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Activity Report 2019

Project-Team AGORA

ALGorithmes et Optimisation pour Réseaux Autonomes

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

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Networks and Telecommunications

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1. Team, Visitors, External Collaborators

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2. Overall Objectives

2.1. Overall Objectives

The Agora team is positioned in Inria research domain of "Networks, Systems and Services, Distributed Computing" under the theme "Networks and Telecommunications", as a joint team between Inria and INSA Lyon, within the CITI laboratory. The Agora team focus is on the wireless access part of the Internet, where several network architectures and paradigms co-exist: heterogeneous cellular networks, multi-hop wireless networks, long-range low-power connectivity. We work on the deployment of these networking technologies and their combined exploitation, while understanding the spatio-temporal dynamics of users, machines and data.

The deployment of dense networks is challenged by large scale and dense scenarios, with consequences on the optimization of the placement of both the components and functionalities of the network. At the same time, Machine-to-Machine (M2M) communication protocols, designed for running on the Internet of Things (IoT) architectures, need a coherent rethinking to face issues on both saturated cellular networks and fresh deployments of multi-hop wireless networks unable to cover large areas. Exploiting the data carried by the network opens new questions on the network deployment and functioning, by understanding the spatio-temporal dynamics of the users or connected objects.

The main networking fact that motivates the direction of the Agora team is the coming saturation of cellular networks. Even though developed cities can rely on a full coverage of their territory with very high throughput wireless access networks, the expected - and already measured - tremendous growth of mobile data traffic will overwhelm these infrastructures without a dramatic change of communication paradigm.

Beyond cellular networks. The networking functions are today almost only managed through cellular infrastructures. Even current smart-metering network architectures follow a hierarchical organization alike cellular networks. This approach features a number of advantages, including pervasive geographical coverage, seamless connectivity, a good level of security and possibly guaranteed bandwidth and latency. However, this centralized paradigm is over twenty years old now. The access network capacity has already reached its limit, and the explosion of popular, bandwidth-hungry digital services will make the newest technologies, such as LTE, already unable to accommodate the future demand - expected to grow 11-fold in 2018, with respect to 2014. A clear trend is to decentralize the network operation, leveraging network function virtualization so as to make it more pervasive (Small Cells), heterogeneous (HetNets) and self-organizing (SON). Beyond cellular networks, multi-hop wireless mobile networks have been extensively studied in the literature, in particular wireless sensor networks, ad hoc networks, wireless mesh networks and vehicular networks. Such wireless multi-hop solutions met scarce practical success over the last decade, mainly because of the lack of a clear application context and of important use cases. There are however now mature technologies for some specific applications that provide a wealth of connectivity surrounding mobile devices. Combined with the emergence of long range low power technologies dedicated to small traffic IoT applications, one can foresee the emergence of hybrid network architectures (cellular and multi-hop) that need to be developed and evaluated.

Low cost sensors and density. We also witness the emergence of a new market of sensing devices that is closely related to the industrial effort toward the IoT. Recent breakthroughs in micro and nano technologies are indeed enabling dense deployments of low-cost sensing devices that produce reliable enough measurements of physical phenomena while being energetically autonomous. Density is however challenging network infrastructures deployment and data collection. The deployment of such devices has to be suitable for the application and fitted to the constraints of the environment. Self-organization and self-healing are required for sustainable infrastructure management and operation. Combining all these notions into optimization models is an issue that needs to be addressed to understand and evaluate the relevant networking infrastructures and protocols. On the other hand, density is also an opportunity if one can understand and take advantage of the spatio-temporal characteristics of the data produced and the citizens behavior. Redundancy and correlations are a way to improve on data reliability and network usage.

3. Research Program

3.1. Wireless network deployment

The deployment of networks has fostered a constant research effort for decades, continuously renewed by the evolution of networking technologies. Fundamentally, the deployment problem addresses the trade-off between the cost of the network to be minimized or fitted into a budget and the features and services provided by the system, that should reach a target level or be maximized. The variety of cost models and type of features gives rise to a wide scientific field. There are several cost factors of network infrastructure: components (number and capacity), energy, man power (installation and maintenance), etc. The features of the network matter as much as the metric to evaluate them. Coverage and capacity are basic features for wireless networks on which we will focus in the following. One recurrent question is therefore: What are the optimal number and position of network components to deploy so that a given territory is covered and enough networking capacity is provided?

Traditional telecommunication infrastructures were made of dedicated components, each of them providing a given set of functions. However, recently introduced paradigms yield issues on the deployment of network functions. Indeed, the last decade saw a trend towards adding more intelligence within the network. In the case of the access network, the concept of Cloud Radio Access Network (C-RAN) emerged. In the backhaul, the Evolved Packet Core (EPC) network can also benefit from virtualization techniques, as the convergence point for multiple access technologies, as imagined in the case of future 5G networks. The performance limits of a virtualized EPC remain unknown today: Is the delay introduced by this new architecture compatible with the requirements of the mobile applications? How to deploy the different network functions on generic hardware in order to maximize the quality of service?

Network component deployment. In this research direction, we address new issues of the optimal network deployment. In particular, we focus on the deployment of wireless sensor networks for environmental monitoring (e.g. atmospheric pollution). Most current air quality monitoring systems are using conventional measuring stations, equipped with multiple lab quality sensors. These systems are however massive, inflexible and expensive. An alternative – or complementary – solution is to use low-cost flexible wireless sensor networks. One of the main challenges is to introduce adequate models for the coverage of the phenomenon. Most of the state of the art considers a generic coverage formulation based on detection ranges which are not adapted to environmental sensing. For example, pollution propagation models should take into account the inherently stochastic weather conditions. An issue is to develop an adequate formulation and efficient integer linear programming (ILP) models and heuristics able to compute deployments at a relevant scale. In particular, it seems promising to adapt stochastic or robust optimization results of the operational research community in order to deals with uncertainty. Defining the quality of a coverage is also a modeling issue, which depends on the application considered. The detection of anomaly is close to a combinatorial problem. A more difficult objective is to deploy sensors in order to map the phenomenon by interpolation (or other reconstruction mechanisms). This challenge requires interdisciplinary research with fluid mechanics teams who develop numerical models of pollution propagation and practitioners like Atmo Auvergne-Rhône-Alpes.

Regarding the network connectivity, another challenge is to integrate suitable wireless link models accounting for the deployment environment. For example, modeling the integration of sensors in urban areas is challenging due to the presence of neighboring walls and obstacles, as well as moving vehicles and pedestrians that may induce field scattering. Also, the urban constraints and characteristics need to be carefully modeled and considered. Indeed, the urban environment yields constraints or facilities on the deployment of sensor nodes and gateways, such as their embedding within street furniture. Understanding the structure of these spatial constraints is necessary to develop efficient optimization methods able to compute on large scale scenarios.

Network function deployment. In this research direction, we do not address network virtualization per se, but the algorithmic and architectural challenges that virtualization brings in both radio access and core networks. As a first challenge, we focus on the evaluation of Cloud Radio Access Network solutions. The capacity of a C-RAN architecture and the way this compares to classical RAN is still an open question. The fact that C-RAN enables cooperation between the remote radio heads (RRH) served by the same base-band units (BBU) indicates an improved performance, but at the same time the resulting cells are much larger, which goes against the current trend of increasing capacity through the deployment of small cells. We propose to study the problem both from a user and a network perspective. On the user side, we use standard information theory tools, such as multiple-access channels to model C-RAN scenarios and understand their performance. On the network side, this translates in a resource allocation problem with cooperative base stations. We will extend our previous models for non-cooperative scenarios. Regarding the core network function deployment, we are interested in the specific case of Professional Mobile Radio (PMR) networks. These networks, used for public safety services and in scenarios like post-disaster relief, present the particularity of an EPC formed by a mobile wireless network. Due to its nature, the network can not be pre-planned, and the different EPC functions need to be autonomously deployed on the available network elements. We study the EPC function deployment problem as an optimization problem, constrained by the user capacity requests. User attachment mechanisms will also be proposed, adapted to the network function distribution, the global user demand, and the source/destination of the flows. These challenges are tackled as centralized optimization problems, then extended to the context of real-time decisions. Finally, in order to complete these theoretical works based on ILP models and heuristics, experiments using OpenAir Interface are used to evaluate our proposals.

3.2. Wireless data collection

With an anticipated 11-fold growth between 2014 and 2018, facing the growth of the mobile demand is the foremost challenge for mobile operators. In particular, a 100-fold increase in the number of supported connected devices, mostly newly connected objects with M2M trafic, is expected. A question therefore arises: how to cope with a dense set of M2M low bit rate traffics from energy and computing power constrained devices while classic cellular infrastructures are designed for the sparse high bit rate traffics from powerful devices?

A technological answer to the densification challenge is also embodied by long-range low-power networks such as SigFox, LoRa, NB-IoT, etc. In this context, the idea of offloading cellular traffic to different wireless access technologies is emerging as a very promising solution to relieve the traditional mobile network from its overwhelming load. In fact, offloading is already employed today, and, globally, 45% of total mobile data traffic was offloaded onto the fixed network through Wi-Fi or femtocells in 2013. Device-to-device (D2D) communications in hybrid networks, combining long-range cellular links and short-range technologies, opens even more possibilities. We aim at providing solutions that are missing for efficiently and practically mix multi-hop and cellular networks technologies.

Cellular M2M. Enabling a communication in a cellular network follows two major procedures: a resource allocation demand is first transmitted by the UE which, if successful, is followed by the actual data transmission phase, using dedicated resources allocated by the eNodeB (eNB) to the UE. This procedure was designed specifically for H2H traffic, which is bursty by nature, and it is based on the notions of session and call, activities that keep the user involved for a relatively long time and necessitate the exchange of a series of messages with the network. On the contrary, M2M traffic generates low amounts of data periodically or sporadically. Going through a signaling-heavy random access (RA) procedure to transmit one short message is strongly inefficient for both the M2M devices and the infrastructure.

In the perspective of 5G solutions, we are investigating mechanisms that regulate the M2M traffics in order to obtain good performances while keeping a reasonable quality of service (QoS) for human-to-human (H2H) terminals. The idea of piggybacking the M2M data transmission within one of the RA procedure messages is tempting and it is now considered as the best solution for this type of traffic. This means that the M2M data is transmitted on the shared resources of the RACH, and raises questions regarding the capacity of the RACH, which was not designed for these purposes. In this regard, our analysis of the access capacity of LTE-A RACH procedure has to be adapted to multi-class scenarios, in order to understand the competition between M2M and H2H devices. Modeling based on Markov chains provides trends on system scale performances, while event-based simulations enable the analysis of the distribution of the performances over the different kinds of users. Combining both should give enough insights so as to design relevant regulation techniques and strategies. In particular two open questions that have to be tackled can be stated as: When should access resources be opened to M2M traffics without penalizing H2H performances? Does an eNodeB have a detailed enough knowledge of the system and transmit enough information to UE to regulate the traffics? The objective is to go to the analysis of achievable performances to actual protocols that take into account realistic M2M traffic patterns.

Hybrid networks. The first objective in this research axis is a realistic large-scale performance evaluation of Wi-Fi offloading solutions. While the mechanisms behind Wi-Fi offloading are now clear in the research community, their performance has only been tested in small-scale field tests, covering either small geographical areas (i.e. a few cellular base stations) and/or a small number of specific users (e.g. vehicular users). Instead, we evaluate the offloading performance at a city scale, building on real mobile network traces available in the team. First of all, through our collaboration with Orange Labs, we have access to an accurate characterization of the mobile traffic load at each base station in all major French cities. Second, a data collection application for Android devices has been developed in the team and used by hundreds of users in the Lyon metropolitan area. This application monitors and logs all the Wi-Fi access points in the coverage range of the smartphone, allowing us to build a map of Wi-Fi accessibility in some parts of the city. Combining these two data sources and completing them with simulation studies will allow an accurate evaluation of Wi-Fi offloading solutions over a large area.

On the D2D side, our focus is on the connected objects scenario, where we study the integration of short-range links and long-range technologies such as LTE, SigFox or LoRa. This requires the design of network protocols to discover and group the devices in a certain region. For this, we build on our expertise on clustering sensor and vehicular nodes. The important difference in this case is that the cellular network can assist the clustering formation process. The next step is represented by the selection of the devices that will be using the long-range links on behalf of the entire cluster. With respect to classical cluster head selection problems in ad-hoc networks, our problem distinguishes itself through device heterogeneity in terms of available communication technologies (not all devices have a long-range connection, or their quality is poor), energy resources (some devices might have energy harvesting capabilities) and expected lifetime. We will evaluate the proposed mechanisms both analytically (clustering problems are generally modeled by dominating set problems in graph theory) and through discrete-event simulation. Prototyping and experimental evaluation in cooperation with our industrial partners is also foreseen in this case.

3.3. Network data exploitation

Mobile devices are continuously interacting with the network infrastructure, and the associated geo-referenced events can be easily logged by the operators, for different purposes, including billing and resource management. This leads to the implicit possibility of monitoring a large percentage of the whole population with minimal cost: no other technology provides today an equivalent coverage. On the networking side, the exploration of data collected within the cellular network can be the enabler of flexible and reconfigurable cellular systems. In order to enable this vision, algorithmic solutions are needed that drive, in concert with the variations in the mobile demand, the establishment, modification, release and relocation of any type of resources in the network. This raises, in turn, the fundamental problem of understanding the mobile demand, and linking it to the resource management processes. More precisely, we contribute to answer questions about the correlation between urban areas and mobile traffic usage, in particular the spatial and temporal causalities in the usage of the mobile network.

In a different type of architecture, the one of wireless sensor networks, the spatio-temporal characteristics of the data that are transported can also be leveraged to improve on the networking performances, e.g. capacity and energy consumption. In several applications (e.g. temperature monitoring, intrusion detection), wireless sensor nodes are prone to transmit redundant or correlated information. This wastes the bandwidth and accelerates the battery depletion. Energy and network capacity savings can be obtained by leveraging spatial and temporal correlation in packet aggregation. Packet transmissions can be reduced with an overhead induced by distributed aggregation algorithms. We aim at designing data aggregation functions that preserve data accuracy and maximize the network lifetime with low assumptions on the network topology and the application.

Mobile data analysis. In this research axis, we delve deeper in the analysis of mobile traffic. In this sense, temporal and spatial usage profiles can be built, by including in our analysis datasets providing service-level usage information. Indeed, previous studies have been generally using call detail records (CDR) or, at best, aggregated packet traffic information. This data is already very useful in many research fields, but fine-grained usage data would allow an even better understanding of the spatiotemporal characteristics of mobile traffic. To achieve this, we exploit datasets made available by Orange Labs, providing information about the network usage for several different mobile services (web, streaming, download, mail, etc.).

To obtain even richer information, we combine this operator-side data with user-side data, collected by a crowdsensing application we developed within the PrivaMov research project. While covering hundreds of thousands of users, operator data only allows to localize the user at the cell level, and only when the user is connected to the network. The crowdsensing application we are using gathers precise GPS user localization data at a high frequency. Combining these two sources of data will allow us to gain insight in possible biases introduced by operator-side data and to infer microscopic properties which, correctly modeled, can be extended to the entire user population, even those for which we do not possess crowdsensed data.

Privacy preservation is an important topic in the field of mobile data analysis. Mobile traffic data anonymization techniques are currently proposed, mainly by adding noise or removing information from the original dataset. While we do not plan to develop anonymization algorithms, we collaborate with teams working on this topic (e.g. Inria Privatics) in order to assess the impact of anonymization techniques on the spatio-temporal properties of mobile traffic data. Through a statistical analysis of both anonymized and non-anonymized data, we hope to better understand the usability of anonymized data for different applications based on the exploration of mobile traffic data.

Data aggregation. Data-aggregation takes benefit from spatial and/or temporal correlation, while preserving the data accuracy. Such correlation comes from the physical phenomenon which is observed. Temporal aggregation is mainly addressed using temporal series (e.g. ARMA) whereas spatial aggregation is now led by compressive sensing solutions. Our objective is to get rid of the assumption of knowing of the network topology properties and the data traffic generated by the application, in particular for dense and massive wireless networks. Note that we focus on data-aggregation with a networking perspective, not with the background of information theory.

The rational design of an aggregation scheme implies understanding data dynamics (statistical characteristics, information representation), algorithmic optimization (aggregator location, minimizing the number of aggregators toward energy efficiency), and network dynamics (routing, medium sharing policies, node activity). We look for designing a complete aggregation chain including both intra-sensor aggregation and inter-sensor aggregation. For this, we characterize the raw data that are collected in order to understand the dynamics behind several key applications. The goal is to provide a taxonomy of the applications according to the data properties in terms of stationarity, dynamics, etc. Then, we aim to design temporal aggregation functions without knowledge of the network topology and without assumptions about the application data. Such functions should be able to self-adapt to the environment evolution. A related issue is the deployment of aggregators into the wireless network to allow spatial aggregation with respect to the energy consumption minimization, capacity saving maximization and distributed algorithm complexity. We therefore look to define dedicated protocols for each aggregation function family.

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. 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 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 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.

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.

5. Highlights of the Year

5.1. Highlights of the Year

- Walid Bechkit holds the PEDR (2017-2021).
- Khaled Boussetta holds the PEDR (2018-2022).
- Hervé Rivano holds the PEDR (2017-2021).
- Razvan Stanica holds the PEDR (2016-2020).
- Razvan Stanica obtained his HDR from the University Lyon 1 / INSA Lyon, in November 2019.

5.1.1. Awards

- Ahmed Boubrima is runner-up (*accessit*) for the Gilles Kahn thesis prize 2019.

6. New Software and Platforms

6.1. TAPASCologne

Travel and Activity PAtterns Simulation Cologne

KEYWORDS: Mobility - Traces

FUNCTIONAL DESCRIPTION: TAPASCologne is an initiative by the Institute of Transportation Systems at the German Aerospace Center (ITS-DLR), aimed at reproducing, with the highest level of realism possible, car traffic in the greater urban area of the city of Cologne, in Germany.

To that end, different state-of-art data sources and simulation tools are brought together, so to cover all of the specific aspects required for a proper characterization of vehicular traffic:

The street layout of the Cologne urban area is obtained from the OpenStreetMap (OSM) database, The microscopic mobility of vehicles is simulated with the Simulation of Urban Mobility (SUMO) software, The traffic demand information on the macroscopic traffic flows across the Cologne urban area (i.e., the O/D matrix) is derived through the Travel and Activity PAtterns Simulation (TAPAS) methodology, The traffic assignment of the vehicular flows described by the TAPASCologne O/D matrix over the road topology is performed by means of Gawron's dynamic user assignment algorithm.

- Participants: Marco Fiore and Razvan Stanica
- Contact: Marco Fiore
- URL: http://kolntrace.project.citi-lab.fr/#download

6.2. Sense in the City

KEYWORDS: Sensors - Sensors network - Wireless Sensor Networks

FUNCTIONAL DESCRIPTION: Sense in the city is a lightweight experimentation platform for wireless sensor networks in development. The main objective of this platform is to be easily transferable and deployable on the field. It allows a simplified deployment of the code running on the sensors and the collection of logs generated by the instrumentation of the code on a centralized database. In the early stage of the platform, the sensors are powered by small PCs, e.g. Raspberry Pi, but we are investigating the integration of energy harvesting capabilities such as solar panels.

- Participants: Hervé Rivano and Khaled Boussetta
- Contact: Khaled Boussetta

6.3. 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, and is currently available on Google Play.

- Participants: Stéphane d'Alu, Hervé Rivano, Razvan Stanica and Solohaja Rabenjamina
- Contact: Razvan Stanica

6.4. WSNet

KEYWORD: Network simulator

FUNCTIONAL DESCRIPTION: WSNet is a modular event-driven simulator targeted to Wireless Sensor Networks. Its main goals are to offer scalabiliy, extensibility and modularity for the integration of new protocols/hardware models and a precise radio medium simulation. We still hope to find the proper resource to make WSNet evolve into a wireless capillary network simulator suitable for conducting simulations at the urban scale.

- Participants: Rodrigue Domga Komguem and Fabrice Valois
- Partner: CEA-LETI
- Contact: Guillaume Chelius
- URL: https://gforge.inria.fr/projects/wsnet-3/

6.5. Platforms

6.5.1. 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 LoRa 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).
Part of the software is mutualized with the University of Paris 13, where a LoRaWan testbed project is under deployment at the campus of Villetaneuse. This project, is supported by a local BQR and is lead by Khaled Boussetta. The mutualization of the software tools will allow us to conduct multi sites experiments, at Lyon and at Paris. Since 2019, this platform is used in the European Project Interreg Med ESMARTCITY and for the PHC Ulysses (joint collaboration with Nimbus Center, Ireland).

6.5.2. 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.

6.5.3. 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.

7. New Results

7.1. Wireless network deployment

Participants: Walid Bechkit, Ahmed Boubrima, Oana Iova, Rodrigue D. Komguem, Abdoul-Aziz Mbacke, Jad Oueis, Hervé Rivano, Razvan Stanica, Fabrice Valois

7.1.1. Deployment of wireless sensor networks for air quality mapping

Wireless sensor networks (WSN) are widely used in environmental applications where the aim is to sense a physical phenomenon such as temperature, air pollution, etc. A careful deployment of sensors is necessary in order to get a better knowledge of these physical phenomena while ensuring the minimum deployment cost [18]. In this work, we focus on using WSN for air pollution mapping and tackle the optimization problem of sensor deployment [3]. Unlike most of the existing deployment approaches, which are either generic or assume that sensors have a given detection range, we define an appropriate coverage formulation based on an interpolation formula that is adapted to the characteristics of air pollution sensing. We derive from this formulation two deployment models for air pollution mapping using integer linear programming while ensuring the connectivity of the network and taking into account the sensing error of nodes. We analyze the theoretical complexity of our models and propose heuristic algorithms based on linear programming relaxation and binary search. We perform extensive simulations on a dataset of the Lyon city, France in order to assess the computational complexity of our proposal and evaluate the impact of the deployment requirements on the obtained results.

7.1.2. Characterization of radio links in case of a ground deployment

In this work, we are interested in characterizing the link properties of a wireless sensor network with nodes deployed at ground level [5]. Such a deployment is fairly common in practice, e.g., when monitoring the vehicular traffic on a road segment or the status of infrastructures such as bridges, tunnels or dams. However, the behavior of off-the-shelf wireless sensor nodes in these settings is not yet completely understood. Through a thorough experimentation campaign, we evaluated not only the impact of the ground proximity on the wireless links, but also the impact of some parameters such as the packet payload, the communication channel frequency and the topography of the deployment area. Our results show that a ground-level deployment has a significant negative impact on the link quality, while parameters such as the packet size produce unexpected consequences. This allows us to parameterize classical theoretical models in order to fit a ground-level deployment scenario. Finally, based on the lessons learned in our field tests, we discuss some considerations that must be taken into account during the design of communication protocols and before the sensor deployment in order to improve network performance.

7.1.3. Sensor deployment in linear wireless sensor networks using the concept of virtual node

In a multi-hop wireless sensor network with a convergecast communication model, there is a high traffic accumulation in the neighborhood of the sink. This area constitutes the bottleneck of the network since the sensors deployed within it rapidly exhaust their batteries. In this work, we consider the problem of sensors deployment for lifetime maximization in a linear wireless sensor network [6]. Existing approaches express the deployment recommendations in terms of distance between consecutive sensors. Solutions imposing such constraints on the deployment may be costly and difficult to manage. We propose a new approach where the network is formed of virtual nodes, each associated to a certain geographical area. An analytical model of the network traffic per virtual node is proposed and a greedy algorithm to calculate the number of sensors that should form each virtual node is presented. Performance evaluation shows that the greedy deployment can improve the network lifetime by up to 40%, when compared to the uniform deployment. Moreover, the proposed approach outperforms the related work when complemented by a scheduling algorithm which reduces the messages overhearing. It is also shown that the lifetime of the network can be significantly improved if the battery capacity of each sensor is dimensioned taking into account the traffic it generates or relays.

7.1.4. Core network function placement in self-deployable mobile networks

Emerging mobile network architectures (e.g., aerial networks, disaster relief networks) are disrupting the classical careful planning and deployment of mobile networks by requiring specific self-deployment strategies. Such networks, referred to as self-deployable, are formed by interconnected rapidly deployable base stations that have no dedicated backhaul connection towards a traditional core network. Instead, an entity providing essential core network functionalities is co-located with one of the base stations. In this work, we tackle the problem of placing this core network entity within a self-deployable mobile network, i.e., we determine with which of the base stations it must be co-located [9], [15] [15]. We propose a novel centrality metric, the flow centrality, which measures a node capacity of receiving the total amount of flows in the network. We show that in order to maximize the amount of exchanged traffic between the base stations and the core network entity, under certain capacity and load distribution constraints, the latter should be co-located with the base station having the maximum flow centrality. We first compare our proposed metric to other state of the art centralities. Then, we highlight the significant traffic loss occurring when the core network entity is not placed on the node with the maximum flow centrality, which could reach 55% in some cases.

7.1.5. Cyber physical systems and Internet of things: emerging paradigms on smart cities

A city is smart when investment in traditional and modern infrastructure, human and social capital, fuel well being, high quality of life, and sustainable economic development. The Smart City paradigm is driven by technological evolution in the field of Information and Communication Technologies, and more specifically the paradigms of Internet of Things, Industrial Internet of Things and their confluence with Cyber Physical Systems [12]. Smart Cities present a number of application domains that are related to their critical infrastructures, including energy and transport. These domains present needs similar to the industrial manufacturing environment utilizing smart devices and employing control automation for their applications. They could thus be labeled as *industrial domains* in the wider sense. This work presents three application domains associated with Smart Cities, namely Smart Lighting, Smart Buildings / Energy, and Smart Urban Mobility, identifies their requirements and challenges and reviews existing solutions.

7.2. Wireless data collection

Participants: Oana Iova, Abderrahman Ben Khalifa, Razvan Stanica

7.2.1. Reliable and efficient support for downward traffic in RPL

Modern protocols for wireless sensor networks efficiently support multi-hop upward traffic from many sensors to a collection point, a key functionality enabling monitoring applications. However, the ever-evolving scenarios involving low-power wireless devices increasingly require support also for downward traffic, e.g., enabling a controller to issue actuation commands based on the monitored data. The IETF Routing Protocol for Low-power and Lossy Networks (RPL) is among the few tackling both traffic patterns. Unfortunately, its support for downward traffic is significantly unreliable and inefficient compared to its upward counterpart. We tackle this problem by extending RPL with mechanisms inspired by opposed, yet complementary, principles [7]. At one extreme, we retain the route-based operation of RPL and devise techniques allowed by the standard but commonly neglected by popular implementations. At the other extreme, we rely on flooding as the main networking primitive. Inspired by these principles, we define three base mechanisms, integrate them in a popular RPL implementation, analyze their individual and combined performance, and elicit the resulting tradeoffs in scalability, reliability, and energy consumption. The evaluation relies on simulation, using both real-world topologies from a smart city scenario and synthetic grid ones, as well as on testbed experiments validating our findings from simulation. Results show that the combination of all three mechanisms into a novel protocol, T-RPL *i)* yields high reliability, close to the one of flooding, *ii)* with a low energy consumption, similar to route-based approaches, and *iii)* improves remarkably the scalability of RPL w.r.t. downward traffic.

7.2.2. Performance evaluation of LED-to-camera communications

The use of LED-to-camera communication opens the door to a wide range of use cases and applications, with diverse requirements in terms of quality of service. However, while analytical models and simulation tools exist for all the major radio communication technologies, the only way of currently evaluating the performance of a network mechanism over LED-to-camera is to implement and test it. Our work aims to fill this gap by proposing a Markov-modulated Bernoulli process to model the wireless channel in LED-to-camera communications, which is shown to closely match experimental results [11]. Based on this model, we develop and validate *CamComSim*, the first network simulator for LED-to-camera communications.

7.2.3. Performance evaluation of channel access methods for dedicated IoT networks

Networking technologies dedicated for the Internet of Things are different from the classical mobile networks in terms of architecture and applications. This new type of network is facing several challenges to satisfy specific user requirements. Sharing the communication medium between (hundreds of) thousands of connected nodes and one base station is one of these main requirements, hence the necessity to imagine new solutions, or to adapt existing ones, for medium access control. In this work, we start by comparing two classical medium access control protocols, CSMA/CA and Aloha, in the context of Internet of Things dedicated networks [13]. We continue by evaluating a specific adaptation of Aloha, already used in low-power wide area networks, where no acknowledgement messages are transmitted in the network. Finally, we apply the same concept to CSMA/CA, showing that this can bring a number of benefits. The results we obtain after a thorough simulation study show that the choice of the best protocol depends on many parameters (number of connected objects, traffic arrival rate, allowed retransmission number), as well as on the metric of interest (e.g. packet reception probability or energy consumption).

7.2.4. On the use of wide channels in WiFi networks

An increased density of access points is common today in WiFi deployments, and more and more parameters need to be configured in such networks. In this work, we question current industrial guidelines for both residential and enterprise scenarios [14]. More precisely, we investigate the joint channel, power, and carrier sense threshold allocation problem in IEEE 802.11ac networks, showing that the current practice, which is to use narrower channels at maximum power when the deployment is dense, yields much worse performance than a solution using the widest possible channel with a much lower power.

7.3. Network data exploitation

Participants: Florent Delaine, Panagiota Katsikouli, Hervé Rivano, Razvan Stanica

7.3.1. Calibration algorithms for environmental sensor networks

The recent developments in both nanotechnologies and wireless technologies have enabled the rise of small, low cost and energy efficient environmental sensing devices. Many projects involving dense sensor networks deployments have followed, in particular within the Smart City trend. If such deployments are now within economical and technical reach, their maintenance and reliability remain however a challenge. In particular, reaching, then maintaining, the targeted quality of measurement throughout deployment duration is an important issue. Indeed, factory calibration is too expensive for systematic application to low-cost sensors and as these sensors are usually prone to drifting because of premature aging. In addition, there are concerns about the applicability of factory calibration to field conditions [4]. These challenges have fostered many researches on in situ calibration. In situ means that the sensors are calibrated without removing them from their deployment location, preferably without physical intervention, often leveraging their communication capabilities. It is a critical challenge for the economical sustainability of networks with large scale deployments. In this work, we focus on in situ calibration methods for environmental sensor networks. We propose a taxonomy of the methodologies in the literature. Our classification relies on both the architecture of the network of sensors and the algorithmic principles of the calibration methods. This review allows us to identify and discuss two main challenges: how to improve the performance evaluation of such methods and how to enable a quantified comparison of these strategies?

7.3.2. Characterizing and Removing Oscillations in Mobile Phone Location Data

Human mobility analysis is a multidisciplinary research subject that has attracted a growing interest over the last decade. A substantial amount of such recent studies is driven by the availability of original sources of real-world information about individual movement patterns. An important task in the analysis of mobility data is reliably distinguishing between the stop locations and movement phases that compose the trajectories of the monitored subjects. The problem is especially challenging when mobility is inferred from mobile phone location data: here, oscillations in the association of mobile devices to base stations lead to apparent user mobility even in absence of actual movement [10]. In this work, we leverage a unique dataset of spatiotemporal individual trajectories that allows capturing both the user and network operator perspectives in mobile phone location data, and investigate the oscillation phenomenon. We present probabilistic and machine learning approaches for detecting oscillations in mobile phone location data, and a filtering technique for removing those. Our analyses and comparison with state-of-the-art approaches demonstrate the superiority of our solution, both in terms of removed oscillations and of error with respect to ground-truth trajectories.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

- We have contracted a first bilateral contract with Total (2018-2021) 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 industrial and academic partners in the context of the PSPC Fed4PMR project (2015-2019). In this context, we are working on the design of new professional mobile radio solutions, compatible with 4G and 5G standards. This collaboration funds the PhD thesis of Jad Oueis, the PhD thesis of Romain Pujol, and a part of the PhD thesis of Abderrahman Ben Khalifa.

8.2. Bilateral Grants with Industry

- Common Laboratory Inria/Nokia Bell Labs - ADR Network Information Theory.
  Agora is part of the ADR Network Information Theory of the common laboratory Inria/Nokia Bell Labs.
- Spie - INSA Lyon IoT Chaire.
  Agora is involved in the SPIE INSA Lyon IoT Chaire, launched in November 2016. The IoT Chaire partially funds the PhD thesis of Abderrahman Ben Khalifa.
- Volvo - INSA Lyon Chaire.
  Agora is involved in the Volvo Chaire at INSA Lyon, on the area of autonomous electrical distribution vehicle in urban environments. Razvan Stanica is a member in the steering committee of this structure.

9. Partnerships and Cooperations

9.1. Regional Initiatives

- FIL Grant, 2019
  Participants: Razvan Stanica
  The partners of this project, supported by the *Fédération d'Informatique de Lyon*, are: CITI, LIP.
  WLANs (Wireless Local Area Networks) are typically based on IEEE 802.11 (known as WiFi). However, WLANs are prone to performance issues such as unfairness and inefficiencies. 802.11 includes a Rate Adaptation (RA) mechanism that allows user devices to change their transmission rate with regard to the current quality of the radio channel. The RA mechanism is based on preset values that may lead to suboptimal WLAN performance. Our goal is to address this issue by making fine adjustments to the parameters related to the RA mechanism. The search for an adequate setting is made complex due to the vast number of parameters to be considered that precludes the finding of general closed-form expressions. We propose to explore a data-driven approach based on techniques from Machine Learning to design an adaptive and distributed solution.
- Labex IMU 3M'Air 2018-2021
  Participants: Walid Beckhit, Ahmed Boubrima, Manoel Dahan, Mohamed Anis Fekih, Ichrak Mokhtari, Hervé Rivano.
  The partners in this project are: EVS, LMFA, Métropole de Lyon, Ville de Lyon , Atmo AURA, Météo France, Lyon Météo. Inria Agora is the leader of this project.
  The 3M'Air project explores the potential of participatory sensing to improve local knowledge of air quality and urban heat islands. The main aim of this project is therefore to equip citizens with low-cost mobile sensors and then ensure an efficient real-time data collection and analysis. This allows to obtain a finer spatiotemporal granularity of measurements with lighter installation and operational costs while involving citizens.
- ARC6 Robot fleet mobility under communication constraints, 2016-2019.
  Participant : Fabrice Valois.
  This work is a joint project with the Inria Chroma research group. Considering a fleet of drones moving in a 3D area, looking for a given target, we focus on how to maintain the wireless connectivity of the network of drones while the drones patrol autonomously. The other partners in this project are University of Grenoble and Viameca.
- Labex IMU Veleval, 2017-2019
  Participant: Hervé Rivano.
  The partners in this project are: EVS, LIRIS, LLSETI and CITI, with LAET leading the project.
  The goal of this pluridisciplinary project is to study, understand and model the behavior of cyclists in an urban environment with a methodology combining quantitative measurements of mobility traces and image analysis with qualitative information from reactivation interviews. In particular the input of Agora is to provide crowdsourcing tools for gathering mobility data that are optimized for the practice of urban cycling.

9.2. National Initiatives

9.2.1. 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 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 int he 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 CoWorkWorlds 2018 - 2020.
  Participants: Solohaja Rabenjamina, Razvan Stanica.
  The ANR CoWorkWorlds (Sustainability and spatiality in co-workers' mobility practices) project is led by ENTPE. Its focus is on the study of co-working environments, and more precisely on the mobility behavior of users of such spaces. Our role in the project is to collect and analyse mobility data from a set of users, using the PrivaMov smartphone application.

9.2.2. GDR CNRS RSD - Pôle ResCom

- Ongoing participation (since 2006)
  Communication networks, working groups of GDR ASR/RSD, CNRS (https://gdr-rsd.cnrs.fr/pole_rescom). Hervé Rivano is member of the scientific committee of ResCom.

9.2.3. EquipEx

- SenseCity
  We have coordinated the participation of several Inria teams to the SenseCity EquipEx. Within the SenseCity project, several small reproductions of 1/3rd scale city surroundings will be built under a climatically controlled environment. Micro and nano sensors will be deployed to experiment on smart cities scenarios, with a particular focus on pollution detection and intelligent transport services. Agora will have the opportunity to test some of its capillary networking solutions in a very realistic but controlled urban environment. A proof of concept test site has been built in 2015. We have deployed an experiment on low cost sensor network for vehicle detection and one on atmospheric pollution sensor calibration. The operational site is built, the information system is operational since April 2018.

9.3. European Initiatives

9.3.1. Collaborations in European Programs, Except FP7 & H2020

- Herve Rivano is member of European COST action CA18204 - Dynamics of placemaking and digitization in Europe´s cities on behalf of Ecole Urbaine de Lyon and Labex IMU.

  Program: Interreg Med

  - Project acronym: ESMARTCITY
  - Project title: Enabling Smarter City in the MED Area through Networking
  - Duration: 02/2018 - 07/2020
  - Coordinator: Abruzzo Region, Italy
  - Other partners: ARIC and RWG (Greece), APEGR (Spain), RAIS (Bosnia and Herzegovina), ENA (Portugal), MCM and PoliMi (Italy), Capergies (France)

- Abstract: The project has its primary objective in improving the innovation capacity of MED cities by creating innovation ecosystems, which involve actors of the quadruple helix (Citizens, Businesses Operators, Research, Universities and Public Authorities), and in applying the Smart City concept, which utilizes digital and energy saving technologies to allow better services for the citizen with less impact on the environment, producing furthermore new employability and living scenarios. To achieve this goal, the project envisages the pilot testing of the Smart City concept to provide specific services to citizens in the field of intelligent urban districts, energy efficiency of buildings and smarter public lighting.

9.4. International Initiatives

9.4.1. Inria International Partners

9.4.1.1. Informal International Partners

- **University of Waterloo, ON, Canada**. Joint publications and visits to/from the group of Prof. Catherine Rosenberg.
- **Digital Catapul, London, UK**. Collaboration around LoRa experiments with Dr. Ramona Marfievici.
- **CNR-IEIIT, Turin, Italy**. Joint publications and projects with Dr. Marco Fiore.
- **Trento University, Italy**. Collaboration around routing for IoT networks with the group of Prof. Gian Pietro Picco.
- **Rice University**. Collaboration around network deployment and data assimilation for air quality monitoring with the group of Prof. Edward W. Knightly.
- **University of Edinburgh, UK**. Joint publications and visits to/from the group of Dr. Paul Patras.
- **Biskra University, Algeria**. Joint publications and visits from Prof. Abdelmalik Bachir.

9.4.2. Participation in Other International Programs

9.4.2.1. PHC Campus France

- **University College Cork, Ireland**. PHC Ulysses (2019-2021) on real-world characterisation of long range wireless newtorks, a collaboration with Khaled Abdelfadeel.
- **INPT Rabat, Morocco**. PHC Toubkal (2019-2021) on efficient data collection for smart building and smart city applications, a collaboration with the group of Prof. Loubna Echabbi.
- **University of Cluj-Napoca, Romania**. PHC DRONEM (2017-2019) on monitoring using connected fleet of drones, a collaboration with the group of Prof. Gabriela Czibula.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

- Abdelmalik Bachir, Professor, Biskra University, Algeria: visiting professor at INSA Lyon (november, 2019).
- Ravi Mazumdar, Waterloo University, Canada, visiting scientist at INSA Lyon (february, 2019).
- Priscilla Solis, Professor, Brasilia University, Brazil, visiting the Agora team to prepare a sabbatical.

9.5.1.1. Internships

- Sami Abdelatif, PhD student, Biskra University, Algeria: visiting professor at INSA Lyon (november, 2019).

9.5.2. Visits to International Teams

9.5.2.1. Research Stays Abroad

- Mihai Popescu visited the group of Prof. Gabriela Czibula, at University of Cluj-Napoca, Romania (2 periods of 1 month duration: April and July 2019).
- Fabrice Valois visited Prof. Catherine Rosenberg, University of Waterloo, Canada (6 weeks between January and March 2019).

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Organisation

10.1.1.1. General Chair, Scientific Chair

- Oana Iova was the scientific chair of the first Low Power and Wide Area Networks Days (GDR RSD), 11-12 July 2019, Lyon.
- Oana Iova was co-chair of NewNets 2019 - The 1st Workshop on Emerging Technologies and Trends in Engineering Low-Power Networks (collocated with IEEE WF-IoT), April 15, 2019, Limerick, Ireland.
- Razvan Stanica co-organized a workshop on New Architectures and Services for Autonomous and Flexible Cellular Networks, within the Jacques Cartier Meetings organised in November in Montreal (Canada).

10.1.1.2. Member of the Organizing Committees

- Oana Iova was on the Organizing Committee of the first Low Power and Wide Area Networks Days (GDR RSD), 11-12 July 2019, Lyon.
- Hervé Rivano was on the Organizing Committee of the first Low Power and Wide Area Networks Days (GDR RSD), 11-12 July 2019, Lyon.
- Fabrice Valois was on the Organizing Committee of the first Low Power and Wide Area Networks Days (GDR RSD), 11-12 July 2019, Lyon.

10.1.2. Scientific Events: Selection

10.1.2.1. Chair of Conference Program Committees

- Oana Iova was program co-chair of CoRes 2019: 4ème Rencontre Francophone sur la Conception de Protocoles, l'Évaluation de Performance et l'Expérimentation des Réseaux de Communication, June 3-4, 2019, Toulouse (France).

10.1.2.2. Member of the Conference Program Committees

- Oana Iova was in the TPC of the following conferences: IAUV, UrbCom, IoT-HPC, ACM SIGCOMM AINTEC, AdHoc-Now, EWSN, IEEE DIPI.
- Razvan Stanica was in the TPC of the following conferences: IEEE ICC, IEEE GlobeCom, IEEE CCNC, IEEE WCNC, IEEE PIMRC, IFIP WD, ICIN, ISNCC, GIoT.
- Fabrice Valois was in the TPC of the following conferences: IEEE Globecom, IEEE ICC, IEEE ICT, IEEE WCNC, WiSARN.

10.1.2.3. Reviewer

- Oana Iova was a reviewer for the following conference: IEEE INFOCOM 2019 (demo and posters).

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

- Fabrice Valois is associated editor for Annals of Telecommunications (IF: 1.412).

10.1.3.2. Reviewer - Reviewing Activities

- Walid Bechkit was reviewer for the following journals: Elsevier Ad hoc Networks.
- Oana Iova was reviewer for the following journals: IEEE Transactions on Mobile Computing, Elsevier Sustainable Computing, Informatics and Systems.
- Razvan Stanica was a reviewer for the following journals: IEEE Transactions on Mobile Computing, IEEE Communication Letters, Computer Networks, Ad-Hoc Networks, Wireless Networks, IEEE Transactions on Network and Service Management, IEEE Access, Mobile Information Systems.

10.1.4. Invited Talks

- Hervé Rivano was invited speaker IMERIR, Perpignan, France.
- Hervé Rivano was invited speaker Forum Numerica - Learning Center, Campus SophiaTech, France.
- Hervé Rivano was invited speaker Institut d'Automne en Intelligence Artificielle, GDR IA, Lyon, France.
- Hervé Rivano was invited speaker Les Entretiens Jacques Cartier, Montréal, Canada.
- Hervé Rivano was invited speaker IEEE Societal Automation, Krakow, Poland.
- Hervé Rivano was chair of the panelist A l'école de l'anthropocène, Lyon, France.
- Fabrice Valois was invited speaker IEEE Canada Distinguished Lecture, University of Waterloo, Canada.
- Fabrice Valois was invited speaker Les Entretiens Jacques Cartier, Montréal, Canada.
- Fabrice Valois was invited speaker Mois des Cultures Numériques, Institut Français, Sfax, Tunisie.

10.1.5. Leadership within the Scientific Community

- Walid Bechkit is a nominated member in the scientific committee of the Fédération d'Informatique de Lyon (FR 2000 CNRS).
- Oana Iova is the scientific leader of the steering committee of the LPWAN Days (GDR RSD).
- Hervé Rivano is member of the steering committee of the ResCom axis of the RSD CNRS GdR.
- Hervé Rivano is member ot the steering committee of Ecole Urbaine de Lyon (PIA Institut Convergence), in charge of Smart and Learning Cities.
- Hervé Rivano was co-representative of the Labex IMU at the Smart City Expo World Congres (Barcelona).
- Fabrice Valois is a member of the Scientific Council of the LIMOS-UMR6158 laboratory, Clermont Ferrand.
- Fabrice Valois is member of the Scientific Council of the Labex IMU (Intelligence des Mondes Urbains).

10.1.6. Scientific Expertise

- Hervé Rivano is member of the Scientific Committee of the Digital League Regional Cluster.
- Fabrice Valois was a member in the recruitment committee of an Associate Professor in Computer Science at Université de Clermont Auvergne.
- Fabrice Valois was a member in two recruitment committees of Associate Professors in Computer Science at Université de Cergy-Pontoise.

10.1.7. Research Administration

- Walid Bechkit is responsible for seminar organization and scientific animation within the CITI laboratory.
- Khaled Boussetta is member of the steering committee of the MathStic federation at University Paris 13.
- Hervé Rivano is president of the CITI laboratory council.

- Razvan Stanica is the CITI laboratory correspondent with the Labex IMU.
- Razvan Stanica is member of the steering committee of the Volvo Chaire at INSA Lyon.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Licence: Walid Bechkit, IP Networks, 30h, L3, Telecom. Dpt. INSA Lyon.

Licence: Fabrice Valois, IP Networks, 36h, L3, Telecom. Dpt. INSA Lyon.

Licence: Fabrice Valois, Medium Access Control, 54h, L3, Telecom. Dpt. INSA Lyon.

Licence: Fabrice Valois, Basic networking, 20h, L3, IST / Telecom. Dpt. INSA Lyon (lectures given in english).

Licence: Oana Iova, Network and System Programming, 108h, L3, Telecom. Dpt. INSA Lyon.

Licence: Oana Iova, Introduction to research, 20h, L3, Telecom. Dpt. INSA Lyon.

Licence: Oana Iova, Smart city: networking challenges, 8h, L3, Smart Program, INSA Lyon (lectures given in english).

Licence: Oana Iova, Internet of connected things, 3h, L3, Innov Program, INSA Lyon (lectures given in english).

Licence: Hervé Rivano, Algorithms and programming, 165h, L1 - L2, INSA Lyon.

Licence: Hervé Rivano, Sensors data engineering project, 34h, L2, INSA Lyon.

Licence: Hervé Rivano, Programming robot control, 20h, L2, INSA Lyon.

Licence: Walid Bechkit, Introduction to wireless sensor networks, 50h, L2, INSA Lyon.

Master: Walid Bechkit, Performance evaluation of telecom networks, 100h, M1, Telecom. Dpt. INSA Lyon.

Master: Walid Bechkit, Cryptography and communication security, 30h, M1, Telecom. Dpt., INSA Lyon.

Master: Walid Bechkit, Wireless networks: architecture and security, 30h, M2, INSA Lyon.

Master: Master : Walid Bechkit, Network Acces Control, 6h, M2, Telecom. Dpt. INSA Lyon.

Master: Oana Iova, Network Routing Protocols, 66h, M1, Telecom. Dpt. INSA Lyon.

Master: Oana Iova, Long Range Networks, 10h , M2, Telecom. Dpt. INSA Lyon.

Master: Oana Iova, IoT technical project, 8h, M2, Telecom. Dpt. INSA Lyon.

Master: Hervé Rivano, Smart Cities and IoT, 44h, M2, Telecom. Dpt. INSA Lyon.

Master: Hervé Rivano, Smart Cities, Master Cities, Environment and Urbanism, University of Lyon.

Master: Razvan Stanica, Mobile Networks, 30h, M1, Telecom. Dpt. INSA Lyon.

Master: Razvan Stanica, Network Science, 10h, M2, Telecom. Dpt. INSA Lyon.

MOOC: Hervé Rivano, Razvan Stanica, Fabrice Valois, Connectez à Internet vos Objets Intelligents, production started in the context of the ANR Connect-IO project.

Walid Bechkit is in charge of the admission service of the Telecommunication department at INSA Lyon.

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.

Khaled Boussetta is the studies director of Apprenticeship Education Program Specialty in Computer Science and Network at Sup'Galilée Engineering School (University Paris 13).

Hervé Rivano is responsible for the coordination of all courses in the Smart Cities and IoT option at the INSA Lyon Telecommunications department.

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 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.

10.2.2. Supervision

PhD in progress: Abderrahman Ben Khalifa, Cognitive mechanisms for IoT networks, since 11/2016. Advisors: Hervé Rivano, Razvan Stanica.

PhD in progress : Rodrigue Domga Komguem, Autonomous WSN architectures for road traffic applications, since 11/2012. Advisors: Razvan Stanica, Maurice Tchuente (Univ. Yaoundé, Cameroun), Fabrice Valois.

PhD in progress: Mohamed Anis Fekih, Urban pollution using wireless sensor networks, since 11/2018. Advisors: Walid Bechkit, Hervé Rivano.

PhD in progress: Kawtar Lasri, Data collection and distributed spatial coordination in LPWAN networks, since 01/2019. Advisors: Oana Iova, Fabrice Valois.

PhD in progress: Ichrak Mokhtari, Spatio-temporal analysis of pollution data from low cost sensors, since 11/2019. Advisors: Walid Bechkit, Hervé Rivano.

PhD in progress: Mihai Popescu, Connectivity constrained mobility in fleets of robots, since 11/2015. Advisors: Olivier Simonin (Inria CHROMA), Anne Spalanzanni (Inria CHROMA), Fabrice Valois.

PhD in progress: Romain Pujol, Data collection in dynamic wireless networks, since 11/2018. Advisors: Razvan Stanica, Fabrice Valois.

PhD in progress: Solohaja Rabenjamnia, Data analysis of cellular trafic, since 11/2018. Advisors: Hervé Rivano, Razvan Stanica.

10.2.3. Juries

- Hervé Rivano was a reviewer in the following PhD defense committees:
  - G. Bu, Fiabilité, sécurité et vie privée dans les WBAN, LIP6, Sorbonne Université
  - B. Grozev, Conférences vidéos WebRTC à routage optimisé, Icube, Université de Strasbourg
- Hervé Rivano was a member in the following PhD defense committees:
  - M. Smache, La sécurité des réseaux déterministe de l'Internet industriel des objets (IIoT), CEA Leti, Mines Saint Etienne
  - H. Mazouzi, Algorithmes pour le déchargement de tâches sur serveurs de périphérie mobile, L2TI, Université de Paris Nord
- Razvan Stanica was a member in the following PhD defense committee:
  - M. M. Merah, Conception et réalisation d'un lien Light-Fidelity multi-utilisateur en intérieur, LISV, Université de Versailles Saint Quentin en Yvelines
- Fabrice Valois was a reviewer in the following PhD defense committee:
  - H. Mroue, Développement de réseaux radio d'objets connectés pour les Villes Intelligentes : améioration de la Qualité de Service du réseau LoRa, IETR, Université de Nantes
- Fabrice Valois was a member in the following PhD defense committees:

- R. T. Hermeto, Standard Improvements and Predictable Performance for Industrial Internet of Things in Indoor Deployments, ICube, Université de Strasbourg
- H. Chour, Full-Duplex Device-to-Device Communication for 5G Network, IETR, Centrale Supélec

10.3. Popularization

- Hervé Rivano, Atelier de recherche participative sur la mesure de la qualité de l'air, Ecole Urbaine de Lyon, France.
- Hervé Rivano, Développement et expérimentation du kit pédagogique *Ca va chauffer*, Ecole Jules Guesde, Villeurbanne, France.
- Hervé Rivano, Aterlier autour du kit pédagogique *Ca va chauffer*, Super Demain, Métropole de Lyon.

10.3.1. Articles and contents

- Hervé Rivano is co-author of the blog post *Représenter l'intangible : les défis de la visualisation des données numériques environnementales. Montrer la pollution de l'air, le cas d'Air To Go* https://medium.com/anthropocene2050/
- Hervé Rivano is organizer and moderator of the podcast *Quelle ville intelligente est possible ?*, https://www.sondekla.com/user/event/10011
- Hervé Rivano is moderator of the podcast *Anthropocène et outils numériques*, https://www.sondekla.com/user/event/9805

10.3.2. Interventions

- Walid Bechkit was invited speaker about *3M'Air Mesures citoyennes Mobiles et Modélisation: qualité de l'air et îlots de chaleur à Lyon*, Colloque National Capteurs et Sciences Participatives, Paris, 2019.
- Oana Iova, Hervé Rivano and Fabrice Valois was involved in *Les rêveries lumineuses de Léonard*, https://popsciences.universite-lyon.fr/agenda/les-reveries-lumineuses-de-leonard-fete-des-lumieres-2019/, contribution de l'Ecole Urbaine de Lyon pour l'Université de Lyon, Fête des Lumières, 2019.

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Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] A. BOUBRIMA. *Deployment and Scheduling of Wireless Sensor Networks for Air Pollution Monitoring*, Insa Lyon, March 2019, https://hal.inria.fr/tel-02446568

[2] R. STANICA. *From Networks to Data and Back Again : A Story of Wireless Networks in the 21st Century*, Institut National des Sciences Appliquées de Lyon, November 2019, Habilitation à diriger des recherches, https://hal.inria.fr/tel-02446174

Articles in International Peer-Reviewed Journals

[3] A. BOUBRIMA, W. BECHKIT, H. RIVANO. *On the Deployment of Wireless Sensor Networks for Air Quality Mapping: Optimization Models and Algorithms*, in "IEEE/ACM Transactions on Networking", August 2019, vol. 27, n° 4, pp. 1629-1642 [*DOI :* 10.1109/TNET.2019.2923737], https://hal.inria.fr/hal-02157476

[4] F. DELAINE, B. LEBENTAL, H. RIVANO. *In Situ Calibration Algorithms for Environmental Sensor Networks: a Review*, in "IEEE Sensors Journal", January 2019, vol. 19, n^o 15, pp. pp 5968 - 5978 [*DOI :* 10.1109/JSEN.2019.2910317], https://hal.archives-ouvertes.fr/hal-02174938

[5] R. DOMGA KOMGUEM, R. STANICA, M. TCHUENTÉ, F. VALOIS. *Ground Level Deployment of Wireless Sensor Networks: Experiments, Evaluation and Engineering Insight*, in "Sensors", July 2019, vol. 19, n^o 15, 3358 p. [*DOI :* 10.3390/S19153358], https://hal.sorbonne-universite.fr/hal-02290185

[6] R. DOMGA KOMGUEM, R. STANICA, M. TCHUENTÉ, F. VALOIS. *Sensor Deployment in Wireless Sensor Networks with Linear Topology using Virtual Node Concept*, in "Wireless Networks", November 2019, vol. 25, n^o 8, pp. 4947-4962 [*DOI :* 10.1007/S11276-019-02071-X], https://hal.inria.fr/hal-02354755

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[8] P. LEJOUX, A. FLIPO, N. ORTAR, N. OVTRACHT, S. SOUCHE-LECORVEC, R. STANICA. *Coworking, a Way to Achieve Sustainable Mobility? Designing an Interdisciplinary Research Project*, in "Sustainability", December 2019, vol. 11, n^o 24, 7161 p. [*DOI :* 10.3390/SU11247161], https://hal.archives-ouvertes.fr/hal-02419717

[9] J. OUEIS, V. CONAN, D. LAVAUX, H. RIVANO, R. STANICA, F. VALOIS. *Core Network Function Placement in Self-Deployable Mobile Networks*, in "Computer Communications", January 2019, vol. 133, pp. 12-23 [*DOI :* 10.1016/J.COMCOM.2018.10.009], https://hal.inria.fr/hal-01928552

Invited Conferences

[10] P. KATSIKOULI, M. FIORE, A. FURNO, R. STANICA. *Characterizing and Removing Oscillations in Mobile Phone Location Data*, in "WoWMoM 2019 - 20th IEEE International symposium on a World of Wireless, Mobile and Multimedia Networks", Washington DC, United States, IEEE, June 2019, pp. 1-9 [*DOI :* 10.1109/WOWMOM.2019.8793034], https://hal.inria.fr/hal-02110719

International Conferences with Proceedings

[11] A. DUQUE, A. DESPORTES, R. STANICA, H. RIVANO. *Performance Evaluation of LED-to-Camera Communications*, in "MSWiM 2019 - 22nd ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems", Miami Beach, United States, ACM, November 2019, pp. 135-142 [*DOI :* 10.1145/3345768.3355922], https://hal.inria.fr/hal-02270454

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Scientific Books (or Scientific Book chapters)

[18] A. BOUBRIMA, W. BECHKIT, H. RIVANO. *On the Optimization of WSN Deployment for Sensing Physical Phenomena: Applications to Urban Air Pollution Monitoring*, in "Mission-Oriented Sensor Networks and Systems: Art and Science", Studies in Systems, Decision and Control, Springer, 2019, vol. 163, pp. 99-145 [*DOI :* 10.1007/978-3-319-91146-5_4], https://hal.inria.fr/hal-02159770