.1.3 Journal

Member of the editorial boards

- Claire Goursaud is associate editor of European Transactions on Telecommunications (ETT) and of Internet Technol. Letters (ITL).
- Malcolm Egan is Ass. Editor of IEEE Com. Letters

Reviewer - reviewing activities

- MARACAS Members are regular reviewers of AD HOC NETWORKS, IEEE IoT, IEEE Sensors, IEEE QINP, IEEE TCOM.

11.1.4 Invited talks

- Jean-Marie Gorce : "Plateforme d'experimentation réseau CortexLab" at *Journée AFF3CT 2022; Colloque des utilisateurs et développeurs du logiciel AFF3CT*, 24 nov 2022, Bordeaux, France ()
- Malcolm Egan gave a tutorial on Mathematical Models and Methods for Molecular Communication (with M. Schaefer and S. Lotter) at the 6th Workshop on Molecular Communications July 13-15, 2022, University of Warwick, UK.

11.1.5 Scientific expertise

- JM Gorce was a member of the CRCN jury for the concours of Inria Lille.
- JM Gorce was a member of the DR jury for the national concours of Inria.
- C. Goursaud was a member of recruiting committee for MCF Université de Lorraine, MCF INSA de Rennes, MCF Université de Rennes 1, Concours IR INRIA centre de Lyon.

11.1.6 Research administration

- JM Gorce is head of research for the Inria Lyon centre.
- JM Gorce is a member of the scientific council of the doctoral school EEA Lyon.
- C. Goursaud is vice-head of the CITI Research lab.
- M. Egan is member of the COMI, Inria Lyon centre.
- L. S. Cardoso is an ongoing CorteXlab testbed technical and scientific manager.

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 activity. The main ones are:

- 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, J. Hamié - 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, J Hamié, A. Jeannerot - Advanced Digital Communications, M1, Telecommunications dept, INSA Lyon, France.
- Master : J Hamié, A Paris - 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.

11.2.2 Supervision

- JM Gorce was
  - PhD director of Lélio Chetot: "Activity models and Bayesian estimation algorithms for wireless grant-free random access", Université de Lyon, Jul 7, 2022.
  - PhD director of Matthieu Goutay: "Applications of deep learning to the design of enhanced wireless communication systems", Université de Lyon, Jan 28, 2022.
- JM Gorce is PhD director of
  - Alix Jeannerot (since oct. 21), co-advised wih Malcolm Egan.
  - Shashwat Mishra (since oct. 21).
  - Mateus Pontes Mota (since oct. 20)
  - Shenglin Yang (since sept. 22), co-advised with Guillaume Villemaud.
- Léonardo Cardoso is supervising the PhD of José Rugelles (start Jan 2017), with Edward Guillén: Deep Learning for Security in GSM Based IoT Systems.

- Claire Goursaud is PhD director of:
  - Idham Habibie (since oct. 20)
  - Guillaume Marthe (since oct. 21)
  - Fabrice Dupuy (since jan. 22)

11.2.3 Juries

- JM Gorce was
  - Reviewer of the PhD of Mohammadreza Mardani Varmazyar: "Contributions à l'analyse des réseaux sans fil aléatoires avec interférence partielle", 24/03/22, Insa Rennes.
  - Reviewer of the PhD of Kassem Saied: "Transmission par trames courtes quasi-cycliques pour l'internet des objets", 25/03/22, U. Bretagne Sud.
  - Reviewer of the PhD of Marie-Anne Lacroix: "Détection d'événements sonores environnementaux dans les réseaux de capteurs sans fil à faible consommation" , 05/04/22, ENSSAT, Lannion.
  - Reviewer of the PhD of Khaled Taleb: "Sécurité de La couche physique: codes polaires wiretap pour des communications sécurisées", 19/05/22, Supaero, Toulouse.
  - Reviewer of the PhD of Carola Rizza: "New Communication Paradigms based on Emerging Technologies", 27/09/22 Inria, U. Lille.
  - Chair of the HdR jury of Maël Le Treust: "Coordination et communication stratégique", 29/11/22, U. Cergy Pontoise.
  - Chair of the PhD jury of Rony Bou Rouphaël: "Compression stratégique pour persuasion. Bayesienne multi-user" 01/12/22, U. Cergy Pontoise.
  - Chair of the PhD jury of Hajar El Hassani: "Solutions efficaces en énergie pour des systèmes exploitant l'accès multiple non-orrhogonal aidés par la rétro-diffusion ambiante" 02/12/22, U. Cergy Pontoise.
  - Reviewer of the PhD of Syang Liu: "Efficient machine learning techniques for indoor localization in wireless communication systems", 20/12/22, Centrale-Supélec Paris Saclay.
- L. S. Cardoso was PhD Opponent of Nicolas Malm: "Software-defined Communication Platform Implementation on Commodity Hardware", 12 August, Aalto University, Espoo, Finland.

11.3 Popularization

11.3.1 Education

Claire Goursaud published a paper related to teaching with games:

- Escape the ClassRoom: retour sur la création et utilisation d'escape game en TD pour les transmissions optiques; in J3eA, 2022, publisher:EDP Sciences.

12 Scientific production

12.1 Major publications

[1] B. C. Akdeniz, M. Egan and B. Q. Tang. 'Equilibrium Signaling: Molecular Communication Robust to Geometry Uncertainties'. In: *IEEE Transactions on Communications* 69.2 (Feb. 2020), pp. 752–765. DOI: 10.1109/TCOMM.2020.3034662. URL: https://hal.science/hal-03018278.

[2] 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.

[3] S. Belhadj Amor, S. Perlaza, I. Krikidis and H. V. Poor. 'Feedback Enhances Simultaneous Wireless Information and Energy Transmission in Multiple Access Channels'. In: *IEEE Transactions on Information Theory* 63.8 (Aug. 2017), pp. 5244–5265. DOI: 10.1109/TIT.2017.2682166. URL: https://hal.inria.fr/hal-01857373.

[4] M. De Freitas, M. Egan, L. Clavier, A. Goupil, G. W. Peters and N. Azzaoui. 'Capacity Bounds for Additive Symmetric α -Stable Noise Channels'. In: *IEEE Transactions on Information Theory* 63.8 (Aug. 2017), pp. 5115–5123. DOI: 10.1109/TIT.2017.2676104. URL: https://hal.univ-reims.fr/hal-02088563.

[5] M. Egan, B. C. Akdeniz and B. Q. Tang. 'Equilibrium Signaling in Spatially Inhomogeneous Diffusion and External Forces'. In: *IEEE Transactions on Molecular, Biological and Multi-Scale Communications* 7.2 (June 2021), pp. 106–110. DOI: 10.1109/TMBMC.2021.3054908. URL: https://hal.science/hal-03099183.

[6] M. Egan, L. Clavier, C. Zheng, M. De Freitas and J.-M. Gorce. 'Dynamic Interference for Uplink SCMA in Large-Scale Wireless Networks without Coordination'. In: *EURASIP Journal on Wireless Communications and Networking* 2018.1 (Aug. 2018), pp. 1–14. DOI: 10.1186/s13638-018-1225-z. URL: https://hal.archives-ouvertes.fr/hal-01871576.

[7] M. Egan, J. Drchal, J. Mrkos and M. Jakob. 'Towards Data-Driven On-Demand Transport'. In: *EAI Endorsed Transactions on Industrial Networks and Intelligent Systems* 5.14 (June 2018), pp. 1–10. DOI: 10.4108/eai.27-6-2018.154835. URL: https://hal.archives-ouvertes.fr/hal-01839452.

[8] M. Egan, V. Loscrì, T. Q. Duong and M. D. Renzo. 'Strategies for Coexistence in Molecular Communication'. In: *IEEE Transactions on NanoBioscience* 18.1 (Jan. 2019), pp. 51–60. DOI: 10.1109/tnb.2018.2884999. URL: https://hal.archives-ouvertes.fr/hal-01928205.

[9] M. Egan, T. C. Mai, T. Q. Duong and M. Di Renzo. 'Coexistence in Molecular Communications'. In: *Nano Communication Networks* 16 (Feb. 2018), pp. 37–44. DOI: 10.1016/j.nancom.2018.02.006. URL: https://hal.archives-ouvertes.fr/hal-01650966.

[10] M. Egan, S. Perlaza and V. Kungurtsev. 'Capacity sensitivity in additive non-gaussian noise channels'. In: *2017 IEEE International Symposium on Information Theory (ISIT)*. IEEE. 2017, pp. 416–420.

[11] I. Esnaola, S. Perlaza, H. V. Poor and O. Kosut. 'Maximum Distortion Attacks in Electricity Grids'. In: *IEEE Transactions on Smart Grid* 7.4 (2016), pp. 2007–2015. DOI: 10.1109/TSG.2016.2550420. URL: https://hal.archives-ouvertes.fr/hal-01343248.

[12] Y. Fadlallah, O. Oubejja, S. Kamel, P. Ciblat, M. Wigger and J.-M. S. Gorce. 'Cache-Aided Polar Coding: From Theory to Implementation'. In: *IEEE Journal on Selected Areas in Information Theory* (22nd Nov. 2021), pp. 1–17. DOI: 10.1109/JSAIT.2021.3128232. URL: https://hal.inria.fr/hal-03482281.

[13] Y. Fadlallah, A. M. Tulino, D. Barone, G. Vettigli, J. Llorca and J.-M. Gorce. 'Coding for Caching in 5G Networks'. In: *IEEE Communications Magazine* 55.2 (Feb. 2017), pp. 106–113. DOI: 10.1109/MCOM.2017.1600449CM. URL: https://hal.inria.fr/hal-01492353.

[14] C. Genes, I. Esnaola, S. Perlaza, L. F. Ochoa and D. Coca. 'Robust Recovery of Missing Data in Electricity Distribution Systems'. In: *IEEE Transactions on Smart Grid* (2018).

[15] J.-M. Gorce, Y. Fadlallah, J.-M. Kelif, H. V. Poor and A. Gati. 'Fundamental limits of a dense iot cell in the uplink'. In: *Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt), 2017 15th International Symposium on*. IEEE. 2017, pp. 1–6.

[16] C. Goursaud and J.-M. Gorce. 'Dedicated networks for IoT : PHY / MAC state of the art and challenges'. In: *EAI endorsed transactions on Internet of Things* (Oct. 2015). DOI: 10.4108/eai.26-10-2015.150597. URL: https://hal.archives-ouvertes.fr/hal-01231221.

[17] M. Goutay, F. A. Aoudia, J. Hoydis and J.-M. S. Gorce. 'Machine Learning for MU-MIMO Receive Processing in OFDM Systems'. In: *IEEE Journal on Selected Areas in Communications* (18th June 2021). DOI: 10.1109/JSAC.2021.3087224. URL: https://hal.science/hal-03082846.

[18] A. Guizar, C. Goursaud and J.-M. Gorce. 'Performance of IR-UWB cross-layer ranging protocols under on-body channel models with body area networks'. In: *Annals of Telecommunications - annales des télécommunications* (Mar. 2016). http://link.springer.com/article/10.1007/s12243-016-0500-4, pp. 453–46. DOI: 10.1007/s12243-016-0500-4. URL: https://hal.archives-ouvertes.fr/hal-01290211.

[19] N. Khalfet and S. M. Perlaza. 'Simultaneous Information and Energy Transmission in the Two-User Gaussian Interference Channel'. In: *IEEE Journal on Selected Areas in Communications* 37.1 (Jan. 2019), pp. 156–170. DOI: 10.1109/jsac.2018.2872365. URL: https://hal.archives-ouvertes.fr/hal-01874019.

[20] T. C. Mai, M. Egan, T. Q. Duong and M. Di Renzo. 'Event Detection in Molecular Communication Networks with Anomalous Diffusion'. In: *IEEE Communications Letters* 21.6 (Feb. 2017), pp. 1249–1252. DOI: 10.1109/LCOMM.2017.2669315. URL: https://hal.archives-ouvertes.fr/hal-01671181.

[21] Y. Mo, M.-T. Do, C. Goursaud and J.-M. Gorce. 'Up-Link Capacity Derivation for Ultra-Narrow-Band IoT Wireless Networks'. In: *International Journal of Wireless Information Networks* 24.3 (June 2017), pp. 300–316. DOI: 10.1007/s10776-017-0361-4. URL: https://hal.inria.fr/hal-01610466.

[22] S. Perlaza, A. Tajer and H. V. Poor. 'Simultaneous Energy and Information Transmission: A Finite Block-Length Analysis'. In: *IEEE International Workshop on Signal Processing Advances in Wireless Communications*. 2018.

[23] V. Quintero, S. Perlaza, I. Esnaola and J.-M. Gorce. 'Approximate Capacity Region of the Two-User Gaussian Interference Channel with Noisy Channel-Output Feedback'. In: *IEEE Transactions on Information Theory* 64.7 (July 2018). Part of this work was presented at the IEEE International Workshop on Information Theory (ITW), Cambridge, United Kingdom, September 2016 and IEEE International Workshop on Information Theory (ITW), Jeju Island, Korea, October, 2015. Parts of this work appear in INRIA Technical Report Number 0456, 2015, and INRIA Research Report Number 8861., pp. 5326–5358. DOI: 10.1109/TIT.2018.2827076. URL: https://hal.archives-ouvertes.fr/hal-01397118.

[24] V. Quintero, S. Perlaza, I. Esnaola and J.-M. Gorce. 'When Does Output Feedback Enlarge the Capacity of the Interference Channel?' In: *IEEE Transactions on Communications* 66.2 (Sept. 2017). Part of this work was presented at the 11th EAI International Conference on Cognitive Radio Oriented Wireless Networks (CROWNCOM), Grenoble, France, May 30-Jun 1 2016, pp. 615–628. DOI: 10.1109/TCOMM.2017.2753252. URL: https://hal.archives-ouvertes.fr/hal-01432525.

[25] D. Tsilimantos, J.-M. Gorce, K. Jaffrès-Runser and H. V. Poor. 'Spectral and Energy Efficiency Trade-Offs in Cellular Networks'. In: *IEEE Transactions on Wireless Communications* 15.1 (Jan. 2016), pp. 54–66. DOI: 10.1109/TWC.2015.2466541. URL: https://hal.inria.fr/hal-01231819.

[26] Y. Yu, L. Mroueh, D. Duchemin, C. Goursaud, G. Vivier, J.-M. Gorce and M. Terré. 'Adaptive Multi-Channels Allocation in LoRa Networks'. In: *IEEE Access* 8 (2020), pp. 214177–214189. DOI: 10.1109/ACCESS.2020.3040765. URL: https://hal.science/hal-03059910.

12.2 Publications of the year

International journals

[27] S.-W. Ho, A. A. Saed, J.-M. Gorce and C. Shue Chen. 'Sinusoidal-Based Multiple Access Scheme for Visible Light Decentralized Asynchronous Systems'. In: *IEEE Transactions on Vehicular Technology* (2022). URL: https://hal.inria.fr/hal-03796114.

[28] J. Matias, V. Kungurtsev and M. Egan. 'Simultaneous Online Model Identification and Production Optimization Using Modifier Adaptation'. In: *Journal of Process Control* 110 (1st Feb. 2022), pp. 110–120. DOI: 10.1016/j.jprocont.2021.12.009. URL: https://hal.inria.fr/hal-03540196.

[29] H. Nikbakht, M. Wigger, M. Egan, S. Shamai Shitz, J.-M. Gorce and H. V. Poor. 'An Information-Theoretic View of Mixed-Delay Traffic in 5G and 6G'. In: *Entropy* 24 (30th Apr. 2022). DOI: 10.3390/e24050637. URL: https://hal.science/hal-03943743.

[30] F. Rostami Ghadi, F. J. Lopez-Martinez, W.-P. Zhu and J.-M. Gorce. 'The Impact of Side Information on Physical Layer Security Under Correlated Fading Channels'. In: *IEEE Transactions on Information Forensics and Security* 17 (5th Oct. 2022), pp. 3626–3636. DOI: 10.1109/TIFS.2022.3212198. URL: https://hal.inria.fr/hal-03946304.

[31] C. Zheng, M. Egan, L. Clavier, G. W. Peters and J.-M. Gorce. 'On the Interference Arising From Random Spatial Fields of Interferers Utilizing Multiple Subcarriers'. In: *EURASIP Journal on Wireless Communications and Networking* 1 (2022), pp. 1–28. DOI: 10.1186/s13638-022-02110-w. URL: https://hal.science/hal-03605575.

International peer-reviewed conferences

[32] M. I. Habibie, J. Hamie, C. Goursaud and C. Goursaud. 'A Performance Comparison of Classical and Quantum Algorithm for Active User Detection'. In: SPAWC 2022 - The 23rd IEEE International Workshop on Signal Processing Advances in Wireless Communications. Oulu, Finland, 4th July 2022. URL: https://hal.archives-ouvertes.fr/hal-03820291.

[33] Y. Mestrah, D. Anade, A. Savard, A. Goupil, M. Egan, P. Mary, J.-M. S. Gorce and L. Clavier. 'Unsupervised Log-Likelihood Ratio Estimation for Short Packets in Impulsive Noise'. In: IEEE Wireless Communications and Networking Conference (WCNC). Austin, United States: IEEE, 10th Apr. 2022, pp. 1–6. DOI: 10.1109/WCNC51071.2022.9771897. URL: https://hal.inria.fr/hal-03540198.

[34] S. Mishra, L. Salaun, J.-M. Gorce and C. Shue Chen. 'Maximizing Downlink User Connection Density in NOMA-aided NB-IoT Networks Through a Graph Matching Approach'. In: IEEE VTC2022-Fall - IEEE 96th Vehicular Technology Conference. London, United Kingdom, 26th Sept. 2022. URL: https://hal.science/hal-03760000.

[35] M. Mota, A. Valcarce and J.-M. Gorce. 'Scalable Joint Learning of Wireless Multiple-Access Policies and their Signaling'. In: *2022 IEEE 95th Vehicular Technology Conference (VTC2022-Spring)*. 2022 IEEE 95th Vehicular Technology Conference (VTC2022-Spring). Helsinki, Finland: IEEE, 19th June 2022, pp. 1–5. DOI: 10.1109/VTC2022-Spring54318.2022.9860804. URL: https://hal.science/hal-03963663.

[36] H. Nikbakht, M. Egan and J.-M. Gorce. 'Joint Channel Coding of Consecutive Messages with Heterogeneous Decoding Deadlines in the Finite Blocklength Regime'. In: WCNC 2022 - IEEE Wireless Communications and Networking Conference. Austin, United States: IEEE, 10th Apr. 2022, pp. 1–6. URL: https://hal.inria.fr/hal-03540199.

[37] H. Nikbakht, M. Wigger, S. S. Shitz, J.-M. Gorce and H. V. Poor. 'Joint Coding of URLLC and eMBB in Wyner's Soft-Handoff Network in the Finite Blocklength Regime'. In: GLOBECOM 2022 - 2022 IEEE Global Communications Conference. Rio de Jaineiro, Brazil, 4th Dec. 2022. DOI: 10.1109/globecom48099.2022.10000942. URL: https://hal.science/hal-03943787.

[38] C. Zheng, M. Egan, L. Clavier, A. E. Kalør and P. Popovski. 'Stochastic Resource Allocation for Outage Minimization in Random Access with Correlated Activation'. In: IEEE Wireless Communications and Networking Conference (WCNC). Austin, United States: IEEE, 10th Apr. 2022, pp. 1–6. DOI: 10.1109/WCNC51071.2022.9771709. URL: https://hal.inria.fr/hal-03517852.

Conferences without proceedings

[39] M. I. Habibie, J. Hamie and C. Goursaud. 'Comparaison des performances des algorithmes classiques et quantiques pour la détection dans un système NOMA'. In: GRETSI 2022 - XXVIIIème Colloque Francophone de Traitement du Signal et des Images. Nancy, France, 5th Sept. 2022. URL: https://hal.archives-ouvertes.fr/hal-03820290.

Doctoral dissertations and habilitation theses

[40] L. Chetot. 'Activity models and Bayesian estimation algorithms for wireless grant-free random access'. Université de Lyon, 7th July 2022. URL: https://theses.hal.science/tel-03871656.

[41] M. Goutay. 'Applications of deep learning to the design of enhanced wireless communication systems'. Université de Lyon, 28th Jan. 2022. URL: https://theses.hal.science/tel-03783228.

Reports & preprints

[42] H. Nikbakht, M. Egan and J.-M. Gorce. *Dirty Paper Coding for Consecutive Messages with Heterogeneous Decoding Deadlines in the Finite Blocklength Regime*. RR-9462. Inria - Research Centre Grenoble – Rhône-Alpes, 4th Feb. 2022, pp. 1–21. URL: https://hal.inria.fr/hal-03556888.

[43] A. Paris, L. Sampaio Cardoso and J.-M. Gorce. *Slotted, synchronised and modular framework for the evaluation of channel access policies in dense IoT network using FIT/CorteXlab*. Insa Lyon; Inria; CITI - CITI Centre of Innovation in Telecommunications and Integration of services, 13th June 2022. URL: https://hal.inria.fr/hal-03876369.

12.3 Cited publications

[44] S. Dörner, S. Cammerer, J. Hoydis and S. ten Brink. 'Deep learning based communication over the air'. In: *IEEE Journal of Selected Topics in Signal Processing* 12.1 (2018), pp. 132–143.

[45] M. G. Khoshkholgh, K. Navaie, K. G. Shin, V. Leung and H. Yanikomeroglu. 'Caching or No Caching in Dense HetNets?' In: *arXiv preprint arXiv:1901.11068* (2019).

[46] S. Li, M. A. Maddah-Ali, Q. Yu and A. S. Avestimehr. 'A fundamental tradeoff between computation and communication in distributed computing'. In: *IEEE Transactions on Information Theory* 64.1 (2018), pp. 109–128.

[47] W. Liu, S. Xue, J. Li and L. Hanzo. 'Topological Interference Management for Wireless Networks'. In: *IEEE Access* 6 (2018), pp. 76942–76955.

[48] Y. Mao, C. You, J. Zhang, K. Huang and K. B. Letaief. 'A survey on mobile edge computing: The communication perspective'. In: *IEEE Communications Surveys & Tutorials* 19.4 (2017), pp. 2322–2358.

[49] Y. Polyanskiy, H. V. Poor and S. Verdú. 'Channel coding rate in the finite blocklength regime'. In: *IEEE Transactions on Information Theory* 56.5 (2010), p. 2307.

[50] J. Sachs, L. A. A. Andersson, J. Araújo, C. Curescu, J. Lundsjö, G. Rune, E. Steinbach and G. Wikström. 'Adaptive 5G Low-Latency Communication for Tactile InternEt Services'. In: *Proceedings of the IEEE* 107.2 (Feb. 2019), pp. 325–349.

[51] V. Y. Tan. 'Asymptotic estimates in information theory with non-vanishing error probabilities'. In: *Foundations and Trends® in Communications and Information Theory* 11 (2014), pp. 1–184.

[52] G. Vazquez-Vilar, A. G. i Fabregas, T. Koch and A. Lancho. 'Saddlepoint approximation of the error probability of binary hypothesis testing'. In: *2018 IEEE International Symposium on Information Theory (ISIT)*. IEEE. 2018, pp. 2306–2310.

[53] Q. Yan, S. Yang and M. Wigger. 'Storage, computation, and communication: A fundamental tradeoff in distributed computing'. In: *2018 IEEE Information Theory Workshop (ITW)*. IEEE. 2018, pp. 1–5.

[54] X. Yi and G. Caire. 'Topological interference management with decoded message passing'. In: *IEEE Transactions on Information Theory* 64.5 (2018), pp. 3842–3864.