RESEARCH CENTRE

**Inria Lyon Center**

**IN PARTNERSHIP WITH:**

**Institut national des sciences appliquées de Lyon**

2022

# ACTIVITY REPORT

## Project-Team AGORA

## Wireless Networks for Digital Cities

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

**DOMAIN**

**Networks, Systems and Services, Distributed Computing**

**THEME**

**Networks and Telecommunications**

Inria

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# Project-Team AGORA

*Creation of the Project-Team: 2018 April 01*

## Keywords

**Computer sciences and digital sciences**

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A1.2.3. – Routing

A1.2.4. – QoS, performance evaluation

A1.2.5. – Internet of things

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A1.3.6. – Fog, Edge

A1.6. – Green Computing

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B8.1.2. – Sensor networks for smart buildings

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# 1 Team members, visitors, external collaborators

## Research Scientist

- Juan Andres Fraire [INRIA, ISFP]

## Faculty Members

- Hervé Rivano [Team leader, INSA LYON, Professor, HDR]
- Walid Bechkit [INSA LYON, Associate Professor]
- Alexandre Guitton [UNIV CLERMONT AUVERGNE, Professor, (Inria Delegation), HDR]
- Oana Iova [INSA LYON, Associate Professor]
- Razvan Stanica [INSA LYON, Associate Professor, HDR]
- Fabrice Valois [INSA LYON, Professor, HDR]

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- Youssef Badra [INSA LYON, from Mar 2022]
- Anais Boumendil [INSA LYON, from Nov 2022]
- Mohamed Fekih [UDL, until Oct 2022]
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### Interns and Apprentices

- Esther Allain [INSA Lyon, from May 2022 until Aug 2022]
- Mohamed Sami Assenine [ESI, INSA Lyon, until Jun 2022]
- Thibaut Bellanger [INSA Lyon, from Mar 2022 until Aug 2022]
- Anais Boumendil [ESI, INSA LYON, until Jun 2022]
- Carlos Fernandez Hernandez [Universidad Tecnica Federico Santa Maria (UTFSM) (Valparaiso, Chile), from Apr 2022 until Jul 2022]
- Lise Jacquot [INRIA, until Feb 2022]
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- Rachida Saroui [INRIA, until Feb 2022]
- Yuxuan Song [INSA Lyon, from May 2022 until Jul 2022]

### Administrative Assistants

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- Aurélie Reymond [INSA Lyon, until Sep 2022]
- Salwa Selmi [INRIA, from Sep 2022]
- Linda Soumari [INSA Lyon, from Oct 2022]

### External Collaborator

- Alexis Duque [RTONE, from Feb 2022]

## 2 Overall objectives

Smart city is a constantly reshaped concept, embracing the future of dense metropolitan areas, with references to efficient and sustainable infrastructure, improving citizens' quality of life and protecting the environment. A consensus on the Smart City philosophy is however that it will be primarily achieved by leveraging a clever integration of Information and Communication Technologies (ICT) in the urban tissue.

Indeed, ICTs are enabling an evolution from the current duality between the real world and its digitized counterpart to a continuum in which digital contents and applications are seamlessly interacting with classical infrastructures and services. Smart Cities are often described by the digital services that they provide, which are inherently dependent on dense measurements of the city environment and activities, the collection of this data, their processing into information, and their redistribution. The networking infrastructure therefore plays a critical role in enabling advanced services, in particular the wireless infrastructure supporting high user density and mobility.

From a wireless networking viewpoint, the digitization of cities can be seen as a paradigm shift extending the Internet of Things (IoT) to a citizen-centric model in order to leverage the massive data collected by pervasive sensors, connected mobiles or fixed devices, and social applications. Note that our focus is not limited only to ICT in urban areas but can be extended to any scenario where coverage challenges meet density, such as satellite-IoT constellations or networks for rural areas.

The Agora research team aims at contributing to the following consequent challenges of data collection wireless networks in smart environments:

- The **deployment of dense networks** is challenged by the scale of the problems and the versatility of the environment, with consequences on the optimization of the placement of both network devices and functions.
- **Data collection** and distribution communication protocols, designed for IoT network architectures, need a coherent rethinking to face issues on saturated cellular networks, star-topologies networks, and multi-hop networks unable to cover large areas.
- **Exploiting the data** carried by the network opens new questions on the network deployment and usage, by understanding the spatio-temporal dynamics of the users, and on in-network computations in order to reduce the traffic load or enhance the quality of the data.

We are not limited to any wireless technologies. Our research takes place in the context of three different wireless network topologies:

- **carefuly deployed** topologies such as cellular networks and environmental monitoring,
- **planned and dynamic** topologies such as fleet of drones and satellite communications,
- **uncontrolled** topologies such as individual IoT and self-deployable networks.

# 3 Research program

The Agora research program is organized in three axes. All our works share the same general methodology that aims at combining:

- modeling to get insights on average and extreme behaviors,
- simulation to investigate large scale networks and asymptotic behavior,
- experimentation to get validation from real devices and users.

Modeling is typically in the form of mathematical optimization, stochastic performance evaluation, or machine learning algorithms. Simulation is mostly done by discrete event simulations, for networks, environment or user mobility. Experiments can be done on proof-of-concept prototypes, lab-controlled test beds or real-world deployments and data collection.

## 3.1 Wireless network deployment

The team addresses challenges in the three following directions:

- We develop optimization models and heuristics for network component deployment, with a specific focus on wireless sensor networks (for monitoring environmental phenomena) and direct-to-satellite communications (to improve IoT coverage, especially for outside areas).
- We investigate the impact of network function deployment enabled by their virtualization on the performances of radio access networks and self-deployable cellular networks.
- We develop and experiment self-configuration and self-healing protocols to enable deployments without human in the loop.

## 3.2 Wireless data collection

In this axis, we investigate design challenges of network mechanisms and protocols such as medium access, medium sharing, and routing protocols.

- Such mechanisms are addressed with a focus on enabling self-organization, self-healing and opportunistic communications.

- New technologies such as low power and long range networks, non terrestrial networks, and human-centric networks yield intermittent connectivity and dynamic architectures. We investigate them in terms of performance, scalability, sustainability, etc.
- We combine our expertise in these diverse architectures and consider hybrid networks, that we foresee as the relevant solution for supporting dense and dynamic topologies.

### 3.3 Network data exploitation

In this axis, we focus on the spatio-temporal characteristics of the network usage and data collected in the three following directions.

- Mobile data are analyzed to understand the coupling between users activity and the network usage.
- Data aggregation is investigated with the objective to have the most efficient and sober usage of wireless communications.
- Finally distributed sensor calibration will exploit the wireless network to increase the reliability of the collected data and ultimately improve the cost/quality trade-off of a wireless sensor network.

## 4 Application domains

### 4.1 Smart Cities

One major characteristic of modern societies is that they are prevalently urban. Consequently, the contributions of the Agora team are in particular applied to provide solutions tailored to the emergence of the Internet of Things (IoT) and to Smart Cities applications. A major motivation of the team is the forthcoming explosion of the number of connected devices and the numerous wireless network technologies, supporting potential end device mobility. In particular, low cost - small data devices are supposed to be densely deployed in our environment, fostering the interest for a convergence of the traditional wireless networking paradigms.

Smart City is a constantly reshaped concept, embracing the future of dense metropolitan areas, with references to efficient and sustainable infrastructure, improving citizens' quality of life and protecting the environment. A consensus on the Smart City philosophy is however that it will be primarily achieved by leveraging a clever integration of ICT in the urban tissue. Indeed, ICTs are enabling an evolution from the current duality between the real world and its digitized counterpart to a continuum in which digital contents and applications are seamlessly interacting with classical infrastructures and services. Smart Cities are often described by the digital services that should be provided which are inherently dependent on dense measurements of the city environment and activities, the collection of these data, their processing into information, and their redistribution. The networking infrastructure plays therefore a critical role in enabling advanced services, in particular the wireless infrastructure supporting density and mobility. In such wireless network infrastructure, whether it is a cellular one or an IoT one, new features arise: mobile devices to provide connectivity (e.g. UAVs), on-demand deployment, heterogeneous technologies, that shape the future of wireless networks.

From a wireless networking viewpoint, the digitization of cities can be seen as a paradigm shift extending the IoT to a citizen-centric model in order to leverage the massive data collected by pervasive sensors, connected mobiles or fixed devices, and social applications.

## 5 Social and environmental responsibility

### 5.1 Impact of research results

Some of our research activities are specifically focused on social and environmental responsibility, through crowd-sensing environmental monitoring.

Since the preliminary project UrpolSens (*Wireless SENSor Networks for URban POLlution Monitoring*[1]) funded in 2015 by the Labex IMU, the Agora Inria team is building a long success story about air and pollution monitoring. With several research projects and bilateral collaborations with companies (e.g., Total), we propose an interdisciplinary approach to efficiently monitor chronic and accidental pollution as well as Urban Heat Island (UHI) . We are focusing on three main use cases: *i)* Static wireless low-cost sensor networks for air quality monitoring while designing efficient deployment and scheduling models, *ii)* participatory crowdsensing for UHI and air quality assessment while addressing the challenge of analyzing dense data from low-cost sensors and their contribution to the fine-grained mapping [42] and *iii)* drone fleet for monitoring pollution plumes while proposing adapted spatio-temporal prediction architectures and new anticipatory path planning approaches [19].

Our work on this side combines theory and real-word experiments where we design, set up and validate low-cost sensor based platforms [42]. Moreover, we also keep our sights on social issues like the pollution perception by residents that we studied in the first axis and the citizen involvement in participatory sensing which was a key issue of the second axis. We hence believe that our work may have benefits to improve the human health and the resilience of the social system against pollution and UHI issues on one side and to better involve citizens in scientific issues on the other side.

# 6 Highlights of the year

## 6.1 Awards

- Walid Bechkit holds the PEDR (2021-2025).
- Alexandre Guitton is now Full Professor *Première Classe*.
- Alexandre Guitton obtained a second year of Inria Delegation.
- Oana Iova holds the RIPEC-C3 (2022-2025).
- Hervé Rivano holds the PEDR (2021-2025).
- Razvan Stanica holds the PEDR (2020-2024).

# 7 New software and platforms

## 7.1 New software

### 7.1.1 PrivaMovApp

**Keyword:** Crowd-sensing

**Functional Description:** Agora is leading the development of an Android application for user data collection purposes. The application is based on the Funf framework.

**Contact:** Razvan Stanica

**Participants:** Stéphane d'Alu, Hervé Rivano, Razvan Stanica, Solohaja Rabenjamina

### 7.1.2 urpolsens

**Name:** UrPolSens Platform

**Keywords:** Wireless Sensor Networks, Air Quality

[1] Project presentation.

**Functional Description:** A micro-controller is integrated into a lab-designed printed circuit which includes among others: a high precision ADC, a micro-SD card reader and a radio communication module. The designed nodes measure the nitrogen dioxide (NO2) pollutant in addition to temperature and humidity, and transmit data using LoRa to a gateway, which is connected to our servers using a 4G connection. The sensors are also equipped with solar panels in order to extend their lifetime when their batteries are drained. Our platform has been operational in the downtown of the city of Lyon with 12 sensor nodes deployed in the Garibaldi street from mid-July to mid-October 2018. It has then been improved and generalized to match the need of the collaboration with Total LQA lab. It is now a versatile multi-sensors platform able to run autonomously on solar energy for months.

**Contact:** Walid Bechkit

**Participants:** Walid Bechkit, Hervé Rivano

**Partner:** Intelligence des Mondes Urbains

#### 7.1.3 3M'Air

**Name:** 3M'Air Platform

**Keywords:** Wireless Sensor Networks, Air Quality

**Functional Description:** We have built our own nodes equipped with multiple sensors measuring Nitrogen-Dioxide (NO2), Particulate Matter (PM1, PM2.5, PM10), temperature and humidity. They are battery-powered and equipped with a GPS module to have the position of the measurements. Data are stored on a micro SD card and at the same time sent over LoRa to a server we have developed that is responsible to store these data for future analysis. A web platform has also been developed to display the collected concentration measurements in real time. This developed solution is used in several participatory planned measurement campaigns in Lyon city.

**Contact:** Walid Bechkit

**Participants:** Walid Bechkit, Hervé Rivano

**Partner:** Intelligence des Mondes Urbains

#### 7.1.4 eSmartCity

**Name:** eSmartCity Smart Lighting platform

**Keywords:** Lighting, Sensors

**Functional Description:** The objective is to analyze the pedestrian mobility on a street and to evaluate the opportunity to deploy a Smart Lighting solution. Mobility is monitored using PIR sensors and correlated with light, environment and noise sensor measurements. We are discussing with a company the opportunity to adapt our sensors to their own public lighting products.

**Contact:** Oana Iova

**Participants:** Oana Iova, Hervé Rivano

#### 7.1.5 Dense LoRaSim

**Name:** Extension to support dense LPWAN in LoRaSim

**Keyword:** LoRaWAN

**Functional Description:** In the settings of our dense networks research topic, we have modified the LoRaSim simulator so that it supports up to a million devices, while keeping a realistic modelisation of the channel. This will allow us to evaluate the scalability of different algorithms and protocols in a realistic scenario. We also created a fork to support ultra dense network emulation.

**Contact:** Fabrice Valois

**Participants:** Fabrice Valois, Oana Iova, Hervé Rivano

#### 7.1.6 FLoRaSat

**Name:** Extension of FLoRa for Direct-to-Satellite IoT

**Keywords:** Iot, Satellite, LoRaWAN

**Functional Description:** Direct to Satellite IoT (DtS-IoT) is a promising approach to deliver data transfer services to IoT devices in remote areas where deploying terrestrial infrastructure is not appealing or feasible. In this context, low-Earth orbit (LEO) satellites can serve as passing-by IoT gateways to which devices can offload buffered data to. However, transmission distances and channel dynamics, combined with highly constrained devices on the ground makes DtS-IoT a very challenging problem. To explore DtS-IoT, we propose to extend the Flora simulator based on Omnet++: i) to support Class B end-devices ii) to support LEO orbits iii) to support large scale satellite constellation. It allows us to model and simulate realistic DtS-IoT scenarios to measure the expected performance of LoRaWAN in a satellite context. Available on: https://gitlab.inria.fr/jfraire/florasat

**Contact:** Juan Andres Fraire

**Participants:** Juan Andres Fraire, Oana Iova, Fabrice Valois

### 7.2 New platforms

**Participants:** Walid Bechkit, Oana Iova, Hervé Rivano, Razvan Stanica, Fabrice Valois.

**PPAIR Plateforme LoRa - Campus Connecté** The project aims at providing a platform that offers connectivity through a long-range, low-energy network to smart objects. The platform uses LoRa technology, which offers a wide connectivity, covering the entire INSA Lyon campus and providing a data collection service to all campus users. The main purpose of the LoRaWAN plateform is: *(i)* research (researchers can use it for studying reliability and capacity problems, privacy related challenges, etc.), and *(ii)* teaching (several courses from INSA, especially in the Telecom department can use this platform as a pedagogical tool).
Since 2019, this platform is used in the European Project Interreg Med ESMARTCITY and for the PHC Ulysses (joint collaboration with Nimbus Center, Ireland).

**UrPolSens Platform** We designed from scratch an energy efficient air pollution sensor network using Atmega micro-controllers and electrochemical air pollution probes. The micro-controller is integrated into a lab-designed printed circuit which includes among others: a high precision ADC, a micro-SD card reader and a radio communication module. The designed nodes measure the nitrogen dioxide (NO2) pollutant in addition to temperature and humidity and transmit data using LoRa to a gateway, which is connected to our servers using a 4G connection. The sensors are also equipped with solar panels in order to extend their lifetime when their batteries are drained. Our platform has been operational in the downtown of the Lyon city with 12 sensor nodes deployed in the Garibaldi street from mid-July to Mid-October 2018.

**3M'air sensor platform** We developed the 3M'Air sensor platform to be used in participatory sensing of temperature and air quality. We have built our own nodes equipped with multiple sensors measuring Nitrogen-Dioxide (NO2), Particulate Matter (PM1, PM2.5, PM10), temperature and humidity. They are battery-powered and equipped with a GPS module to have the position of the measurements. Data are stored on a micro SD card and at the same time sent over LoRa to a server we have developed that is responsible to store these data for future analyses. A web platform has also been developed to display the collected concentration measurements in real time. This developed solution is used in several participatory planned measurement campaigns in Lyon city.

**The AgoraLTEplateform (ALP)** The AgoraLTEplateform is leveraging the opensource srsLTE software suite and Software Defined Radio (SDR) to perform experimental research about autonomous and flexible cellular networks. This platform emulates an entire cellular network thanks to three software components of srsLTE. The cellular network is composed of three main elements: the core network (srsEPC), the radio access network (srsENB) ans the user equipment (srsUE). Those elements can be run on several remote machines and operate an LTE connection by the means of SDR elements: USRP-2901 from National Instrument in our case. We also have at our disposal custom sim cards usable by any off-the-shelf smartphone that permit them to access the experimental network. This platform being run by a regularly updated open source code allows us to modify its structure, tune, add or remove network parameters and run scientific experiments that are yet to few in the literature. This testbed is issued to investigate new user association mechanisms considering quality of service requirements, or emergency situations.

# 8 New results

## 8.1 Wireless network deployment

**Participants:** Walid Bechkit, Juan A. Fraire, Alexandre Guitton, Oana Iova, Hervé Rivano, Fabrice Valois.

**Leveraging Predictability for Global Optimization of IoT Networks** We consider IoT networks where nodes are able to move to change the network topology and improve area coverage and network performance. In [27], we focus on the problem of global optimization where the nodes make use of the predictability of circumstances that affect network operations, such as the communication and sensing ranges, to anticipate future actions that need to be taken so that the correct operation of the network continues to be guaranteed with a minimum global cost. We provide a Mixed Integer Quadratic Program (MIQP)-based solution that minimizes the overall energy consumed over the entire deployment period while maintaining network connectivity and full area coverage. Results show that significant performance enhancement can be obtained when taking predictability into account compared to the case where nodes make decisions based only on their current observations.

**Network Size Estimation for Direct-to-Satellite IoT** The worldwide adoption of the Internet of things (IoT) depends on the massive deployment of sensor nodes and timely data collection. However, installing the required ground infrastructure in remote or inaccessible areas can be economically unattractive or unfeasible. Cost-effective nanosatellites deployed in low Earth orbits (LEO) are emerging as an alternative solution: on-board IoT gateways provide access to remote IoT devices, according to direct-to-satellite IoT (DtS-IoT) architectures. One of the main challenges of DtS-IoT is to devise communication protocols that scale to thousands of highly constrained devices served by likewise constrained orbiting gateways. In [23], we tackle this issue by first estimating the (varying) size of the device set underneath the (mobile) nanosatellite footprint. Then, we demonstrate applicability of the estimation when used to intelligently throttle DtS-IoT access protocols. Since recent works have shown that MAC protocols improve the throughput and energy efficiency of a DtS-IoT network when a network size estimation is available, we present here a novel and computationally-efficient network size estimator in DtS-IoT: our optimistic collision information (OCI) based estimator. We evaluate OCI's effectiveness with extensive simulations

of DtS-IoT scenarios. Results show that when using network size estimations, the scalability of a frame slotted Aloha-based DtS-IoT network is boosted 8-fold, serving up to $4 \times 10^3$ devices, without energy efficiency penalties. We also show the effectiveness of the OCI mechanism given realistic detection ratios and demonstrate its low computational cost implementation, making it a strong candidate for network estimation in DtS-IoT.

**Ring Road Networks: Access for Anyone** Several billion people currently lack reliable access to the Internet and thus to a tremendous source of knowledge. In [21], we describe a field-tested communication approach combining CubeSat platforms and delay-tolerant networking (DTN) solutions to provide asynchronous connectivity to populations and regions that are underserved by the Internet. The resulting class of networks is known as ring road networks (RRNs), a networking approach that is built on technology developed for the construction of a solar system Internet. The necessary self-sufficiency of DTN nodes enables network access to be deployed incrementally at low cost, supporting communities that cannot be profitably served by Internet satellite constellations. We present the RRN architecture and evaluate the expected performance by means of simulations. Based on the latter, we discuss mD3TN: a lightweight and open source DTN protocol stack for RRNs and other DTN classes. mD3TN has been flight-tested in ESA's OPS-SAT in low Earth orbit during December 2020 and May 2021. This work discusses the experiment results as we validated the RRN approach in concrete application use cases. The reported outcomes motivate a new application domain.

**Simulating LoRa-Based Direct-to-Satellite IoT Networks with FLoRaSat** Direct-to-Satellite-IoT (DtS-IoT) is a promising approach for data transfer to/from IoT devices in remote areas where deploying terrestrial infrastructure is not appealing or feasible. In this context, Low-Earth Orbit (LEO) satellites can serve as passing-by IoT gateways to which devices can offload buffered data to. However, transmission distance and orbital dynamics, combined with highly constrained devices on the ground makes DtS-IoT a very challenging problem. In fact, existing IoT medium access control protocols, negotiations schemes, etc. need to be revised and/or extended to scale up to these challenging conditions. The intricate time-dynamic aspects of DtS-IoT networks require of adequate simulation environments to assess the expected performance of enabling technologies. To make up for the lack of such tools, we present a novel event-driven open-source end-to-end simulation tool coined FLORASAT [29]. The simulator leverages Omnet++ and includes a benchmarking DtS-IoT scenario comprising 16 cross-linked LEO satellites and 1500 IoT nodes on the surface. Satellites and devices are connected using the standard LoRaWAN Low-Power Wide Area (LPWAN) protocol (Class A and B). FLoRaSat allows the easy implementation and study of DtS-IoT radio access and core network protocols, and we take advantage of this flexibility to investigate expected network metrics and non-intuitive phenomena emerging from the resulting multi-gateway setup.

**Space-Terrestrial Integrated Internet of Things: Challenges and Opportunities** Large geographical regions of our planet remain uncovered by terrestrial network connections. Sparse and dense constellations of near-Earth orbit satellites can bridge this gap by providing Internet of Things (IoT) connectivity on a worldwide scale in a flexible and cost-effective manner. In [22], we present STEREO: a novel Space-Terrestrial Integrated IoT Architecture spanning direct-and indirect-to-satellite access from IoT assets on the surface. Framed on the identified requirements, we analyze NB-IoT and LoRa/LoRaWAN features to put these technologies forward as appealing candidates for future satellite IoT deployments. Finally, we list and discuss the key open research challenges to be addressed in order to achieve a successful space-terrestrial IoT integration.

**Sparse Satellite Constellation Design for Global and Regional Direct-to-Satellite IoT Services** In [18], we introduce and design sparse constellations for Direct-to-Satellite Internet of Things (DtS-IoT). DtS-IoT does not require a ground infrastructure, because the devices are directly connected to Low Earth Orbit satellites acting as orbiting gateways. The key idea of sparse constellations is to significantly reduce the number of in-orbit DtS-IoT satellites by (i) a proper dimensioning of the delivery delay anyway present in resource-constrained IoT services, and (ii) an optimal positioning of the orbiting gateways. First, we analyze LoRa/LoRaWAN and NB-IoT standards and derive realistic constraints on the maximum gap time between two consecutive passing-by satellites. Then, we introduce and optimize an algorithm to

design quasi-optimal topologies for sparse IoT constellations. Finally, we apply our design to both global and regional coverage and we analyze the trade-off between latency, number of orbit planes and total number of satellites. Results show that sparse constellations can provide worldwide IoT coverage with only 12.5% and 22.5% of the satellites required by traditional dense constellations considering 3-hour and 2-hour gaps. Also, we show that region specific coverage of Africa and Europe can be achieved with only 4 and 3 satellites for LoRa/LoRaWAN and NB-IoT, respectively.

## 8.2 Wireless data collection

**Participants:** Juan A. Fraire, Alexandre Guitton, Hervé Rivano.

**FAM: A frame aggregation based method to infer the load level in IEEE 802.11 networks** In many environments, connected devices are exposed to and must choose between multiple Wi-Fi networks. However, the procedure for selecting an access point is still based on simple criteria that consider the device to be unique in the network. In particular, the network load is not taken into account even though it is a key parameter for the quality of service and experience. In [16], we investigate how an unmodified vanilla device could estimate the load of a network in the user space with no interventions from the access points. In this regard, we propose a novel and practical method, FAM (Frame Aggregation based Method). It leverages the frame aggregation mechanism introduced in recent IEEE 802.11 amendments to estimate the network load through its channel busy time fraction. FAM combines an active probing technique to measure the actual packet aggregation and Markovian models that provide the expected rate as a function of the volume and nature of the traffic on the network. We validate the effectiveness of FAM against both ns-3 simulations and test-bed experiments under several scenarios. Results show that our method FAM is able to infer the network load with a granularity based on six different levels of network loads for the considered scenarios.

**Integrating LoRa Collision Decoding and MAC Protocols for Enabling IoT Massive Connectivity** One major goal of Beyond 5G and 6G networks is to provide connectivity for a massive number of Internet-of-Things (IoT) devices. Towards that goal, Long Range (LoRa) is a promising physical layer technology which features low data-rates and large communication ranges, while requiring only low power. However, as the number of devices increases, more and more collisions occur, hence severely degrading LoRa system performances. To cope with this critical drawback, several LoRa collision decoding algorithms and MAC protocols have been proposed. In [26], we present how collision decoding algorithms interact with MAC layer protocols, and we discuss the potential of such integrated approaches. To do so, we first classify the collision decoding algorithms according to their principles and distinctive features, and compare some reference algorithms in a single simulation setup, using a Software Defined Radio (SDR) hardware. Then, we analyze how each class of MAC protocols can benefit from each category of collision decoding algorithms. Finally, we discuss longterm perspectives and open issues in this active research area.

**Inference of Wi-Fi busy time fraction based on Markov chains** IEEE 802.11 has emerged as a vital wireless network access technology for mobile devices. By providing the potential for high connectivity speeds, this technology has led to a huge rise in the number of access points (APs). In such environments, mobile devices have the choice to join several Wi-Fi networks. Despite its importance to user Quality of Experience (QoE), the AP selection is still trivial since it focuses at best on the received signal strength if not only on the user's history. Crucial metrics that capture the overall dynamics of the AP load condition, such as the network load, are not taken into account. In [17], we propose to use the Busy Time Fraction (BTF) as a metric to choose the best AP to attach to. The BTF level of a given channel is inferred based on the frame aggregation scheme proposed since the 802.11n standard. In this regard, we build a proof of concept system, FAM (Frame Aggregation based method), that leverages the theoretical frame aggregation levels of a probe traffic returned by two analytical Markovian models and the measured ones in order to

estimate not only the BTF but also the nature of the traffic. We validate the accuracy of our proposed approach against ns-3 simulations under several scenarios.

**Rendez-vous Based Drift Diagnosis Algorithm For Sensor Networks Towards In Situ Calibration** In recent years, low-cost sensors have raised strong interest for environmental monitoring applications. These instruments often suffer from degraded data quality. Notably, they are prone to drift. It can be mitigated with costly periodic calibrations. To reduce this cost, in situ calibration strategies have emerged, enabling the recalibration of instruments while leaving them in the field. However, they rarely identify which instruments actually need a calibration because of drift, so that in situ calibration may instead degrade performances. Therefore, we present novel drift detection algorithm, exploiting the concept of rendezvous between measuring instruments [19]. Its originality lies mainly in the comparisons of values determining the state of the instruments, for which the quality of the measurement results is taken into account. It defines the concept of compatibility between measurement results. A case study is developed, showing an accuracy of 88% for correct detection of drifting instruments. The results of the diagnosis algorithm are then combined with calibration approaches. Results show a significant improvement of the measurement results. Notably, an increase of 15% of the coefficient of determination of the linear regression between their true values and the measured values is observed with the correction and the error on the slope and on the intercept respectively is reduced by 50% and 60% at least.

**Uplink Transmission Policies for LoRa-Based Direct-to-Satellite IoT** Direct-to-Satellite IoT (DtS-IoT) is a promising approach to deliver data transfer services to IoT devices in remote areas where deploying terrestrial infrastructure is not appealing or feasible. In this context, low-Earth orbit (LEO) satellites can serve as passing-by IoT gateways to which devices can offload buffered data to. However, transmission distances and channel dynamics, combined with highly constrained devices on the ground makes of DtS-IoT a very challenging problem. In [14], we propose LoRa-based approaches to realize scalable and energy-efficient DtS-IoT. Our work includes the Long Range-Frequency Hopping Spread Spectrum (LR-FHSS) physical layer, currently on the roadmap of future space IoT projects. Specifically, we propose uplink transmission policies that exploit satellite trajectory information. These schemes are framed with a theoretical Mixed Integer Linear Programming (MILP) model providing an upper bound on performance as well as inspiration for scheduled DtS-IoT solutions. Simulation results provide compelling evidence that trajectory based policies can duplicate the amount of IoT nodes, while specific variants can further boost the scalability by 30% without incurring energy penalties. We also quantify that LR-FHSS can improve the deployment scalability by a factor of 75x at the expenses of 30% higher device's power consumption compared to the legacy LoRa modulation.

## 8.3 Network data exploitation

**Participants:** Oana Iova, Lise Jacquot, Lucas Magnana, Solohaja Rabenjamina, Hervé Rivano, Razvan Stanica.

**Comparison of User Presence Information from Mobile Phone and Sensor Data** Data collected from mobile phones or from motion detection sensors are regularly used as a proxy for user presence in networking studies. However, little attention was paid to the actual accuracy of these data sources, which present certain biases, in capturing actual human presence in a given geographical area. In [33], we conduct the first comparison between mobile phone data collected by an operator and human presence data collected by motion detection sensors in the same geographical area. Through a detailed spatio-temporal analysis, we show that a significant correlation exists between the two datasets, which can be seen as a cross validation of the two data sources. However, we also detect some significant differences at certain times and places, raising questions regarding the data used in certain studies in the literature. For example, we notice that the most important daily mobility peaks detected in mobile phone data are not actually detected by on ground sensors, or that the end of the workday activities in the considered area is not synchronised between the two data sources. Our results allow to distinguish the metrics and the scenarios where user presence information is confirmed by both mobile phone and sensor data.

**Data-driven Mobility Analysis and Modeling: Typical and Confined Life of a Metropolitan Population** The idea of using mobile phone data to understand the impact of the Covid-19 pandemic and that of the sanitary constraints associated with it on human mobility imposed itself as evidence in most countries. In [20], we use spatiotemporal aggregated mobile phone data provided by a major French telecom operator, covering a geographical region centered on Paris for early 2020, i.e., periods before and during the first French lockdown. An essential property of this data is its fine-grained spatial resolution, which, to the best of our knowledge, is unique in the COVID-related mobility literature. Contrarily to regions or country-wide resolution, it describes population mobility flows among zones ranging from 0.025 $km^2$ to 5.40 $km^2$ , corresponding to 326 aggregated zones over the total area of 93.76 $km^2$ of the city of Paris. We perform a data-driven mobility investigation and modeling to quantify (in space and time) the population attendance and visiting flows in different urban areas. Second, when looking at periods both before and during the lockdown, we quantify the consequences of mobility restrictions and decisions on an urban scale. For this, per zone, we define a so-called signature, which captures behaviors in terms of population attendance in the corresponding geographical region (i.e., their land use) and allows us automatically detect activity, residential, and outlier areas. We then study three different types of graph centrality, quantifying the importance of each zone in a time-dependent weighted graph according to the habits in the mobility of the population. Combining the three centrality measures, we compute per zone of the city, its impact-factor, and employ it to quantify the global importance of zones according to the population mobility. Our results firstly reveal the population's daily zone preferences in terms of attendance and mobility, with a high concentration on business and touristic zones. Second, results show that the lockdown mobility restrictions significantly reduced visitation and attendance patterns on zones, mainly in central Paris, and considerably changed the mobility habits of the population. As a side effect, most zones identified as mainly having activity-related population attendance in typical periods became residential-related zones during the lockdown, turning the entire city into a residential-like area. Shorter distance displacement restrictions imposed by the lockdown increased visitation to more "local" zones, i.e., close to the population's primary residence. Decentralization was also favored by the paths preferences of the still-moving population. On the other side, "jogging activities" allowing people to be outside their residences impacted parks visitation, increasing their visitation during the lockdown. By combining the impact factor and the signatures of the zones, we notice that areas with a higher impact factor are more likely to maintain regular land use during the lockdown.

**Implicit GPS-based bicycle route choice model using clustering methods and a LSTM network** Biking is gaining in popularity all around the world as a healthy and environmentally friendly mode of transportation. Urban policies tend to encourage citizens to use bicycles. This can be done by creating new cycling infrastructures, the renovation of old ones or the deployment of bike-sharing systems (BSS). These policies having a cost, understanding and predicting the behavior of cyclists has become a necessity in order to optimize them. Classical methods analyzing cyclists' route choices use external factors and generated choice sets of paths along with a logit model to create a discrete route choice model. Nevertheless, few studies focus on the predictive capacity that this type of model can offer. In [24], we developed a prediction-centered bicycle route choice model. Our model is created without using external factors or choice sets of paths as in the more classical methods. The idea of our method is to use deep and machine learning algorithms on GPS tracks. These algorithms learn representations from the data which replace explicit factors. To build the model, we clustered the GPS tracks using DBSCAN. The clusters allow to identify the cyclists' preferred road segments and are used to create paths using them. A method weighting the road graph weights is developed to create paths passing through the preferred road segments of a given cluster. A LSTM is finally trained in order to retrieve a cluster from a shortest path between an origin/destination pair. Tracks created by our model are more similar to the original GPS tracks than the shortest paths or tracks generated by a prominent path computation service.

**In-depth Study of RNTI Management in Mobile Networks: Allocation Strategies and Implications on Data Trace Analysis** The advance of mobile network technologies and components heavily relies on data-driven techniques. This is especially true for fifth generation (5G) and the upcoming sixth generation (6G) networks, as the optimization of network components and protocols is expected to be fueled by artificial intelligence (AI) based solutions. When using real-world radio access measurement traces,

the identity of individual users is not directly accessible because at runtime operation Base Stations (BSs) assign Radio Network Temporary Identifiers (RNTIs) to users. RNTIs are not bound to a user but are reused upon expiration of an inactivity timer, whose duration is operator dependent. This implies that, over time, multiple users are mapped to the same RNTI. In fact, the allocation of RNTIs to users is implemented in diverse and proprietary ways by operators and equipment vendors. Distinguishing individual users within the RNTI space is a non-trivial task and key to analyze traffic traces properly. In [15], we make the following contributions: i) we propose and validate two complementary methodologies to identify the RNTI inactivity threshold, and we characterize ii) the RNTI allocation process of network operators, and iii) the user traffic patterns given the specific RNTI allocation process. Our study is based on a large dataset we collected from production BSs of several mobile network operators across five different countries. We find that there exist heterogeneous strategies for RNTI allocation that BSs dynamically use depending on the traffic load and daytime. We further observe that the RNTI expiration threshold is in the order of minutes, and demonstrate how using thresholds around 10 seconds, as in the vast majority of the literature, can bias subsequent analyses. Overall, our work provides an important step towards dependable mobile network trace analysis, and lays solid foundations to research relying on traffic traces for data-driven analysis.

# 9 Bilateral contracts and grants with industry

## 9.1 Bilateral contracts with industry

**Participants:** Walid Bechkit, Oana Iova, Alexandros Sidiras Galante, Razvan Stanica.

- We have contracted a serie of bilateral contracts with Total (2018-2022) where we work with the laboratory LQA of Total on the design and the test of autonomous low cost air quality sensors. The LoRa-based developed platform is currently deployed and evaluated by LQA.
- We have contracted bilateral cooperation with NRGYBox (2020-2023) on the use of IoT sensors and mobile data aggregation for detection of human presence for Smart Lighting application.

## 9.2 Bilateral grants with industry

**Participants:** Youssef Badra, Walid Bechkit, Alexandre Guitton, Gwendoline Hochet Derevianckine, Oana Iova, Razvan Stanica, Fabrice Valois, Sekinat Yahya.

- Semtech: Agora is involved in a research contract with Université of Clermont Auvergne and INSA Lyon about opportunities and challenges of LoRa 2.4GHz, since April 2021.
- Agora started a new industrial collaboration with Snef Telecom in December 2021, for a duration of 3.5 years. The topic of this collaboration is the energy consumption measurement and modelling in 4G and 5G cellular networks.
- Spie - INSA Lyon IoT Chair: Agora is involved in the SPIE INSA Lyon IoT Chaire, launched in November 2016. Razvan Stanica is responsible of the “cognitive networks” research axes in this collaboration.
- SPIE - INSA Lyon Chair about AI applied to data flows and network infrastructure analysis, launched in 2022. Walid Bechkit is co-responsible of the "embedded AI" research axis in this collaboration, whereas Razvan Stanica is co-responsible of the "data-oriented protocols and infrastructures" research axis.

# 10 Partnerships and cooperations

## 10.1 International initiatives

### 10.1.1 Associate Teams in the framework of an Inria International Lab or in the framework of an Inria International Program

**Participants:** Oana Iova, Razvan Stanica, Fabrice Valois.

**IOTA(i)**

**Title:** Self-healing mechanisms for IoT networks based on IA paradigms

**Duration:** 2021 -> 2022

**Coordinator:** Fabrice Valois

**Partners:**
- Inria
- INSA Lyon
- LIRIMA
- Université de Yaoundé 1, Yaoundé (Cameroun)

**Inria contact:** Fabrice Valois

**Summary:** In IOTA(i), we are focused on the design of self-healing mechanisms to allow dynamic adaptation of the main parameters of IoT networking protocols. We claim that self-healing is a continuous process based on measurements and monitoring of the network behavior to adapt the networking protocol configuration to the environment dynamic and application changes. We believe that machine learning will help us to continuously optimize the network.

### 10.1.2 STIC/MATH/CLIMAT AmSud projects

**STARS**

**Participants:** Juan A. Fraire.

**Title:** SaTellite networks Architectures pRotocols and informaticS

**Duration:** 2020 -> Ongoing

**Coordinator:** Juan A. Fraire

**Partners:**
- Inria
- Laboratoire d'analyse et d'architecture des systèmes, CNRS UPR8001, France
- Universidad Nacional de Córdoba, Argentina
- Universidad de Chile, Chile

**Inria contact:** Juan A. Fraire

**Summary:** In this project, we tackle the challenges involved in the modernization of satellite-based communications by considering the requirements and restrictions of the deployments of large-scale satellite constellations including nano and small satellites. The contributions of the participant institutions are threefold: 1) the application of state-of-the-art informatics for the operation and design of large scale satellite constellations; 2) the definition and evaluation of hybrid architectures

with LPWA and nano/small satellite technologies, and 3) the design of networking protocols for challenging and restricted networks in space communications. Besides developing a strong international collaboration network around these topics, during the execution of this project we expect to provide student mobility and scientific training to the participants. Dissemination activities will also take place to share the results and possibly to incorporate new actors for further collaborations in the next stages of this research.

#### 10.1.3 Participation in other International Programs

- Walid Bechkit was co-coordinator of the digital work-package of the FSPI project *LISEN: L'Intelligence Sociale Et le Numérique* led by the French Embassy in Algeria (2020-2022).

**Other international visits to the team**

**Mohamed Sami Assenine**

**Status** intern master

**Institution of origin:** ESI, Ecole Nationale Supérieure d'Informatique

**Country:** Algeria

**Dates:** until June 2022

**Context of the visit:** internship funded by INSA Lyon

**Mobility program/type of mobility:** internship

**Razvan Bodgan**

**Status** associate professor

**Institution of origin:** Politehnica university of Timisoara

**Country:** Romania

**Dates:** from 28 November 2022 until 02 December 2022

**Context of the visit:** Meeting of the CHIST-ERA 20202 ECOMOME project

**Mobility program/type of mobility:** research stay

**Anais Boumendil**

**Status** intern master

**Institution of origin:** ESI, Ecole Nationale Supérieure d'Informatique

**Country:** Algeria

**Dates:** until June 2022

**Context of the visit:** internship funded by INSA Lyon

**Mobility program/type of mobility:** internship

**Beyza Butun**

**Status** PhD

**Institution of origin:** IMDEA Networks Institute

**Country:** Spain

**Dates:** from 28 November 2022 until 02 December 2022

**Context of the visit:** Meeting of the CHIST-ERA 20202 ECOMOME project

**Mobility program/type of mobility:** research stay

**Carlos Fernandez Hernandez**

**Status** intern master

**Institution of origin:** Universidad Tecnica Federico Santa Maria (UTFSM)

**Country:** Chile

**Dates:** from Apr 2022 until Jul 2022

**Context of the visit:** Inria International Program Chile

**Mobility program/type of mobility:** internship

**Marco Fiore**

**Status** researcher

**Institution of origin:** IMDEA Networks Institute

**Country:** Spain

**Dates:** 29 & 30 November 2022

**Context of the visit:** Meeting of the CHIST-ERA 20202 ECOMOME project

**Mobility program/type of mobility:** research stay

**Marian Ionascu**

**Status** PhD

**Institution of origin:** Politehnica university of Timisoara

**Country:** Romania

**Dates:** from 28 November 2022 until 02 December 2022

**Context of the visit:** Meeting of the CHIST-ERA 20202 ECOMOME project

**Mobility program/type of mobility:** research stay

**Diego Maldonado Munoz**

**Status** intern master

**Institution of origin:** Universidad Tecnica Federico Santa Maria (UTFSM)

**Country:** Chile

**Dates:** from March 2022 until August 2022

**Context of the visit:** Inria International Program Chile

**Mobility program/type of mobility:** internship

**Marius Marcu**

**Status** full professor

**Institution of origin:** Politehnica university of Timisoara

**Country:** Romania

**Dates:** from 28 November 2022 until 02 December 2022

**Context of the visit:** Meeting of the CHIST-ERA 20202 ECOMOME project

**Mobility program/type of mobility:** research stay

**Diala Naboulsi**

**Status** full professor

**Institution of origin:** ETS Montréal, Québec

**Country:** Canada

**Dates:** 29 & 30 November 2022

**Context of the visit:** Meeting of the CHIST-ERA 20202 ECOMOME project

**Mobility program/type of mobility:** research stay

**Sergiu Nimara**

**Status** post-Doc

**Institution of origin:** Politehnica university of Timisoara

**Country:** Romania

**Dates:** from 28 November 2022 until 02 December 2022

**Context of the visit:** Meeting of the CHIST-ERA 20202 ECOMOME project

**Mobility program/type of mobility:** research stay

#### 10.1.4 Visits to international teams

**Research stays abroad**

**Walid Bechkit**

**Visited institution:** ESI Alger

**Country:** Algeria

**Dates:** from 19 February to 3 March 2022

**Context of the visit:** non formal collaboration

**Mobility program/type of mobility:** research stay

**Alexandre Guitton**

**Visited institution:** National Institute of Informatics

**Country:** Japan

**Dates:** from 2 November 2022 until 2 December 2022

**Context of the visit:** non formal collaboration

**Mobility program/type of mobility:** research stay

## 10.2 European initiatives

### 10.2.1 H2020 projects

- Program: H2020-ICT-2018-2020
  - Project acronym: BUGWRIGHT2
  - Project title: Autonomous Robotic Inspection and Maintenance on Ship Hulls and Storage Tanks
  - Duration: 01/2020-03/2025
  - Coordinator: GeorgiaTech Lorraine / UMI2958GT-CNRS
  - Other partners: 9 academics partners(CNRS, UPORTO, UIB, INSA, RWTH, UNI-KLU ,NTNU, UT, WMU) and 11 industrial partners (CETIM, LSL, RBP, BEYE, RINA, GLM, APDL, AASA, TRH, IEIC, DANAOS, SBK).
  - Abstract: The objective of BUGWRIGHT2 is to bridge the gap between the current and desired capabilities of ship inspection and service robots by developing and demonstrating an adaptable autonomous robotic solution for servicing ship outer hulls. By combining the survey capabilities of autonomous Micro Air Vehicles (MAV) and small Autonomous Underwater Vehicles (AUV), with teams of magnetic-wheeled crawlers operating directly on the surface of the structure, the project inspection and cleaning system will be able to seamlessly merge the acquisition of a global overview of the structure with performing a detailed multi-robot visual and acoustic inspection of the structure, detecting corrosion patches or cleaning the surface as necessary – all of this with minimal user intervention.
- Program: Horizon2020 Research and Innovation Staff Exchange(RISE)
  - Project acronym: MISSION
  - Project title: Models in Space Systems: Integration, Operation, and Networking
  - Duration: 2021->ongoing (4y ears)
  - Coordinator: University of Twente, Netherlands
  - Other partners: Netherlands RWTH Aachen University, Germany Saarland University, Universidad Nacional de Córdoba, Argentina Universidad Nacional de Río Cuarto, Argentina D3TN,Germany GOMspace, Luxembourg Ascentio, Argentina INVAP, Argentina Skyloom, Argentina Institute of Intelligent Software, Guangzhou (IISG), China
  - Abstract: Spacecraft must work robustly in the presence of uncertainties such as random hardware faults, operator mistakes, space debris, and radiation. Classic space missions address uncertainty via large safety margins and built-in redundancy, leading to a spiral of increasing cost and complexity. A recent trend is the small-business commercialisation of space using commercial-off-the-shelf components for networked constellations of small satellites. This "New Space" approach reduces component weight, size, price, and lead time, and makes innovation increasingly driven by software. This pertains especially to resource management and data handling, while simpler components and new interactions increase uncertainty, and come with less reliable parts. Thus, overall mission connectivity, efficiency,

dependability and safety in the New Space needs to be achieved on a system level - for which there is no systematic approach yet. This is partly rooted in the empirical focus of many teams, and partly in a lack of easy-to-use methods to model, analyse, and guarantee system-level dependability. This interdisciplinary project sets out to solve this space engineering problem by exploiting highly advanced techniques from the forefront of computing science research, especially model-based algorithmics. We strive for sound and efficient software tools for the development of dependable, networked, and resource-aware New Space missions. For this, the MISSION project will develop an integrated model-based technology to establish and maintain system-level properties of critical space mission parameters. A strong consortium of excellent academic and industrial partners in Europe, Argentina and China have agreed on a joint research and knowledge sharing agenda that will foster a shared culture of research and innovation, to finally deliver an ecosystem of easy-to-use methods and software tools to the New Space industry.

#### 10.2.2 Other european programs/initiatives

- Program: CHIST-ERA 2020
  - Project acronym: ECOMOME
  - Project title: Measurement and Optimisation of Energy Consumption in Cellular Networks
  - Duration: 02/2022-01/2025 (accepted in 09/2021)
  - Coordinator: INSA Lyon
  - Otherpartners: ETS Montréal, Québec, Canada ; IMDEA, Madrid, Spain ; Politehnica University of Timisoara, Romania.
  - Abstract: This project addresses the problem of accurately modelling and optimising the energy consumption of a mobile network, with a focus on 4G and 5G technologies. This will be achieved through three main research axes. The first contribution will be represented by the first independent measurement study of energy consumption in a mobile network. The second objective of the project is to use this measurement data in order to design accurate energy consumption models for mobile networks. Finally, the project also targets the proposal of energy efficient networking solutions. Indeed, the measurement data and the energy consumption models will allow us to detect the most energy-hungry phases in a mobile network. To reduce their impact, we will propose network intelligence solutions, which are based on observing the traffic transported by the network, detecting whenever the network settings are over-consuming, and adapting the network configuration with energy efficiency metrics in mind.

### 10.3 National initiatives

#### 10.3.1 Inria Mission Covid

- SafeCityMap project: mobile network data analysis covering the first Covid lockdown to map the epidemic risk factor.
  Coordinators: Aline Viana (Inria Tribe), Razvan Stanica (Inria Agora).
  Participants: Solohaja Rabenjamina (Inria Agora), Haron Calegari Fantecele (LNCC, Brazil), Artur Ziviani (LNCC, Brazil).
  Human mobility properties have been investigated at length using mobile phone data. However, the COVID-19 pandemic highly perturbed our mobility patterns and use of urban spaces. This raises two important questions, addressed in the SafeCityMap project. First of all, we investigate how mobility patterns at an urban scale were affected by the pandemic, and especially by harsh lockdown conditions in Spring 2020. Second, we argue that the modeling of such patterns can provide a clear association with the epidemic spread, such as for COVID-19, in different areas of a city. By understanding how different types of areas are visited in a city, SafeCityMap aims to track the temporal evolution of the potential risk of virus spread in these areas.

### 10.3.2 ANR

- ANR CANCAN 2019 - 2022
  Participants: Solohaja Rabenjamina, Razvan Stanica.
  The partners in this project are: CEDRIC, Inria, Orange Labs, with Thalès Communications & Security leading the project.
  The ANR CANCAN (Content and context based adaptation in mobile networks) targets the following objectives: *i)* collecting novel measurement datasets that describe mobile network data traffic at unprecedented spatial and temporal accuracy levels, and for different mobile services separately. The datasets will be gathered in an operational nationwide network, *ii)* evaluating existing analytics for classification, prediction and anomaly detection within real-world high-detail per-service mobile network data, and tailoring them to the specifications of the management of resources at different network levels, and *iii)* demonstrating the integration of data analytics within next-generation cognitive network architectures in several practical case studies.

- ANR CoCo5G (Traffic Collection, Contextual Analysis, Data-driven Optimisation for 5G), 2023-2027, accepted in 2022
  Participants: Hervé Rivano, Razvan Stanica.
  The partners in this project are: Thales (leader), Orange, CNAM, Inria Agora, IMDEA Networks.
  The objective of CoCo5G is to collect the first-of-its-kind longitudinal nationwide measurements dataset combining 4G and 5G data traffic. This dataset will then be used for an extensive analysis of the evolution (in France) and the dynamics of 5G traffic for various mobile services usages. This will represent a unique opportunity for the evaluation and tailoring of existing analytics for classification, prediction and anomaly detection within real-world high-detail per-service mobile network data. Finally, CoCo5G targets to demonstrate the integration of data analytics within next-generation cognitive network architecture in three practice case studies: energy-prudent 5G NR control, URLLC service support, and automated anomaly response in edge computing.

- ANR JCJC Demon (Deployment of Mobile base stations in cellular Networks), 2021-2024 (accepted in 2020)
  Participants: Thibault Bellanger, Razvan Stanica (leader), Fabrice Valois, Zhiyi Zhang.
  The main objective of the DEMON project is to enable an architectural shift and provide dedicated solutions for rapidly deployable mobile base stations. Three main challenges can be outlined in this new approach. The first problem is the initial deployment of mobile base stations in the target geographical area. The second challenge is the configuration of the radio access network to provide the required capacity. Finally, the permanent reconfiguration of the network needs to be considered, accounting not only for UE, but also for base station movement.

- ANR JCJC Doll (Efficient DOwnLink Communication for Increased LoRaWAN Capacity), 2022-2025 (accepted in 2021)
  Participants: Alexandre Guitton, Gwendoline Hochet Derevianckine, Oana Iova (leader), Fabrice Valois.
  The goal of this project is to propose a downlink strategy that will unleash the full potential of LoRaWAN networks and push the deployment of new applications that until now could not properly take advantage of the downlink communication available in LoRaWAN. In order to increase network capacity under confirmed traffic, while maintaining a reliable uplink communication and a low energy consumption for the end devices, we set the following objectives: *i)* understand and quantify the consequences of overlapping uplink and downlink communications, *ii)* evaluate and improve gateway selection algorithm for downlink communication, and *iii)* propose an energy efficient scheduling for handling acknowledgements.

- ANR JCJC Dron-Map (Réseau de drones pour le suivi de panaches de pollution dans les situations d'urgence), 2021-2024 (accepted in 2021)
  Participants: Mohamed Sami Assenine, Walid Bechkit (leader), Ichrak Mokhtari, Hervé Rivano, Alexandros Sidiras Galante.
  The DRON-MAP project focuses on the use of cooperative UAV networks for pollution plume

monitoring in emergency situations (industrial accidents, natural disasters, deliberate terrorist releases, etc.). The deployment of a UAV network in these situations face different scientific and technical challenges such as taking into account the strong plume dynamics, the timely data analysis, the reliable communication and coordination between UAVs and the planning of optimal trajectories. The objective of DRON-MAP project is to address these challenges while proposing a new global and systemic approach. Based on reliable communications and coordination between drones, our approach will federate an instantaneous estimation and a prediction of the plume evolution with efficient anticipatory algorithms of optimal path planning. A network testbed of few communicating UAVs will be set up in order to assess real-world feasibility and performance at a small scale.

- ANR MAESTRO 5G 2019 - 2022
  Participants: Hervé Rivano, Razvan Stanica.
  The partners in this project are: CEDRIC, Inria, L2S, LIA, Nokia Bell Labs, TSP, with Orange Labs leading the project.
  The ANR MAESTRO 5G (Management of slices in the radio access of 5G networks) is expected to provide: *i)* a resource allocation framework for slices, integrating heterogeneous QoS requirements and spanning on multiple resources including radio, backhauling/fronthauling and processing resources in the RAN, *ii)* a complete slice management architecture including provisioning and re-optimization modules and their integration with NFV and SDN strata, *iii)* a business layer for slicing in 5G, *iv)* a demonstrator showing the practical feasibility as well as integration of the major functions and mechanisms proposed by the project, on a 5G Cloud RAN platform. The enhanced platform is expected to support the different 5G services.

- ANR Stereo (Space-Terrestrial Integrated IoT), 2023-2027, accepted in 2022
  Participants: Juan A. Fraire, Oana Iova, Fabrice Valois.
  The partners in this project are: Inria (leader of the project), IRIT / ENSEEIHT (UMR CNRS 5505), Kinésis, LAAS (CNRS UPR 8001), LIG / UGA (UMR CNRS 5217).
  The objective of this project is to achieve a Space-Terrestrial Integrated Internet of Things (STEREO) network, in which IoT devices can seamlessly hook to gateways on ground or directly to low-Earth orbit (LEO) satellites when no network infrastructure is present. The feasibility and expected performance will be assessed by objectives described in this section: O.1) defining new network architectures, O.2) evaluating the enabling IoT technologies, O.3) designing the software components, and O.4) prototyping the hardware modules.

- ANR Plan de relance - mesure de préservation de l'emploi de R&D
  Participants: Walid Bechkit, Hervé Rivano, Razvan Stanica.
  Agora started a collaboration with Rtone in December 2021, for a duration of 2 years. The objective of this collaboration is to integrate artificial intelligence solutions in the control of a fleet of drones for pollution monitoring purposes.

#### 10.3.3 GDR CNRS RSD - Pôle ResCom

- Ongoing participation (since 2006)
  Communication networks, working groups of GDR ASR/RSD, CNRS. Oana Iova is member of the steering committee of the GDR RSD. Razvan Stanica is member of the scientific council of the GDR RSD. Fabrice Valois is member of the steering committee of the GDR RSD and also chair of the Networking axis of the GDR RSD. All the members of Agora are regular participants to the GDR RSD.

### 10.4 Regional initiatives

- Ecole Urbaine de Lyon, Institut Convergence (2017-2027)
  - Participants: Hervé Rivano.
  - The partners are: Université Lyon 1, Université Lyon 2, Université Lyon 3, Université Jean Monnet Saint-Étienne, ENS Lyon, INSA de Lyon, CNRS, Ecole Centrale de Lyon, Sciences Po

Lyon, VetAgroSup, ENSAL, ENSSIB, ENTPE, Ecole des Mines de Saint-Étienne, IFSTTAR, Inria, INRA, ISARA, UGA.

  - Through its experimental interdisciplinary project for research, doctoral training and the economic, social and cultural promotion of scientific knowledge, the Lyon Urban School is breaking new ground by establishing an emerging field of knowledge and expertise: the Urban Anthropocene.
  - This program has been closed in 2022 (instead of 2027).

- INSA-Lyon ATMO-Aura Chair, *L'air: un enjeu de santé & d'innovation, une mobilisation citoyenne* (2020-Present). Walid Bechkit and Hervé Rivano was deeply involved in this Chair proposal and its animation. More details on the site of the chair.

# 11 Dissemination

## 11.1 Promoting scientific activities

### 11.1.1 Scientific events: organisation

**General chair, scientific chair**

- Oana Iova was general co-chair of LPWAN Days, Toulouse, July 2022.
- Razvan Stanica were scientific chair of the *École d'été RESCOM* of the GDR RSD about Non terrestrial communications, Yenne, France, July 2022.

**Member of the organizing committees**

- Razvan Stanica were organizing chair of the *École d'été RESCOM* of the GDR RSD about Non terrestrial communications, Yenne, France.

### 11.1.2 Scientific events: selection

**Member of the conference program committees**

- Oana Iova was member in the TPC of the following conferences: CoRes, EWSN, IEEE ICDCS, IEEE WiMob.
- Razvan Stanica was member in the TPC of the following conferences: IEEE SECON, IFIP Networking, IEEE ICC, IEEE GlobeCom, IEEE PIMRC, IEEE WCNC, WiMob, ICIN, MobiArch, WMNC, NoF, IEEE MeditCom.
- Fabrice Valois was member in the TPC of the following conferences: CoRes, IEEE FNWF, IEEE ICC, IEEE Globecom, IEEE ISCC, IEEE VTC, IEEE IWCMC, IEEE WiMob.

### 11.1.3 Journal

**Member of the editorial boards**

- Oana Iova is Area editor for Ad Hoc Networks (Elsevier).
- Razvan Stanica is Area editor for Annals of Telecommunications (Springer).

**Reviewer - reviewing activities**

- Oana Iova was reviewer for the following journals: IEEE Internet of Things Magazine, IEEE Internet of Things.
- Razvan Stanica was reviewer for the following journals: IEEE Transactions on Mobile Computing, IEEE Transactions on Network and Service Management, IEEE Network.

#### 11.1.4 Invited talks

- Walid Bechkit gave a research seminar about "Réseaux de capteurs sans fil au service du suivi des phénomènes physiques : de la théorie à la pratique", February 2022, ESI Alger, Algeria.
- Walid Bechkit was panelist at the scientific day of theLabex IMU, "La transition urbaine dans tous ses états", November 2022, Lyon.
- Oana Iova gave a talk about Research Challenges in LoRaWAN, I-Cube, Université de Strasbourg.

#### 11.1.5 Leadership within the scientific community

- Oana Iova is member of the steering committee of the GDR RSD.
- Oana Iova is in charge of the mentorship actions (*e.g.*, seminars) for the GDR RSD.
- Razvan Stanica is member of the scientific council of the GDR RSD.
- Fabrice Valois is chair of the scientific committee of the Labex IMU.
- Fabrice Valois is member of the steering committee of the GDR RSD.
- Fabrice Valois is chair of the Networking axis of the GDR RSD.

#### 11.1.6 Scientific expertise

- Walid Bechkit was president of the recruitment committee for an ATER position (CITI research Laboratory, Telecommunications Department, INSA Lyon).
- Walid Bechkit is member of "Club des experts" of the "Conseil Économique, Social et Environnemental Régional - CESER - ATMO-AURA".
- Alexandre Guitton was the member of the Hcérés committee for the FEMTO-ST (UMR CNRS 6174).
- Razvan Stanica was member of the associate professor recruitement committee at CNAM Paris.
- Razvan Stanica was reviewer for the ANR, APP 2023, CE48 (Fondements du numérique : informatique, automatique, traitement du signal).

### 11.2 Teaching - Supervision - Juries

#### 11.2.1 Teaching

**Bachelor and License**

- Walid Bechkit, Introduction to wireless sensor networks, 40h, L2, INSA Lyon.
- Oana Iova, Introduction to research, 20h, L3, Telecom. Dpt. INSA Lyon.
- Oana Iova, Computer Networks - Advanced notions, 20h, L3, INSA Lyon.
- Hervé Rivano, Algorithms and programming, 165h, L1 - L2, INSA Lyon.
- Hervé Rivano, Sensors data engineering project, 34h, L2, INSA Lyon.
- Hervé Rivano, Programming robot control, 20h, L2, INSA Lyon.
- Razvan Stanica, Internet Metrology, 16h, L3, Telecom. Dpt. INSA Lyon.
- Fabrice Valois, IP Networks, 24h, L3, Telecom. Dpt. INSA Lyon.
- Fabrice Valois, Medium Access Control, 38h, L3, Telecom. Dpt. INSA Lyon.

**Master**

- Walid Bechkit, Performance evaluation of telecom networks, 50h, M1, Telecom. Dpt. INSA Lyon.
- Walid Bechkit, Wireless networks: architecture and security, 30h, M2, Telecom. Dpt. INSA Lyon.
- Walid Bechkit, Network acces control, 6h, M2, Telecom. Dpt. INSA Lyon.
- Juan A. Fraire, Satelite communications, 32h, M2, Telecom. Dpt. INSA Lyon.
- Alexandre Guitton, Network and security, 8h, M1, University of Clermont Auvergne.
- Alexandre Guitton, Network management and supervision, 10h, M2, University of Clermont Auvergne.
- Alexandre Guitton, Computer architecture, 6h, M1, University of Clermont Auvergne.
- Alexandre Guitton, Long range networks, 6h, M2, INSA Lyon.
- Alexandre Guitton, Advanced network simulation, 24h, M2, INSA Lyon.
- Alexandre Guitton, Network security, 2h, M2, INSA Lyon.
- Oana Iova, Network routing protocols, 66h, M1, Telecom. Dpt. INSA Lyon.
- Oana Iova, Long range networks, 10h , M2, Telecom. Dpt. INSA Lyon.
- Oana Iova, IoT technical project, 8h, M2, Telecom. Dpt. INSA Lyon.
- Hervé Rivano, Smart cities and IoT, 44h, M2, Telecom. Dpt. INSA Lyon.
- Hervé Rivano, Smart cities, Master Cities, Environment and Urbanism, University of Lyon.
- Razvan Stanica, Mobile networks, 30h, M1, Telecom. Dpt. INSA Lyon.
- Razvan Stanica, Mobile networks, 34h, M1, INSA EuroMed, Fés, Morocco.
- Razvan Stanica, Content delivery networks (routing protocols), 10h, M2, Telecom. Dpt. INSA Lyon.
- Razvan Stanica, Advanced Network Simulation, 32h, M2, Telecom. Dpt. INSA Lyon.
- Fabrice Valois, Cellular networks, 18h, M1, Telecom. Dpt. INSA Lyon.
- Fabrice Valois, Local loop (ADSL & Fiber access), 10h, M1, Telecom. Dpt. INSA Lyon.
- Fabrice Valois, Performance evaluation of network, 32h, M1, Telecom. Dpt. INSA Lyon.

**Apprenticeship (license and master)**

- Licence: Razvan Stanica, IP Networks, 36h, L3, Telecom. Dpt. INSA Lyon.
- Licence: Fabrice Valois, Medium Access Control, 16h, L3, Telecom. Dpt. INSA Lyon.
- Master: Walid Bechkit, Performance evaluation of telecom networks, 50h, M1, Telecom. Dpt. INSA Lyon.
- Master: Oana Iova, Network Routing Protocols, 20h, M1, Telecom. Dpt. INSA Lyon.
- Master: Fabrice Valois, Mobile Networks, 44h, M1, Telecom. Dpt. INSA Lyon.

**Administration and services linked to teaching activities**

- Walid Bechkit is an elected member of the Telecommunication department council at INSA Lyon.
- Walid Bechkit is the head of the networking teaching team in the Telecommunications department at INSA Lyon, coordinating all the courses in the networking domain.
- Oana Iova is the head of international relations at the Telecommunications department of INSA Lyon.
- Oana Iova is coordinator leader of the Information Science & Technology semester at the INSA Lyon.
- Oana Iova is member of the TC department executive committee.
- Hervé Rivano is responsible of the Smart program (international teaching program with Tohoku University and Tokyo University) about Smart Cities.
- Hervé Rivano is responsible of the IoT specialization of the Innov program (INSA Lyon and US students).
- Hervé Rivano is the head of the Computer Science discipline in FIMI department of INSA Lyon.
- Hervé Rivano is referent DSI in the FIMI Dpt., INSA Lyon.
- Razvan Stanica is responsible of the research option at the Telecommunications department of INSA Lyon.
- Razvan Stanica is vice dean of the Telecommunications department of INSA Lyon, in charge of education related affairs.
- Fabrice Valois is in charge of the Humanities course about creative process in Modern Art, Science and technology.

### 11.2.2 Supervision

- Masters
  - Esther Allain, from 05/2022 until 08/2022, Network Server Deployment for LoRaWAN. Advisors: Oana Iova, Alexandre Guitton, Fabrice Valois.
  - Mohamed Sami Assenine, until 06/2022, Apprentissage par renforcement pour l'optimisation de la mobilité dans les réseaux de capteurs sans fil. Advisors: Walid Bechkit, Hervé Rivano.
  - Thibaut Bellanger, from 03/2022 until 08/2022, Slicing in LoRaWAN networks. Advisors: Alexandre Guitton, Razvan Stanica, Fabrice Valois.
  - Anais Boumendil, until 06/2022, Réduction de la consommation énergétique des modèles d'apprentissage automatique. Advisor: Walid Bechkit.
  - Carlos Fernandez Hernandez, from 04/2022 until 07/2022, Experimentations of LoRa 2.4 GHz. Advisors: Alexandre Guitton, Gwendoline Hochet Derevianckine, Oana Iova, Fabrice Valois.
  - Lise Jacquot , until 02/2022, Energy consumption of RAN mechanisms. Advisor: Razvan Stanica.
  - Diego Maldonado Munoz, from 03/2022 until 08/2022, Convergence of Satellite - IoT networks. Advisor: Juan A. Fraire.
  - Rachida Saroui , until 02/2022, Impact du lien descendant sur la performance de LoRaWAN. Advisors: Alexandre Guitton, Oana Iova, Fabrice Valois.
  - Yuxuan Song, from 05/2022 until 07/2022, Gateway selection algorithm for LoRaWAN networks. Advisors: Oana Iova, Alexandre Guitton, Fabrice Valois.
- PhD, defended in 2022

  - Mohamed Anis Fekih, Urban pollution using wireless sensor networks, from 11/2018 until 10/2022. Advisors: Walid Bechkit, Hervé Rivano.
  - Romain Pujol, User association in self-deployable cellular network, from 11/2018 until 07/2022. Advisors: Razvan Stanica, Fabrice Valois.

- PhD, started in 2022

  - Mohammed Sami Assenine, Apprentissage par renforcement pour l'optimisation de la mobilité dans les réseaux de capteurs sans fil : application au suivi de la pollution, since 10/2022. Advisors: Walid Bechkit, Hervé Rivano.
  - Youssef Badra, Measuring and modelling energy consumption in cellular networks, since 03/2022. Advisor: Razvan Stanica.
  - Anais Boumendil, Vers des modèles d'apprentissage automatique à faible consommation d'énergie pour les plateformes à ressources limitées, since 11/2022. Advisor: Walid Bechkit.
  - Diego Maldonado Munoz, Adaptations, Optimizations, and Learning Approaches for Direct-to-Satellite Internet of Things, since 12/2022. Adivsors: Juan A. Fraire, Hervé Rivano.
  - Sekinat Yahya, Energy consumption optimisation in cellular networks, since 02/2022. Advisor: Razvan Stanica.

- Phd on going

  - Gwladys Djuikom, Mobility analysis using cellular data, since 10/2021. Advisors: Diala Naboulsi (ETS Montréal, Québec, Canada), Razvan Stanica.
  - Mohamed El Emary,Task offloading in airborne-assisted networks, since 07/2021. Advisors: Diala Naboulsi (ETS Montréal, Québec, Canada), Razvan Stanica.
  - Gwendoline Hochet Derevianckine,Faisabilité et performances d'un réseau LoRaWAN dans la bande ISM 2.4GHz, since 04/2021. Advisors: Alexandre Guitton, Oana Iova, Baozhu Ning (Semtech), Fabrice Valois.
  - Kawtar Lasri, Data collection and distributed spatial coordination in LPWAN networks, since 01/2019. Advisors: Loubna Echabbi (INPT Rabat, Morocco), Oana Iova, Yann Ben Maissa (INPT Rabat, Morocco), Fabrice Valois.
  - Lucas Magnana, De la ville intelligente à la ville prédictive, application aux modes de transport actifs, since 10/2020. Advisors: Nicolas Chiabaut (LICIT, ENTPE / IFSTTAR), Hervé Rivano.
  - Ichrak Mokhtari, Spatio-temporal analysis of pollution data from low cost sensors, since 11/2019. Advisors: Walid Bechkit, Hervé Rivano.
  - Camille Moriot, DDos Attacks and their impacts on the Internet Architecture, since 09/2020. Advisors: François Lesueur (CITI) Nicolas Stouls (CITI), Fabrice Valois.
  - Hnin Pann Phyu, End-to-end mobile network slicing, since1 0/2020. Advisors: DialaNaboulsi (ETS Montréal, Québec Canada), Razvan Stanica.
  - Mihai Popescu, Connectivity constrained mobility in fleets of robots, since 11/2015. Advisors: Olivier Simonin (CITI, INSA Lyon), Anne Spalanzanni (LIG, UGA), Fabrice Valois.
  - Solohaja Rabenjamnia,Data analysis of cellular trafic, since 11/2018. Advisors: HervéRivano, Razvan Stanica.
  - Zhiyi Zhang, Deployment and management of mobile base stations, since 10/2021. Advisors: Razvan Stanica, Fabrice Valois.

#### 11.2.3 Juries

- Oana Iova was a examiner in the following PhD defense committees:

  - M. Hamnache, Performances et gestion de l'itinérance dans les réseaux LoRaWAN, IRIT, ENSEEIHT.

- Hervé Rivano was a reviewer in the following PhD defense committees:
  - N. Okafor, Artificial Intelligence Enabled IoT-based System for Environmental Monitoring: Design and Evaluation, University College Dublin.
- Fabrice Valois was a reviewer in the following HDR defense committees:
  - J. Montavont, Mobility Support in Low Power Asynchronous Wireless Networks, I-Cube, Université de Strasbourg.
- Fabrice Valois was a reviewer in the following PhD defense committees:
  - R. C. Juacaba-Neto, Privacy-aware Aggregation of IoT Streams in Multi-Owner Networks, ICube, Université de Strasbourg.
  - R. Barbau, Performances des réseaux NB-IoT terrestres et satellite, IRIT, ENSHEEIT.
  - J. Hérard, Structuration autonome des réseaux IoT de type LoRa / LoRaWAN, Crestic, URCA.
- Fabrice Valois was a examiner in the following PhD defense committees:
  - A. Amoordon, Méthodes de détection d'attaques cybernétiques par une surveillance multi-couches de communication, Université Gustave Eiffel.

## 11.3 Popularization

### 11.3.1 Internal or external Inria responsibilities

- Oana Iova is in charge of Sustainable and socially responsible development (DDRS) for Agora.
- Hervé Rivano is the best ever REP.
- Hervé Rivano was in charge of the IoT panel discussion for the Networking Prospective of Inria.

### 11.3.2 Interventions

- Lucas Magnana and Hervé Rivano was interviewed on the concept of virual bicycle lanes, La Tribune de Lyon, June 2022.
- Hervé Rivano was interviewed on the urban heat island phenomena for TV News, M6, July 2022.
- Hervé Rivano was involved on the topic *Les enjeux environnementaux du numérique*, for *Fête de la science*, Vienne, France, October 2022.

# 12 Scientific production

## 12.1 Major publications

[1] G. Álvarez, J. A. Fraire, K. A. Hassan, S. Céspedes and D. Pesch. 'Uplink Transmission Policies for LoRa-Based Direct-to-Satellite IoT'. In: *IEEE Access* (12th July 2022), pp. 1–1. DOI: 10.1109/ACCESS.2022.3189647. URL: https://hal.science/hal-03722756.

[2] D. Benchaira, O. Tibermacine, W. Bechkit and A. Bachir. 'Leveraging Predictability for Global Optimization of IoT Networks'. In: *ICC 2022 - IEEE International Conference on Communications*. ICC 2022 - IEEE International Conference on Communications. Seoul, South Korea: IEEE, 2022, pp. 3586–3591. DOI: 10.1109/ICC45855.2022.9838916. URL: https://hal.science/hal-03904118.

[3] N. E. H. Bouzouita, A. Busson and H. Rivano. 'FAM: A frame aggregation based method to infer the load level in IEEE 802.11 networks'. In: *Computer Communications* 191 (July 2022), pp. 36–52. DOI: 10.1016/j.comcom.2022.04.021. URL: https://hal.inria.fr/hal-03692553.

[4] N. E. H. Bouzouita, A. Busson and H. Rivano. 'Inference of Wi-Fi busy time fraction based on Markov chains'. In: *Ad Hoc Networks* (22nd July 2022), p. 102963. DOI: 10.1016/j.adhoc.2022.102963. URL: https://hal.inria.fr/hal-03762029.

[5] G. M. Capez, S. Henn, J. A. Fraire and R. Garello. 'Sparse Satellite Constellation Design for Global and Regional Direct-to-Satellite IoT Services'. In: *IEEE Transactions on Aerospace and Electronic Systems* (24th June 2022), pp. 1–16. DOI: 10.1109/TAES.2022.3185970. URL: https://hal.science/hal-03722737.

[6] F. Delaine, B. Lebental and H. Rivano. 'Rendez-vous Based Drift Diagnosis Algorithm For Sensor Networks Towards In Situ Calibration'. In: *IEEE Transactions on Automation Science and Engineering* (June 2022). DOI: 10.1109/TASE.2022.3182289. URL: https://hal.inria.fr/hal-03692440.

[7] H. Fanticelli, S. Rabenjamina, A. Carneiro Viana, R. Stanica, L. Santos de Oliveira and A. Ziviani. 'Data-driven Mobility Analysis and Modeling: Typical and Confined Life of a Metropolitan Population'. In: *ACM Transactions on Spatial Algorithms and Systems* 8.3 (1st Sept. 2022), pp. 1–33. DOI: 10.1145/3517222. URL: https://hal.inria.fr/hal-03569051.

[8] M. Feldmann, J. Fraire, F. Walter and S. Burleigh. 'Ring Road Networks: Access for Anyone'. In: *IEEE Communications Magazine* 60.4 (2022), pp. 38–44. DOI: 10.1109/MCOM.001.2100835. URL: https://hal.science/hal-03692361.

[9] J. A. Fraire, P. Madoery, M. Ait Mesbah, O. Iova and F. Valois. 'Simulating LoRa-Based Direct-to-Satellite IoT Networks with FLoRaSat'. In: WoWMoM 2022 - IEEE 23rd International Symposium on a World of Wireless, Mobile and Multimedia Networks. Belfast, United Kingdom, 14th June 2022. URL: https://hal.science/hal-03698223.

[10] J. A. A. Fraire, O. Iova and F. Valois. 'Space-Terrestrial Integrated Internet of Things: Challenges and Opportunities'. In: *IEEE Communications Magazine* (30th Sept. 2022). URL: https://hal.science/hal-03789116.

[11] P. Ilabaca, S. Montejo-Sánchez, J. Fraire, R. D. Souza and S. Céspedes. 'Network Size Estimation for Direct-to-Satellite IoT'. In: *IEEE Internet of Things Journal* (24th Nov. 2022). DOI: 10.1109/JIOT.2022.3224678. URL: https://hal.inria.fr/hal-03935406.

[12] L. Magnana, H. Rivano and N. Chiabaut. 'Implicit GPS-based bicycle route choice model using clustering methods and a LSTM network'. In: *PLoS ONE* (17th Mar. 2022), pp. 1–20. DOI: 10.1371/journal.pone.0264196. URL: https://hal.inria.fr/hal-03619678.

[13] W. Xiao, M. Kaneko, N. El Rachkidy and A. Guitton. 'Integrating LoRa Collision Decoding and MAC Protocols for Enabling IoT Massive Connectivity'. In: *IEEE Internet of Things Magazine* (2022). URL: https://hal.science/hal-03808081.

## 12.2 Publications of the year

**International journals**

[14] G. Álvarez, J. A. Fraire, K. A. Hassan, S. Céspedes and D. Pesch. 'Uplink Transmission Policies for LoRa-Based Direct-to-Satellite IoT'. In: *IEEE Access* (12th July 2022), pp. 1–1. DOI: 10.1109/ACCESS.2022.3189647. URL: https://hal.archives-ouvertes.fr/hal-03722756.

[15] G. Attanasio, C. Fiandrino, M. Fiore, J. Widmer, N. Ludant, B. Bloessl, K. Kousias, Ö. Alay, L. Jacquot and R. Stanica. 'In-depth Study of RNTI Management in Mobile Networks: Allocation Strategies and Implications on Data Trace Analysis'. In: *Computer Networks* 219 (20th Oct. 2022), p. 109428. DOI: 10.1016/j.comnet.2022.109428. URL: https://hal.inria.fr/hal-03840152.

[16] N. E. H. Bouzouita, A. Busson and H. Rivano. 'FAM: A frame aggregation based method to infer the load level in IEEE 802.11 networks'. In: *Computer Communications* 191 (July 2022), pp. 36–52. DOI: 10.1016/j.comcom.2022.04.021. URL: https://hal.inria.fr/hal-03692553.

[17] N. E. H. Bouzouita, A. Busson and H. Rivano. 'Inference of Wi-Fi busy time fraction based on Markov chains'. In: *Ad Hoc Networks* (22nd July 2022), p. 102963. DOI: 10.1016/j.adhoc.2022.102963. URL: https://hal.inria.fr/hal-03762029.

[18] G. M. Capez, S. Henn, J. A. Fraire and R. Garello. 'Sparse Satellite Constellation Design for Global and Regional Direct-to-Satellite IoT Services'. In: *IEEE Transactions on Aerospace and Electronic Systems* (24th June 2022), pp. 1–16. DOI: 10.1109/TAES.2022.3185970. URL: https://hal.science/hal-03722737.

[19] F. Delaine, B. Lebental and H. Rivano. 'Rendez-vous Based Drift Diagnosis Algorithm For Sensor Networks Towards In Situ Calibration'. In: *IEEE Transactions on Automation Science and Engineering* (June 2022). DOI: 10.1109/TASE.2022.3182289. URL: https://hal.inria.fr/hal-03692440.

[20] H. Fanticelli, S. Rabenjamina, A. Carneiro Viana, R. Stanica, L. Santos de Oliveira and A. Ziviani. 'Data-driven Mobility Analysis and Modeling: Typical and Confined Life of a Metropolitan Population'. In: *ACM Transactions on Spatial Algorithms and Systems* 8.3 (1st Sept. 2022), pp. 1–33. DOI: 10.1145/3517222. URL: https://hal.inria.fr/hal-03569051.

[21] M. Feldmann, J. Fraire, F. Walter and S. Burleigh. 'Ring Road Networks: Access for Anyone'. In: *IEEE Communications Magazine* 60.4 (2022), pp. 38–44. DOI: 10.1109/MCOM.001.2100835. URL: https://hal.archives-ouvertes.fr/hal-03692361.

[22] J. A. A. Fraire, O. Iova and F. Valois. 'Space-Terrestrial Integrated Internet of Things: Challenges and Opportunities'. In: *IEEE Communications Magazine* (30th Sept. 2022). URL: https://hal.archives-ouvertes.fr/hal-03789116.

[23] P. Ilabaca, S. Montejo-Sánchez, J. Fraire, R. D. Souza and S. Céspedes. 'Network Size Estimation for Direct-to-Satellite IoT'. In: *IEEE Internet of Things Journal* (24th Nov. 2022). DOI: 10.1109/JIOT.2022.3224678. URL: https://hal.inria.fr/hal-03935406.

[24] L. Magnana, H. Rivano and N. Chiabaut. 'Implicit GPS-based bicycle route choice model using clustering methods and a LSTM network'. In: *PLoS ONE* (17th Mar. 2022), pp. 1–20. DOI: 10.1371/journal.pone.0264196. URL: https://hal.inria.fr/hal-03619678.

[25] M. Rady, Q. Lampin, D. Barthel and T. Watteyne. 'Bringing life out of diversity: Boosting network lifetime using multi-PHY routing in RPL'. In: *Transactions on emerging telecommunications technologies* (17th July 2022), e4592. DOI: 10.1002/ett.4592. URL: https://hal.inria.fr/hal-03726255.

[26] W. Xiao, M. Kaneko, N. El Rachkidy and A. Guitton. 'Integrating LoRa Collision Decoding and MAC Protocols for Enabling IoT Massive Connectivity'. In: *IEEE Internet of Things Magazine* (2022). URL: https://hal.science/hal-03808081.

**International peer-reviewed conferences**

[27] D. Benchaira, O. Tibermacine, W. Bechkit and A. Bachir. 'Leveraging Predictability for Global Optimization of IoT Networks'. In: *ICC 2022 - IEEE International Conference on Communications*. ICC 2022 - IEEE International Conference on Communications. Seoul, South Korea: IEEE, 2022, pp. 3586–3591. DOI: 10.1109/ICC45855.2022.9838916. URL: https://hal.archives-ouvertes.fr/hal-03904118.

[28] P. R. D'argenio, J. A. Fraire, A. Hartmanns and F. Raverta. 'Comparing Statistical and Analytical Routing Approaches for Delay-Tolerant Networks'. In: *QEST 2022: Quantitative Evaluation of Systems*. QEST 2022: Quantitative Evaluation of Systems. Vol. 13479. Lecture Notes in Computer Science. Warsaw, Poland: Springer International Publishing, 11th Sept. 2022, pp. 337–355. DOI: 10.1007/978-3-031-16336-4_17. URL: https://hal.archives-ouvertes.fr/hal-03827262.

[29] J. A. Fraire, P. Madoery, M. Ait Mesbah, O. Iova and F. Valois. 'Simulating LoRa-Based Direct-to-Satellite IoT Networks with FLoRaSat'. In: 2nd Workshop on Non-Terrestrial Networks in 6G Wireless (NTN-6G), Satellite Workshop of IEEE WoWMoM. Belfast, United Kingdom, 14th June 2022. URL: https://hal.science/hal-03698223.

[30] A. Guitton and M. Kaneko. 'Multi-Gateway Demodulation in LoRa'. In: *GLOBECOM 2022 - IEEE Global Communications Conference*. GLOBECOM 2022 - IEEE Global Communications Conference. Rio de Janeiro, Brazil, 4th Dec. 2022. URL: https://hal.science/hal-03808012.

[31] C. Moriot, F. Lesueur, N. Stouls and F. Valois. 'How to build socio-organizational information from remote IP addresses to enrich security analysis?' In: LCN 2022 - IEEE 47th Conference on Local Computer Networks. Edmonton, Canada: IEEE, Sept. 2022, pp. 287–290. DOI: 10.1109/LCN53696.2022.9843570. URL: https://hal.inria.fr/hal-03901706.

[32] H. Pann Phyu, D. Naboulsi and R. Stanica. 'Mobile Traffic Forecasting for Network Slices: A Federated-Learning Approach'. In: PIMRC 2022 - IEEE 33rd International Symposium on Personal, Indoor and Mobile Radio Communications. Virtual, Japan, 12th Sept. 2022. URL: https://hal.inria.fr/hal-03755115.

[33] S. Rabenjamina, R. Stanica, O. Iova and H. Rivano. 'Comparison of User Presence Information from Mobile Phone and Sensor Data'. In: MSWiM 2022 – 25th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems. Montreal, Canada, 24th Oct. 2022. URL: https://hal.inria.fr/hal-03840106.

[34] R. Saroui, A. Guitton, O. Iova and F. Valois. 'Uplink and downlink are not orthogonal in LoRaWAN!' In: IEEE VTC 2022 Fall - IEEE Vehicular Technology Society. Londres, United Kingdom, 26th Sept. 2022. URL: https://hal.science/hal-03789064.

[35] G. Stock, J. A. Fraire and H. Hermanns. 'Distributed On-Demand Routing for LEO Mega-Constellations: A Starlink Case Study'. In: ASMS/SPSC 2022 - 11th Advanced Satellite Multimedia Systems Conference and the 17th Signal Processing for Space Communications Workshop. Graz, Austria: IEEE, 6th Sept. 2022, pp. 1–8. DOI: 10.1109/ASMS/SPSC55670.2022.9914716. URL: https://hal.archives-ouvertes.fr/hal-03827298.

[36] W. Xiao, N. El Rachkidy and A. Guitton. 'SF-DS: A Slot-Free Decoding Scheme for Collided LoRa Transmissions'. In: VTC 2022 - IEEE 95th Vehicular Technology Conference. Helsinki, Finland, 19th June 2022. URL: https://hal.science/hal-03808037.

[37] W. Xiao, G. de Sousa, N. El Rachkidy and A. Guitton. 'An Open-Source GNU Radio Framework for LoRa Physical Layer and Collision Resolution'. In: IEEE VTC Fall 2022 - IEEE Vehicular Technology Conference. Londres, United Kingdom, 26th Sept. 2022. URL: https://hal.science/hal-03808046.

**National peer-reviewed Conferences**

[38] J. A. A. Fraire, M. Mesbah, P. Madoery, O. Iova and F. Valois. 'FLoRaSat : Le simulateur pour la communication LoRa avec les satellites LEO'. In: CORES 2022 – 7ème Rencontres Francophones sur la Conception de Protocoles, l'Évaluation de Performance et l'Expérimentation des Réseaux de Communication. Saint-Rémy-Lès-Chevreuse, France, 30th May 2022, pp. 1–4. URL: https://hal.science/hal-03657890.

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