RESEARCH CENTRE

Inria Lyon Centre

IN PARTNERSHIP WITH:

Institut national des sciences appliquées de Lyon

2024 ACTIVITY REPORT

Project-Team MARACAS

Models and Algorithms for Reliable Communication Systems

IN COLLABORATION WITH: Centre d'innovation en télécommunications et intégration de services

DOMAIN

Networks, Systems and Services, Distributed Computing

THEME

Networks and Telecommunications

Inria

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2 Overall objectives

2.1 Motivation

In the last decades, telecommunications have improved human connectivity, leading to a seamless worldwide coverage that has become indispensable to human activities. 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. In recent years, 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. New usages have also appeared, such as virtual reality, autonomous vehicles, or the widespread use of machine learning, giving rise to new classes of traffic with specific demands in terms of reliability, latency and throughput. Furthermore, the aforementioned classical network architecture based on a centralized approach are gradually becoming outdated: with the emergence of artificial intellingence (AI) applications often involves the ability for communications network to process data *en-route*, networks are shifting away from the classical "bit-pipe" paradigm to become distributed computing tools.

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: while learning approaches are not always competitive against heavily optimized model-based signal processing algorithms often found in communications systems, they can substantially outperform classical architectures in cases where the model is not or imperfectly known, which is often the case when dealing with physical systems (electronics, propagation, etc).

- 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. [62, 60, 67].

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 [24] 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, the 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.

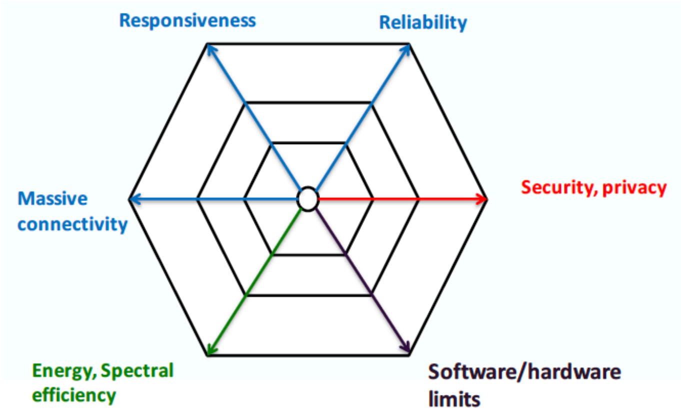

Figure 1: Main metrics for future networks (5G and beyond)

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 [64].

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 [63, 65] 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 statistical signal processing, control theory, game theory and machine learning. 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 address 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 :

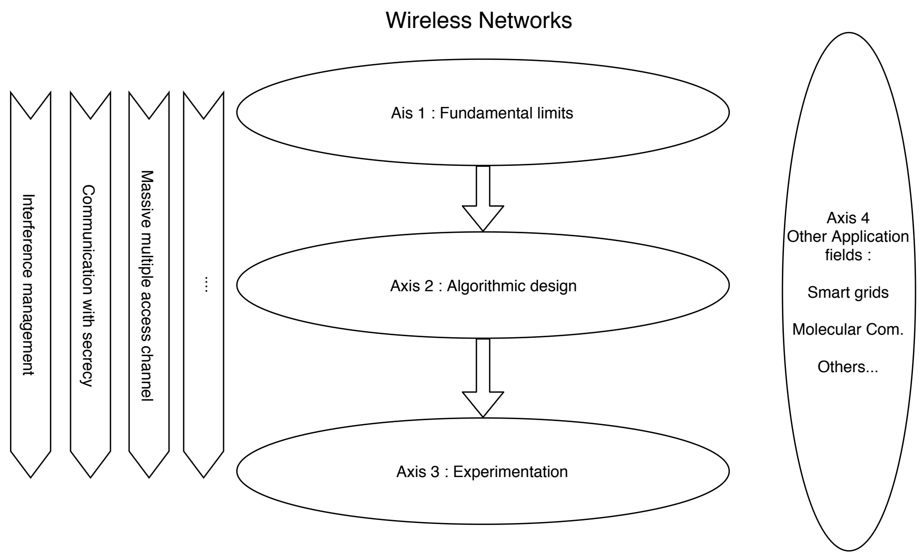

Figure 2: Maracas organization

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 [23].

  This also means revisiting the fundamental estimation-detection problem [66] 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* [59] 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*.

- **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 [68, 61].

Another emerging research direction relies on using machine learning techniques [57] 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 finalized 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 CITI lab, with the Dynamid team 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.
- Developing self-supervised learning methods for statistical processing of long-term propagation data (channel state information)
- 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. These equipments can be turned on only when an experiment is underway.
- Computer sustainability: We generally use computers for at least 5 years, and require extended warranty contracts (5 to 7 years) at the time of purchase.
- Travelling represents an important part of our CO_2 footprint. We strive to avoid frequent long-distance trips and encouraging extended stays including multiple research interactions in the same geographical area during trips involving long flights.

5.2 Impact of research results

We strive to design high-rate, high-QoS wireless protocols under stringent energy consumption contraints. Our research area includes solutions allowing to remove batteries from certain devices (zero-energy devices), as well as energy-efficient approaches which can potentially reduce the CO_2 footprint of future networks. However we acknowledge that the problem of energy consumption of communication networks is often ill-posed, since many results produced in our scientific community merely focus on improving energy efficiency without taking rebound effects into account.

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

Maracas team members were very active in the organization committee of the international conference EUSIPCO.

7 New software, platforms, open data

7.1 New software

7.1.1 cortexlab-minus

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

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. - a statistics module (developped in 2023) which provides some metrics like the calcul of occupancy and usage ratios on a user selected period.

Contact: Pascal Girard

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

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

Contact: Jean-Marie Gorce

7.2 New platforms

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

7.2.1 FIT/CorteXlab toward integration in SLICES/Europe

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 2024, CorteXlab became a part of the SLICES-FR programm funded by PEPR/PC PLATEFORMS, in coordination with Raymond Knopp from Eurecom, and Walid Dabbous from the team DIANA, Inria Sophia. The new deployment is expected by the end of 2025.

7.3 Open data

Radio Fingerprinting Dataset

Cyrille Morin, Léonardo Cardoso, Jean-Marie Gorce

Type: `research`

Audience: `partners`

Evolution and maintenance: `basic`

Figure 3: FIT/CorteXlab facility

Free Description: A dataset of recorded RF signals, labeled by the identifier of the radio device that emitted the signal. The signals are raw IQ samples recorded with a USRP in the CorteXlab platform. The dataset contains a set of different transmission scenarios, with various signal types, and emission conditions, none of which contain explicit identifying signals. Its intended use is to train and/or test algorithms for RF fingerprinting, identification of the transmitter of a signal, solely based on the RF signature imposed by the transmitter's electronic components. The dataset is used and described in details in [22].

Wideband Spectrum Sensing Dataset

Cyrille Morin, Léonardo Cardoso

Type: `research`

Audience: `team`

Evolution and maintenance: `basic`

Free Description: A dataset of recorded RF signals, labeled by metadata such as time, duration frequency, band, modulation and transmitter for each recieved signal. This was recorded with a USRP inside of CorteXlab, with a mixture of modulation types and transmission pattern. It simulates some real world spectrum usage scenarios such as continuous or bursty transmissions for multiple transmitters, with random frequency allocation. Its intended use is to train and/or test algorithms for wideband spectrum sensing, or localisation in time and frequency of unknown signals, as well as modulation recognition.

Multi-Cell Outdoor Channel State Information Dataset (MOCSID)

Mohamed el Mehdi Makhlouf, Yamil Vindas Yassine, Maxime Guillaud

Type: `research`

Audience: `community`

Evolution and maintenance: `lts`

Description: The MOCSID dataset contains synthetic wireless propagation data (a.k.a. channel state information, CSI) designed mainly for the purpose of benchmarking channel charting algorithms such as those developed in the CHASER and INSTINCT European projects. Specifically, CSI time series from several hundreds of realistic pedestrian user trajectories in a multi-cell outdoors (campus) environment have been simulated using the NVIDIA Sionna simulator, based on a 3D scene generated from OpenStreetMap data. The dataset is designed to ensure spatial consistency across the users, and to correctly model overlapping service areas, in order to allow the benchmarking of distributed multi-site channel charting algorithms.

8 New results

As presented is section 3, the research program of MARACAS focuses on reliable communications for multi-user systems, in the context of computing networks. The project is organized in three main axes : i) fundamental limits of multi-user systems, ii) algorithms for efficient multi-user systems, iii) experimentation. A fourth axis covers cross-roads exploration as detailed in section 3.2.

However the research in MARACAS is not siloed. Typically a specific scenario (e.g. Grant free multiple access) is studied from theory to experimentation. To highlight these interactions between the different axes, our activity is organized through challenges.

In 2024, we have been involved on the following challenges

- Challenge 1: foundational results (leveraging on all axes): the objective of this challenge is to develop new models, new algorithms and new experimental setups at the service of current and future applications. These works are not necessarily application driven, but rather motivated by fundamental open questions.

- Challenge 2: IoT massive access and URLLC (leveraging on axes 1,2,3). Massive access is a keystone problem for 5G, 6G in the context of machine to machine communications. We explore fundamental bounds as well as new algorithms mostly based on machine learning, and we develop experimental setups.

- Challenge 3: PHY layer design (leveraging on axes 2,3). The objective is to deeply study and characterize the PHY layer properties and to design new waveforms, e.g. for IRS, for massive MIMO,...

- Challenge 4: Security and Energy (leveraging on axes 2,3). We study new technologies under the light of security and energy constraints at the radio level. Radio-based localisation is one of the key component.

- Challenge 5: Computing Networks (leveraging on all axes). In this axis we explored new paradigms mostly connected to decentralized estimation/detection problems, such as federated learning, with a focus on communication related questions.

In the following we present our activity per axis, referring to these 5 challenges. We do not present specific results on experimentation. Nevertheless, we highlight that a huge effort has been made to prepare the evolution of CorteXlab and to adapt it for the European Instinct project.

8.1 Axis 1 : Foundations of communication theory

Participants: Malcolm Egan, Jean-Marie Gorce, Maxime Guillaud.

In this axis, we contributed on 5 problems :

8.1.1 Heterogeneous delay traffic with small packets

This research [34] is related to challenges 1 and 2. To answer the call for a new theoretical framework to simultaneously accommodate random user activity and heterogeneous delay traffic in Internet of Things (IoT) systems we propose coding schemes and information-theoretic converse results for the transmission of heterogeneous delay traffic over interference networks with random user activity and random data arrivals. The heterogeneous traffic is composed of delay-tolerant traffic and delay-sensitive traffic where only the former can benefit from transmitter and receiver cooperation since the latter is subject to stringent decoding delays. The total number of cooperation rounds at transmitter and receiver sides is limited to D rounds. Each transmitter is active with probability $\rho \in [0,1]$. We consider two different models for the arrival of the mixed-delay traffic: in Model 1, each active transmitter sends a delay-tolerant message, and with probability $\rho \in [0,1]$ also transmits an additional delay-sensitive message; in Model 2, each active transmitter sends either a delay-sensitive message with probability ρ_f or a delay-tolerant message with probability $1-\rho_f$. We derive inner and outer bounds on the fundamental per-user multiplexing gain (MG) region of the symmetric Wyner network as well as inner bounds on the fundamental MG region of the hexagonal model. Our inner and outer bounds are generally very close and coincide in special cases.

8.1.2 When random tensors meet random matrices

This research [35] is related to challenge 1. The proposed study is not directly related to communication problems, but is meaningful for several classes of problems (e.g. massive access, channel charting,...) Relying on random matrix theory (RMT), this paper studies asymmetric order$-d$ spiked tensor models with Gaussian noise. Using the variational definition of the singular vectors and values of (Lim, 2005), we show that the analysis of the considered model boils down to the analysis of an equivalent spiked symmetric block-wise random matrix, that is constructed from contractions of the studied tensor with the singular vectors associated to its best rank-1 approximation. Our approach allows the exact characterization of the almost sure asymptotic singular value and alignments of the corresponding singular vectors with the true spike components. In contrast to other works that rely mostly on tools from statistical physics to study random tensors, our results rely solely on classical RMT tools such as Stein's lemma. Finally, classical RMT results concerning spiked random matrices are recovered as a particular case.

8.1.3 Lossy compression for decision making with risk

Our work in [53] contributes to challenges 1 and 5. Storage or communication of data often requires lossy compression. As this data may be later utilized for decision making, compression introduces a source of uncertainty. In order to verify the quality of decisions, it is often desirable to quantify this uncertainty. This is often achieved via families of risk measures (such as distortion risk measures), rather than the mean. In this work, we study fixed-length lossy compression subject to distortion risk measure constraints. We first establish conditions for the existence of a fixed-length lossy source code, which satisfies a distortion risk measure constraint. We then investigate the impact of quantifying uncertainty via a distortion risk measure, rather than standard expected distortion constraints. Finally, we quantify the impact of changing the source distribution on performance, measured in terms of a distortion risk measure.

8.1.4 Matching and pricing of buyers and sellers in data exchanges

In [54], we consider matching and pricing of buyers and sellers in data exchanges. This topic falls in the context of challenge 5. Buyers are data consumers that wish to obtain data of a sufficient quality to achieve their goals and who may value quality levels differently. Sellers are data providers that desire to properly value the data that they are selling. Our goal in this work is to develop a tractable formulation of the winner determination problem for such a data exchange, and we show that the problem can be solved via bi-level optimization methods. We also examine how different pricing rules are affected when a data provider is able to replicate their data and thus sell it to multiple buyers. We demonstrate that Vickrey and Balanced Winner Contribution rules can introduce inherent disincentives for data replication. Therefore, we introduce a new rule, the modified Balanced Winner Contribution rule, and show that it can provide flexible incentives for data replication in thin markets.

8.1.5 Dynamic stochastic models

In [29], we study stochastic models for biochemical reaction systems with diffusion. This work continues to explore molecular communications as a special case of challenge 5. As described in section 8.2, additional works are done on molecular communications from optimal detection perspective.

One could either use stochastic, microscopic reaction-diffusion master equations or deterministic, macroscopic reaction-diffusion system. The connection between these two models is not only theoretically important but also plays an essential role in applications. This paper considers the macroscopic limits of the chemical reaction-diffusion master equation for first-order chemical reaction systems in highly heterogeneous environments. More precisely, the diffusion coefficients as well as the reaction rates are spatially inhomogeneous and the reaction rates may also be discontinuous. By carefully discretizing these heterogeneities within a reaction-diffusion master equation model, we show that in the limit we recover the macroscopic reaction-diffusion system with inhomogeneous diffusion and reaction rates.

8.2 Axis 2 : Algorithms for MU networks

Participants: Malcolm Egan, Jean-Marie Gorce, Claire Goursaud, Maxime Guillaud, Cyrille Morin, Leonardo Sampaio.

8.2.1 Massive random access optimization with statistical dependencies

Massive access is an important topic for the development of machine to machine communications, in strong connection with 6G and also non terrestrial networks. This is the topic of challenge 2, with strong connections with challenge 1 and challenge 5.

Grant-free random access (GFRA) is a bottleneck to the development of wireless networks supporting the use cases of massive machine-type communication and ultra reliable and low-latency communication. Such networks are densely and massively popupated and must meet stringent latency and reliability requirements. Due to these characteristics, grant-free random access is envisioned to alleviate the control overhead generated by the classical random access procedure.

The originality of our contribution is the introduction of data dependencies (in time and space).

In [28], we extended the work developed in the PhD of Lélio Chetot extending approximate message passing algorithms taking into account stochastic dependencies, focusing on active user detection and channel estimation algorithms. Existing algorithms assume that the activity of each device is homogeneous and independent, which is not the case in many applications (e.g.,due to sensors observing a common phenomenon). In order to address this problem, we introduce a new flexible model taking into account a group-heterogeneous activity, using the framework of copula theory. It is then leveraged by a hybrid generalized approximate message passing algorithm to solve the active user detection and channel estimation problem. Our numerical results show that the user detection and channel estimation are both improved with this new algorithm w.r.t. state-of-the-art Bayesian algorithms, with gains up to 10 times fewer detection errors and 10 dB less channel estimation error. In [32] we worked on designing frame slotted ALOHA algorithms for networks with heterogeneous activity probabilities. Current algorithms for optimizing the probability a device accesses each slot require perfect knowledge of the active devices within each frame. In practice, this assumption is limiting as device identification algorithms in GFRA rarely provide activity estimates with zero errors. In this context, we developped a new algorithm based on stochastic gradient descent for optimizing slot allocation probabilities in the presence of activity estimation errors. Our algorithm exploits importance weighted bias mitigation for stochastic gradient estimates, which is shown to provably converge to a stationary point of the throughput optimization problem. In moderate size systems, our simulations show that the performance of our algorithm depends on the type of error distribution. We study symmetric bit flipping, asymmetric bit flipping and errors resulting from a generalized approximate message passing (GAMP) algorithm. In these scenarios, we observe gains up to 40%, 66%, and 19%, respectively.

In [39] we extend the slot allocation problem above mentioned to a joint power/slot allocation. In [55], specific algorithms have been adapted in the context of 5G. Overall, these contributions are presented in the PhD of Alix Jeannerot [49].

8.2.2 Quantum algorithms for multiple access

This line of research is more explorative, but is also focused on multi-user access (challenge 2). The objective is to explore the use of quantum alogrithms to optimize active user detections (AUD). This work was initiated with the PhD of Idham Habibie, funded by an Inria exploratory action [30]. This work has been extended to more realistic scenarios with the PhD of Romain Piron [41, 42, 43, 44]. Leveraging quantum annealing (QA) for the AUD problem in massive wireless networks is a promising approach to address the stringent reliability and latency constraints of typical application scenarios. However, the practical implementation of QA on current D-Wave's processors requires embedding the problem. This increases the number of qubits needed for a given network size, which degrades QA performance. In In [41], we propose to add a pre-processing step called the threshold method to mitigate the undesired effects of embedding. Our results show that, within limited computational time, this threshold method improves QA's accuracy in solving the activity detection problem. Thus, this is promising to effectively reduce the negative impact of embedding.

[42] proposes a new strategy based on Grover's quantum algorithm to perform the minimum searching so as to implement the ML receiver. As current quantum processors still suffer from noise in the so-called NISQ era, we propose to use Grover's routine with a reduced number of iterations but with several trials. We show that this approach presents a complexity advantage and allows to reach higher success probabilities than Grover's. This strategy may permit to timely deploy such AUD receiver even without perfect quantum devices. In complement, in [43], we first propose a mapping between the AUD searching problem and the identification of the ground state of an Ising Hamiltonian. Then, we compare the execution times of our QA approach for several code domain multiple access (CDMA) scenarios. We evaluate the impact of the cross- correlation properties of the chosen codes in a NOMA network for detecting the active user's set. In [44] we show that the maximum a posteriori decoder of the activity pattern of the network can be seen as the ground state of an Ising Hamiltonian. For N users in a network with perfect channels, we propose a universal control function to schedule the annealing process. Our approach avoids to continuously compute the optimal control function but still ensures high success probability while demanding a lower annealing time than a linear control function. This advantage holds even in the presence of imperfections in the network.

8.2.3 Spike Neural Networks for Wake Up radio

This work has been done in the context of the U-WAKE project, within the PhD of Guillaume Marthe [50, 40]. This is one of the core contribution of challenge 4, with contributions in the design of a specific PHY layer (challenge 3).

In the context of the Internet of Things (IoT), one of the greatest challenges lies in energy management. Wake-up Radios (WuR) enable devices to remain in standby mode while consuming minimal energy, activating only upon receiving specific signals. In this work, we propose the use of Spiking Neural Networks (SNNs) as Wake-up Radios (WuR). The neural network's role is to recognize the activation sequence of the targeted node within a bitstream to trigger its wake-up.

Our initial contribution demonstrates the relevance of these networks. Our second contribution involves the investigation and proposal of the Saturating Leaky Integrate and Fire (SLIF) model for WuR design. We proposed leveraging a bio-inspired phenomenon called Synaptic Interaction to create a temporal filter dependent on Inter-Spike Timing (IST). This model's parameters have been analyzed to understand how to adapt its IST ranges. The originality of this contribution lies in introducing a novel method for recognizing temporal sequences in the analog domain.

Subsequently, we explored various SLIF neural network topologies, including linear, diamond-shaped, and multilayer architectures, to understand how networks respond to spike sequences. We established foundational work for future research on neuromorphic networks in low-power IoT devices, particularly in WuRs.

8.2.4 Optimization of Zero energy devices

Complementarily to the former task, and in the same context (low energy IoT applications) of challenge 4, we worked with Orange Labs (project 5G Event Labs and CIFRE) [47], on the design of optimal code sequences tfor zero energy devices (ZED). This work concerns the design of new ultra-low power method for smartphones indoor localization, based on ZEDs beacons instead of active wireless beacons. Each ZED is equipped with a unique identification number coded into a bit-sequence, and its precise position on the map is recorded. An SM inside the building is assumed to have access to the map of ZEDs. The ZED backscatters ambient waves from base stations (BSs) of the cellular network. The SM detects the ZED message in the variations of the received ambient signal from the BS. We accurately simulate the ambient waves from a BS of Orange 4G commercial network, inside an existing large building covered with ZED beacons, thanks to a ray-tracing-based propagation simulation tool. Our first performance evaluation study shows that the proposed localization system enables us to determine in which room a SM is located, in a realistic and challenging propagation scenario.

8.2.5 Systems for molecular communications

We worked on Molecular communications for several years. This research aims at studying communication systems based on molecular properties [31, 37]. This work is exploratory and is associated to challenge 1 and challenge 5.

In [31], and in the context of the Internet of Bio-Nano Things (IoBNT), nano-devices are envisioned to perform complex tasks collaboratively, i.e., by communicating with each other. One candidate for the implementation of such devices are engineered cells due to their inherent biocompatibility. However, because each engineered cell has only little computational capabilities, transmitter and receiver (RX) functionalities can afford only limited complexity. In this work, we proposed a simple, yet modular, architecture for a cellular RX that is capable of processing a stream of observed symbols using chemical reaction networks. We proposed two specific detector implementations for the RX. The first detector is based on a machine learning model that is trained offline, i.e., before the cellular RX is deployed. The second detector utilizes pilot symbol-based training and is therefore able to continuously adapt to changing channel conditions online, i.e., after deployment. To coordinate the different chemical processing steps involved in symbol detection, the proposed cellular RX leverages an internal chemical timer. Furthermore, the RX is synchronized with the transmitter via external, i.e., extracellular, signals. The proposed architecture is validated using theoretical analysis and stochastic simulations. The presented results confirm the feasibility of both proposed implementations and reveal that the proposed online learning-based RX is able to perform reliable detection even in initially unknown or slowly changing channels.

In another direction, a challenge for real-time monitoring of biochemical processes, such as cells, is detection of biologically relevant molecules. This is due to the fact that spectroscopy methods for detection may perturb the cellular environment. One approach to overcome this problem is coupled microfluidic-spectroscopy, where a microfluidic output channel is introduced in order to observe biologically relevant molecules. This approach allows for non-passive spectroscopy methods, such as mass spectrometry, to identify the structure of molecules released by the cell. Due to the non-negligible length of the microfluidic channel, when a sequence of stimuli are applied to a cell it is not straightforward to determine which spectroscopy samples correspond to a given stimulus. In [37], we proposed a solution to this problem by taking a molecular communication (MC) perspective on the coupled microfluidic-spectroscopy system. In particular, assignment of samples to a stimulus is viewed as a synchronization problem. Our results show improvements over maximum-likelihood synchronization algorithms in terms of detection performance when there are uncertainties in the composition of the microfluidic channel.

8.2.6 ML based approaches for PHY layer optimization

The use of ML techniques at the PHY layer has been introduced by ten years ago, see e.g. [57]. The use of ML in wireless networks is seen as a keystone problem for 6G. The ambition is to optimize transmission techniques, with a reduction of the complexity of channel models, and a reduction of pilots and signaling requirements. In this context, we are collaborating for about 10 years with Nokia Bell Labs on these topics, including the recent PhD of Mateus Mota defended by end of 2023 [51] on protocol learning.

Another joint PhD is the one of Shashwat Mishra, who published with Noia Bell Labs a contribution on the use of GNN for Cell-free massive MIMO (CFmMIMO) [33]. This a promising paradigm to provide uniform coverage in future wireless networks. However, a fully connected CFmMIMO system where all the access points (APs) serve every user equipment (UE) makes it challenging to deploy and scale in real-time due to high computational complexity and increased signaling overhead. In this work, we study the problem of downlink power allocation in partially connected CFmMIMO (p-CFmMIMO) systems using maximal ratio transmission (MRT). We utilize the underlying geometry of the problem to propose a graph representation of the CFmMIMO system and develop a graph neural network (GNN) based power allocation strategy to maximize the minimum SINR in the system. We demonstrate that the proposed GNN model has excellent generalizability to deployment size, radio propagation morphologies, and per-AP serving density. Our GNN can address the power allocation problem in the fully connected case, the partially connected case, and even the cellular case with magnitudes lower computational complexity compared to the conventional numerical solvers. Notably, we show that over a wide range of service scenarios, the model achieves a median spectral efficiency that is within 10% of the optimal second order cone programming (SOCP) solution while requiring 100 times fewer FLOPS.

We also worked on the project 5G Event Labs, on a new technique for joint transmission of messages in broacast channel setting [45]. A learning-based approach is introduced to optimize a joint constellation for a multi-user MIMO broadcast channel (T Tx antennas,K users, each with R Rx antennas), with perfect channel knowledge. The aim of the optimizer (MAX-MIN) is to maximize the minimum mutual information between the transmitter and each receiver, under a sum-power constraint. The proposed optimization method do neither impose the transmitter to use superposition coding (SC) or any other linear precoding, nor to use successive interference cancellation (SIC) at the receiver. Instead, the approach designs a joint constellation, optimized such that its projection into the subspace of each receiver K, maximizes the minimum mutual information $I(W_k;Y_k)$ between each transmitted binary input W_k and the output signal at the intended receiver Y_k. The rates obtained by our method are compared to those achieved with linear precoders.

8.2.7 Channel charting

Channel charting (CC) is an unsupervised learning technique that utilizes channel state information (CSI) to construct a low-dimensional representation of the radio propagation environment through dimensionality reduction, with applications to predictive radio resource management and beam management, proximity detection, context awareness for digital twin applications, geofencing, and improving localization [58]. We investigate this topic within the CHIST-ERA CHASER project (see Sec. 10.3.3), and leverage CC for the purpose of sensing in project INSTINCT (see Sec. 10.3.1).

With CSI samples being acquired at high sampling rates (typically around 100 samples per second) by each base station (BS), it is not feasible to store all the generated CSI samples. Furthermore, since it is desirable to apply CC over data collected over long durations (potentially weeks or months), it is reasonable to assume that the total amount of CSI that will be acquired is a priori unbounded. We have developed methods for dynamic, online channel charting [56] which solve the core-set selection problem for the specific case of contrastive learning.

Since in a radio access network scenario, it is typical for one mobile user to be within the coverage are of multiple BS, it is desirable to produce a channel chart representation with is consistent across base stations, we have also obtained results on representation alignment in multi-site CC [46]. This method allows to construct a unified channel chart spanning multiple BS, despite the user having completely different CSI when seen from either BS.

8.2.8 Additional contributions

The following references are indicated in our publication list but are not detailed in this report.

- The work in [38, 36] is related to the PhD of Yamil Vindas, done before he joined the team.
- The work in [52] is the scientific report of the PEPR project PERSEUS to which Maracas is contributing.

9 Bilateral contracts and grants with industry

9.1 Bilateral contracts with industry

Participants: Naveed Ahmad, Lelio Chetot, Malcolm Egan, Jean-Marie Gorce, Alix Jeannerot.

We have currently the following partnerships

1. Inria-Nokia Bell Labs common lab : Jean-Marie Gorce lead the future challenge LearnNet starting on January, 1st, 2024. Alix Jeannerot was also partly funded in the framework of this common lab.

2. Challenge FedMalin : Jean-Marie Gorce, Malcolm Egan and Tan Khiem Huynh are involved in this challenge.

9.2 Bilateral grants with industry

Participants: Jean-Marie Gorce, Fabrice Dupuy, Shashwat Mishra, Claire Goursaud, Shanglin Yang.

1. CIFRE with Orange Labs (2022-2025) on passive TAG aided localization with zero-energy-devices anchors. This work is adressed by Mr Shanglin Yang (PhD student), to be defended in 2025.

2. CIFRE with Orange Labs (2022-2025) on quantum algorithms for networks. This project is developed in the PhD of Fabrice Dupuy. The aim of the funded thesis was to pave the way for building a quantum network. The objective was to determine which protocols and algorithms are suitable for the quantum network (i.e. when the transmitted data is quantum), depending on the repeaters and links performances. The thesis had to be stopped due to the student health issues, but has been renewed with a new student (Claire MESNY, PhD starting end of 2024).

3. CIFRE with Nokia Bell Labs (2021-2024) on IA for resource allocation in IoT networks. This work is adressed by Mr Shashwat Mishra (PhD student). The work targeted the maximization of connectivity im massive access and the PhD has been successfully defended in December, 2024.

4. SPIE ICS Chaire (2022-2025) - 2nd phase: A funded postdoc studied communication strategies to support predictive maintenance systems. A funded PhD (in collaboration with Dynamid and Agora) is currently investigating energy efficient training strategies for DNNs.

5. Inria-Nokia Bell Labs common lab : this common lab covered multiple research actions and we were involved in two: i) Analytics and Network Information Theory covering the funding of two PhDs (Cyrille Morin and Lélio Chetot), and ii) machine learning for networks that partly funded of another PhD (Alix Jeannerot) and 1 postdoc (Homa Nikbakht).

10 Partnerships and cooperations

10.1 International initiatives

Participants: Malcolm Egan, Jean-Marie Gorce, Claire Goursaud, Maxime Guillaud, Leonardo Sampaio.

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

AI-HEAL

Title: Development of AI-Driven Signal Processing Techniques for Secure Wireless Healthcare Systems

Duration: 2024 -> 2026

Coordinator: Mahendra Kumar Shukla, Maxime Guillaud

Partners:

- Indian Institute of Information Technology and Management (IIITM) in Gwalior (India)

Inria contact: Maxime Guillaud

Summary: This associate team focuses on the development of AI-Driven signal processing techniques for secure wireless healthcare systems. Work has been initiated on using modern machine learning techniques to enhance CSI-based authentication and protection against CSI spoofing, and on friendly jamming approaches to protect against wiretapping.

FedAutoMoDL

Title: Federated Automated Deep Learning

Duration: 2022 -> 2024

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

Partners:

- Indian Institute of Technology Delhi New Delhi (Inde)

Inria contact: Malcolm Egan

Summary: 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

Maracas is participating to the COST INTERACT CA20120 (INTERACT) on Intelligence-Enabling Radio Communications for Seamless Inclusive Interactions (2021–2025).

Leonardo Sampaio, Claire Goursaud are co-supervising Dalil Beknadj, a PhD student from the Univ. of Bejaia, Algeria.

Additionally we have several long-term collaborations including:

Prof. H Vincent Poor, Princeton University: Long-term collaboration, with recent results on information theoretic limits of multi-user networks obtained in collaboration with H. Nikbakht who had a postdoc in MARACAS followed by another in Princeton.

Prof. Gareth Peters (UCSB): Long-term collaboration (since 2014) on statistical modelling and methodology, including interference modelling and more recently on data exchange platforms.

Group of Prof. Robert Schober. (FAU Erlangen): Collaboration centered on molecular communications.

Dr. Vyacheslav Kungurtsev (CTU Prague): Long-term collaboration (since 2016) on optimization theory and process control

Dr. Michael Barros (University of Essex, UK): Collaboration on molecular communications.

Prof. Nir Oren (University of Aberdeen): Long-term collaboration (since 2014) on multi-agent systems, recently on data exchange platforms.

10.2 International research visitors

10.2.1 Visits of international scientists

Prof. Somantika Datta

Full Professor

Department of Mathematics, University of Idaho

United States of America

August 2024 - September 2024

Prof. Datta is an expert in finite frame theory and collaborated with M. Egan on theory and applications in signal processing and communications.

Cofinanced by the sabbatical programme at the University of Idaho, Inria Lyon invited researcher programme, and the EA FedAutoMoDL.

10.2.2 Visits to international teams

Research stays abroad

Malcolm Egan

Department of Statistics UCSB

United States of America

October 2024 - November 2024

Hosted by Prof. Gareth Peters to collaborate on topics in non-linear regression and risk-measures.

Research stay funded by the TESTBED2 EU project and ANR JCJC TCDTP.

10.3 European initiatives

10.3.1 Horizon Europe

INSTINCT INSTINCT project on cordis.europa.eu

Title: Joint Sensing and Communications for Future Interactive, Immersive, and Intelligent Connectivity Beyond Communications

Duration: From January 1, 2024 to December 31, 2026

Partners:

- INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET AUTOMATIQUE (INRIA), France
- ROBERT BOSCH GMBH (BOSCH), Germany
- OULUN YLIOPISTO (UOULU), Finland
- FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV (Fraunhofer), Germany
- INSTITUT NATIONAL DES SCIENCES APPLIQUEES DE LYON (INSA LYON), France

- BARKHAUSEN INSTITUT GGMBH, Germany
- NEC ITALIA SPA, Italy
- AALTO KORKEAKOULUSAATIO SR (AALTO), Finland
- GREENERWAVE, France
- UNIVERSITY OF PIRAEUS RESEARCH CENTER (UNIVERSITY OF PIRAEUS), Greece
- TELEFONICA INNOVACION DIGITAL SL, Spain
- NEC LABORATORIES EUROPE GMBH, Germany
- CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS (CNRS), France
- CENTRALESUPELEC, France
- FUNDACIO PRIVADA I2CAT, INTERNET I INNOVACIO DIGITAL A CATALUNYA (CERCA - i2CAT), Spain

Inria contact: Jean-Marie Gorce

Coordinator: University of Piraeus

Summary: The INSTINCT project is going to enable globally sustainable, interactive, immersive, and intelligent ‘beyond communications’ 6G connectivity by developing three complementary but critical breakthrough technology pillars:

- sensing-assisted communication technologies, thus allowing localization, tracking, mapping, monitoring, imaging, incident detection and semantics become integral parts of connectivity services (Pillar 1),
- intelligent surfaces, holographic radios and cell free systems, which offer wavefront engineering functionalities and tuneability of the wireless environment and can act as reconfigurable and intelligent sensors (Pillar 2), and
- Machine Learning (ML) techniques-based co-design of Sensing and Communications

INSTINCT proposes a revolutionary path to 6G and has the ambition to specify the relevant KPIs/KVIs, formulate suitable models, devise the theoretical framework, invent new technologies, evaluate via simulations and validate by means of 2 HW and 1 SW demonstrators, a networked intelligence concept able to meet the unprecedented 6G requirements. To realise this vision, INSTINCT consortium brings together all relevant stakeholders from across Europe, with an impressive record of interdisciplinary research excellence, technology innovation, standardisation and transfer, and implementation expertise.

10.3.2 H2020 projects

TESTBED2 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, China
- JINAN UNIVERSITY (JNU), China
- UNIVERSITY OF NEBRASKA, 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 (HELLENIC 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, China
- STICHTING NEDERLANDSE WETENSCHAPPELIJK ONDERZOEK INSTITUTEN (NWO-I), Netherlands

Inria contact: Samir PERLAZA

Coordinator: UNIVERSITY OF DURHAM

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 (2 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.

10.3.3 Other european programs/initiatives

In the framexork of the CHIST-ERA program :

Chaser

Title: Channel Charting as a Service

Duration: From Nov 2023 to Nov 2026

Partners:

- Aalto University - Finland (coordinator)
- INRIA Lyon - France
- University of Minho - Portugal
- Eidgenössische Technische Hochschule Zürich - Switzerland

Inria contact: Maxime Guillaud

Coordinator: Aalto University

Summary: Chaser focuses on making channel charting a practical tool in future radio access networks. By applying dimensionality reduction to channel state information, channel charting produces a pseudo-location with no recourse to classical positioning methods, potentially opening up a range of location-based applications with significantly reduced overhead. The objective of CHASER is to develop methods and algorithms allowing to implement network-wide CC, and to develop its predictive capabilities when applied to real-world use cases involving multiple base stations or access points, heterogeneous users and dynamically changing environments, with the ultimate goals of developing CC into a robust and versatile pseudo-positioning method to assists a number of network functions and user-level applications.

web site: CHASER project

People involved: Maxime Guillaud, Mohamed el Mehdi Makhlouf, Yamil Vindas

Related publications: [46, 56]

10.4 National initiatives

10.4.1 Inria incentive actions

FedMalin challenge (2022-2026) FedMalin is a research project that spans 11 Inria research teams and aims to push FL research and concrete use-cases through a multidisciplinary consortium involving expertise in ML, distributed systems, privacy and security, networks, and medicine. We propose to address a number of challenges that arise when FL is deployed over the Internet, including privacy, fairness, energy consumption, personalization, and location/time dependencies.

LearnNet challenge (2024-2028) This challenge lead by Maracas involves 7 other teams with a deep background either in network and communications, or in statistics and data science. The Learning Networks framework is proposed as a new paradigm to explore novel research avenues at the crossroads of networking and machine learning. The objective is twofold: to revolutionize the design of network protocols in the view of machine learning applications, and to explore the use of machine learning to improve network management itself. Heterogeneity is a central question in this project since future learning networks will have to operate heterogeneous systems.

10.4.2 ANR

U-WAKE

Title: Ultra-Low Power Wake-up Radio

Duration: From 2020 to 2024

Partners:

- IEMN / IMT Nord Europe
- CITI , INSA Lyon, Inria
- IRISA, Lannion

Inria contact: Claire Goursaud

Coordinator: IEMN

Summary: 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 supported the PhD of Guillaume Marthe.

web site: UWAKE

People involved: Claire Goursaud, Guillaume Marthe

Related publications: [40, 50]

JCJC TCDTP

Title: Tailoring Communications in Multi-Tier Computation for Digital Twinned Process Control

Duration: From 2024 to 2027

Partners:

- CITI , INSA Lyon, Inria

Inria contact: Malcolm Egan

Coordinator: Inria

Summary: TCDTP is concerned with the development of digital twin based process control within multi-tier computation architectures from the perspective of communications. Aligned with the goal-oriented perspective, the project aims to jointly design compression, resource allocation, and learning in order to ensure efficient stabilization of physical processes.

People involved: Malcolm Egan

Related publications: [53]

10.4.3 BPI France

- BPI – France Relance – 5G Events Labs [Consortium: CEA – Centre de Saclay, Ericsson, Inria, Orange] [2021–24]. 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.

10.4.4 Research projects in the framework of Programme Agencies

Malcolm Egan,Jean-Marie Gorce,Claire Goursaud,Maxime Guillaud, Leonardo Sampaio, Matthieu Imbert, Cyrille Morin

Within the national *Priority Research Programme and Equipment* (PEPR) programme, we are involved in multiple sub-projects of the “Future Networks” PEPR (PEPR-NF), which is affiliated to the program agency “From components to systems and digital infrastructure”, led by CEA. Telecommunication networks represent a key issue for French and European industry, society and digital sovereignty. The French government launched a dedicated national strategy, with the ambition to produce significant public research efforts so the national scientific community contributes fully to making progress that clearly responds to the challenges of 5G and beyond. In this context, the CNRS, the CEA and the Institut Mines-Télécom (IMT) are co-leading the ’5G’ acceleration PEPR to support upstream research into the development of advanced technologies for 5G+. MARACAS contributes to:

PERSEUS - PEPR Future Networks MARACAS, with TRIBE, contributes to PERSEUS. PERSEUS focuses on the technologies, processing and optimization of cell-free massive MIMO (CF-mMIMO) networks in the sub-7 GHz frequency band. CF-mMIMO technology, combined with reconfigurable intelligent surface (RIS) techniques and artificial intelligence (AI) tools, is a highly promising solution for beyond-5G networks. PERSEUS aims to increase the maturity of these technologies in order to achieve power- and spectrum-efficient massive access. The project covers several aspects with a view to designing a "cell-free massive MIMO" network: (i) design, manufacture and test of RF circuits, RIS and antennas, (ii) proposal of robust PHY and MAC layers based on signal propagation measurements and the incorporation of hardware imperfection models, and (iii) development of proofs of concept to practically evaluate the performance of the selected algorithms and the hardware manufactured within the framework of the project.

FOUND - PEPR Future Networks MARACAS, with MATHSNET and NEO, contributes to FOUNDS. The project organizes fundamental research in the following directions: The study of the fundamental theoretical limits in the sense of physics and information theory, with many open questions linked to the use of the spatial dimension, strong latency constraints or even the taking into account of the signification of what is transmitted from coding, protocols and up to the physical layer. The determination of the optimal spatial organization of the network elements, taking into account the limitations of information theory. This will require new mathematical tools and models, which will be key elements of this project. The design of real-time and non-real-time distributed control algorithms to exploit such network architectures. The main objective here is to get closer to the fundamental limits studied in this project.

FPNG - PEPR Future Networks MARACAS (with DIANA and TRIBE) contributes to the PC Plateforms, which includes the development and the integration of CorteXlab into SLICES-FR. SLICES-FR 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.

10.5 Public policy support

- Maxime Guillaud is a member of the Technical Expert Committee on Mobile Networks of ARCEP, the French regulatory authority for electronic communications.

11 Dissemination

11.1 Promoting scientific activities

11.1.1 Scientific events: organisation

Member of the organizing committees :

- Jean-Marie Gorce, Claire Goursaud and Maxime Guillaud were members of the organization committee of the EUSIPCO 2024 conference, held in Lyon in August 2024.

11.1.2 Scientific events: selection

Reviewer

- Maracas members are usual TPC members of the main conferences : GRETSI, ICT, IEEE GLOBECOM, EUSIPCO, IEEE ICC, IEEE Nanocom, IEEE WCNC...

11.1.3 Journal

Member of the editorial boards

- Malcolm Egan was an associate editor of the IEEE Comm. Letters.
- Jean-Marie Gorce was an associate editor of Entropy (MDPI) and Eurasip JWCN.
- Claire Goursaud is an associate editor of Transactions on Emerging Telecommunications Technologies since 2016.
- Claire Goursaud is an associate editor of Internet Technology Letters since 2017.
- Maxime Guillaud is an associate editor of the IEEE Transactions on Wireless Communications since 2019

Reviewer - reviewing activities

- All Maracas members are usual reviewers for major journals: IEEE Communications Letters, among which IEEE Wireless Communication Letters, IEEE Journal on Selected Areas in Communications, IEEE Journal on Selected Topics in Signal Processing, IEEE Sensors, IEEE Internet of Things Journal, IEEE Trans on Communications, IEEE Trans on Information Theory, IEEE Trans. on Mobile Computing, IEEE Trans on Molecular Biological, IEEE Trans on NanoBioscience, IEEE Trans on Signal Processing, IEEE Trans on Vehicular Technologies, IEEE Trans on Wireless Communications, EURASIP Journal on Advances in Signal Processing, EURASIP Journal on Wireless Communications and Networking.

11.1.4 Invited talks

- Malcolm Egan gave invited talks at Department Statistics UCSB (2024), HALICIOGLU DATA SCIENCE INST UCSD (2024), Workshop on Distributed Computing in Paris (2024), Interdisciplinary Faculty Development Workshop Bennett University (2024).
- Jean-Marie Gorce gave invited talks at Inria-Japan workshop (July 2024), at NII Tokyo (July 2024), at Korea University (Dec 2024).
- Claire Goursaud gave invited talks at ASILOMAR 2024, at IEEE WF IoT 2024.
- Maxime Guillaud gave invited talks at Linköping university, Banff workshop on Algorithmic Structures for Uncoordinated Communications, Thales SIX, ERICSSON Research France.
- Maxime Guillaud gave two IEEE ComSoc Distinguished Lecture tours in Brazil (with 3 lectures) and Germany (with 2 lectures)
- Maxime Guillaud gave a Tutorial on Channel Charting given at ISWCS 2024

11.1.5 Leadership within the scientific community

- Jean-Marie Gorce is a member of the Scientific Committee of GdR IASIS (CNRS Research Group on Information, Learning, Signal, Image and Vision)
- Maxime Guillaud is a member of the Steering Committee of GdR IASIS (CNRS Research Group on Information, Learning, Signal, Image and Vision)
- Maxime Guillaud is Vice-chair of the EURASIP Signal Processing for Communications and Networking technical area committee, since 2024.

11.1.6 Scientific expertise

- Claire Goursaud was reviewer for the JCJC ANR 2024, expert for the ANR Committee TSIA 2024.
- Malcolm Egan was a Reviewer for the Artificial Intelligence Programme (Bennett University, Delhi) 2024.
- Jean-Marie Gorce is a member of the Scientific Committee of GdR IASIS (CNRS Research Group on Information, Learning, Signal, Image and Vision),
- Maxime Guillaud is a member of the Steering Committee of GdR IASIS (CNRS Research Group on Information, Learning, Signal, Image and Vision),
- Maxime Guillaud is Vice-chair of the EURASIP Signal Processing for Communications and Networking technical area committee, since 2024.

11.1.7 Research administration

- Malcolm Egan was
  - Member council of the CITI Laboratory.
  - Lyon representative for the Inria Mission Jeunes Chercheurs.
  - Member COMI Lyon.
  - Organizer seminar of the CITI Laboratory.
- Jean-Marie Gorce was:
  - Head of Science for the Inria Lyon Centre.
  - Member of the Evaluation Committee of Inria.
  - Member of the board of the EEA doctoral school.
  - In charge of the PEPR-NF preparation, for Inria, member of the PEPR-NF operational committee.
- Claire Goursaud was
  - Deputy director of CITI Lab.
  - CNU 61 member.

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, L Chetot - Advanced Digital Communications, M1, Telecommunications dept, INSA Lyon, France.
- Master : JM Gorce, L Chetot - Radio Access Networks, 32h eqTD, M1, Telecommunications dept, INSA Lyon, France.
- Master : C Goursaud - Communications Systems, 32h eqTD, M1, Telecommunications dept, INSA Lyon, France.

11.2.2 Supervision

PhD defended in 2024:

Alix Jeannerot was supervised by Malcolm Egan and Jean-Marie Gorce

Guillaume Marthe was supervised bu Claire Goursaud

Shashwat Mishra was supervised by Jean-Marie Gorce

On-going PhDs :

Tan Khiem Huynh is supervised by Malcolm Egan and Jean-Marie Gorce

Andrea Joly is supervised by Leonardo Sampaio and Jean-Marie Gorce

Mohamed El Mehdi Makhlouf is supervised by Maxime Guillaud and Jean-Marie Gorce

Claire Mesny is supervised by Claire Goursaud

Romain Piron is supervised by Claire Goursaud

Samya Tannir Université Bretagne Sud is cosupervised by Maxime Guillaud and Emmanuel Boutillon

Shanglin Yang is cosupervised by Jean-Marie Gorceand Guillaume Villemaud

11.2.3 Juries

Participation to PhD committees :

- Maxime Guillaud was on the PhD committees of Khodor Safa (CentraleSupelec), A. Oguz Kislal (Chalmers University of Technology), Taha Yassine (INSA Rennes), and Unnikrishnan Kunnath Ganesan (Linköping University). He was in the mid-term PhD committees of Bastien Barbe (INSA Lyon) and Wissal Benzine (EURECOM).
- Jean-Marie Gorce was on the PhD committees of Adam Mekhiche (U Toulouse), Alice Chillet (U Rennes, Lannion), F. Sagheer (L2S, CentraleSupelec), Jiahui Wei (Insa Rennes), Guodong Sun (Inria Paris)

Participation to recruitment committees:

- Claire Goursaud was member of the CRCN Inria Lyon recruitment committee.
- Jean-Marie Gorce was member of the DR Inria recruitment committee and the CRCN admission committee.

Participation to projects evaluation:

- Claire Goursaud was expert for the ANR Committee TSIA 2024.
- Malcolm Egan was a Reviewer for the Artificial Intelligence Programme (Bennett University, Delhi) 2024.

11.3 Popularization

11.3.1 Participation in Live events

Cyrille Morin held a stand with a GNU Radio spectrum monitoring demonstration in FOSDEM 2024 (Bruxelles) and Campus du Libre 2024 (Lyon), showcasing both RF spectrum usage and the use of free software in research.

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 (cit. on p. 7).

[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 (cit. on p. 7).

[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 (cit. on p. 6).

[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 (cit. on p. 7).

[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) (cit. on p. 7).

[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.

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[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] C. Morin. 'Deep learning based approaches for detection in physical layer wireless multiple access'. Université de Lyon, 22nd July 2021. URL: https://theses.hal.science/tel-03470004 (cit. on p. 12).

[23] 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 (cit. on p. 6).

[24] 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 (cit. on p. 4).

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12.2 Publications of the year

International journals

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[29] M. Egan and B. Q. Tang. 'Macroscopic limit for stochastic chemical reactions involving diffusion and spatial heterogeneity'. In: *Stochastic Processes and their Applications* (1st Oct. 2024). URL: https://hal.science/hal-04361261 (cit. on p. 15).

[30] M. I. Habibie, C. Goursaud and J. Hamie. 'Quantum Minimum Searching Algorithms for Active User Detection in Wireless IoT Networks'. In: *IEEE Internet of Things Journal* 11.12 (15th June 2024), pp. 22603–22615. DOI: 10.1109/JIOT.2024.3382337. URL: https://hal.science/hal-04818586 (cit. on p. 16).

[31] B. Heinlein, L. Brand, M. Egan, M. Schäfer, R. Schober and S. Lotter. 'Closing the Implementation Gap in MC: Fully Chemical Synchronization and Detection for Cellular Receivers'. In: *IEEE Transactions on Molecular, Biological and Multi-Scale Communications* (2024). URL: https://hal.science/hal-04713673. In press (cit. on p. 17).

[32] A. Jeannerot, M. Egan and J.-M. Gorce. 'Exploiting Device Heterogeneity in Grant-Free Random Access: A Data-Driven Approach'. In: *IEEE Transactions on Vehicular Technology* (2024), pp. 1–11. DOI: 10.1109/TVT.2024.3396825. URL: https://inria.hal.science/hal-04130618 (cit. on p. 15).

[33] S. Mishra, L. Salaun, H. Yang and C. S. Chen. 'Graph Neural Network Aided Power Control in Partially Connected Cell-Free Massive MIMO'. In: *IEEE Transactions on Wireless Communications* 23.9 (Sept. 2024), pp. 12412–12423. DOI: 10.1109/TWC.2024.3392441. URL: https://hal.science/hal-04933250 (cit. on p. 18).

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[36] Y. Vindas, E. Roux, B. K. Guépié, M. Almar and P. Delachartre. 'An asymmetric heuristic for trained ternary quantization based on the statistics of the weights: an application to medical signal classification'. In: *Pattern Recognition Letters* 188 (9th Nov. 2024), pp. 37–45. DOI: 10.1016/j.patrec.2024.11.016. URL: https://hal.science/hal-04777110. In press (cit. on p. 18).

[37] x. qian xuewen, S. Angerbauer, M. Egan, M. Di Renzo and W. Haselmayr. 'A Molecular Communication Perspective on Synchronization of Coupled Microfluidic-Spectroscopy'. In: *IEEE Transactions on NanoBioscience* (1st July 2024). URL: https://hal.science/hal-04713670 (cit. on p. 17).

International peer-reviewed conferences

[38] M. Dupouy, Y. Vindas, M. Almar, B. Kévin Guépié and P. Delachartre. 'WEAKLY-SUPERVISED SEMANTIC SPACE STRUCTURING: CARDIAC CYCLE POSITION FOR CEREBRAL EMBOLI VISUALIZATION USING CONTRASTIVE LEARNING'. In: *2025 IEEE International Symposium on Biomedical Imaging (ISBI)*. 2025 IEEE International Symposium on Biomedical Imaging (ISBI). Houston, United States, 2025. URL: https://hal.science/hal-04922841 (cit. on p. 18).

[39] A. Jeannerot, M. Egan and J.-M. Gorce. 'Joint Slot and Power Optimization for Grant Free Random Access with Unknown and Heterogeneous Device Activity'. In: *EUSIPCO2024 - 32nd European signal processing conference*. EUSIPCO2024 - 32nd European signal processing conference. Lyon, France, 26th Aug. 2024. URL: https://inria.hal.science/hal-04603280 (cit. on p. 16).

[40] G. Marthe, C. Goursaud and L. Clavier. 'Enabling Low-Power Signature Recognition for the IoT with SLIF neurons'. In: EUSIPCO 2024 - 32nd European conference on signal processing. Lyon, France, 2024, pp. 1–5. URL: https://hal.science/hal-04788239 (cit. on pp. 16, 25).

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