Activity Report 2017

Team AGORA

ALGorithmes et Optimisation pour Réseaux Autonomes

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Networks and Telecommunications

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Creation of the Team: 2017 January 01

Keywords:

Computer Science and Digital Science:

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A1.2.5. - Internet of things
A1.2.6. - Sensor networks
A7.1. - Algorithms
A8.2. - Optimization

Other Research Topics and Application Domains:

B3.4.3. - Pollution
B6.2.2. - Radio technology
B6.2.4. - Optic technology
B6.4. - Internet of things
B8.1.2. - Sensor networks for smart buildings
B8.2. - Connected city

1. Personnel

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2. Overall Objectives

2.1. Overall Objectives

The Agora team is positioned in Inria's 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 and 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 networks 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 breakthrough in micro and nano technologies are indeed enabling dense deployments of low-cost sensing devices that produce reliable enough measurements of physical phenomenon 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 is 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 of 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 consider 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 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 Air RhoneAlpes.

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 work 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 rises: how to cope with a dense set of M2M low bit rate traffics from energy and computing power constrained devices while classic cellular infrastructure 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 through device heterogeneity in terms of available communication technologies (not all devices have a long-range connection, or its 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 leading by compressive sensing solutions. Our objective is to get rid of the assumption of the knowledge 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 dynamic behind several key applications. The goal is to provide a taxonomy of the applications according to the data properties in terms of stationarity, dynamic, 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. In coherence, 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

- Hervé Rivano was appointed as a Full Professor at INSA Lyon, starting from September 2017.
- Oana Iova was appointed as an Associate Professor at INSA Lyon and joined the team, starting from September 2017.

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 Pis, 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 and Razvan Stanica
- 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/

7. New Results

7.1. Wireless network deployment

Participants: Ahmed Boubrima, Rodrigue Domga Komguem, Leo Le Taro, Jad Oueis, Walid Bechkit, Khaled Boussetta, Hervé Rivano, Razvan Stanica, Fabrice Valois.

7.1.1. Deployment of Wireless Sensor Networks for Pollution Monitoring

Air pollution has become a major issue of modern megalopolis because of industrial emissions and increasing urbanization along with traffic jams and heating/cooling of buildings. Monitoring urban air quality is therefore required by municipalities and by the civil society. Current monitoring systems rely on reference sensing stations that are precise but massive, costly and therefore seldom. In our work, we focus on an alternative or complementary approach, with a network of low cost and autonomic wireless sensors, aiming at a finer spatiotemporal granularity of sensing. Generic deployment models of the literature are not adapted to the stochastic nature of pollution sensing.

In this sense, in [2], our main contribution is to design integer linear programming models that compute sensor deployments capturing both the coverage of pollution under time-varying weather conditions and the connectivity of the infrastructure. We evaluate our deployment models on a real data set of Greater London. We analyze the performance of the proposed models and show that our joint coverage and connectivity formulation is tight and compact, with a reasonable enough execution time. We also conduct extensive simulations to derive engineering insights for effective deployments of air pollution sensors in an urban environment.

Unlike most of the existing methods, which rely on simple and generic detection models, our approach is based on the spatial analysis of pollution data, allowing to take into account the nature of the pollution phenomenon. As proof of concept, we apply our approach on real world data, namely the Paris pollution data, which was recorded in March 2014 [7]. In this paper, we consider citywide wireless sensor networks and tackle the minimum-cost node positioning issue for air pollution monitoring. We propose an efficient approach that aims to find optimal sensors and sinks locations while ensuring air pollution coverage and network connectivity.

Mobile wireless sensor networks can also be used for monitoring air pollution, where the aim is usually to generate accurate pollution maps in real time. The generation of pollution maps can be performed using either sensor measurements or physical models which simulate the phenomenon of pollution dispersion. The combination of these two information sources, known as data assimilation, makes it possible to better monitor air pollution by correcting the simulations of physical models while relying on sensor measurements. The quality of data assimilation mainly depends on the number of measurements and their locations. A careful deployment of nodes is therefore necessary in order to get better pollution maps. In an ongoing work [30], we tackle the placement problem of pollution sensors and design a mixed integer programming model allowing to maximize the assimilation quality while ensuring the connectivity of the network. We perform some simulations on a dataset of the city of Lyon in order to show the effectiveness of our model regarding the quality of pollution coverage.

For an air pollution monitoring system deployment to be relevant relative to urban air quality aspects, we are concerned with maintaining the system properties over time. Indeed, one of the major drawbacks of cheap sensors is their drift: chemical properties degrade over time and alter the measurement accuracy. We challenge this issue by designing distributed, online recalibration procedures. In [16], we present a simulation framework modelling a mobile wireless sensor network (WSN) and we assess the system's measurement confidence using trust propagation paradigms. As WSN calibrations translate to information exchange between sensors, we also study means of limiting the number of such transmissions by skipping the calibrations deemed least profitable to the system.

7.1.2. Wireless Sensor Networks with Linear Topology

In wireless sensor networks with linear topology, knowing the physical order in which nodes are deployed is useful not only for the target application, but also to some network services, like routing or data aggregation. Considering the limited resources of sensor nodes, the design of autonomous protocols to find this order is a challenging topic.

In [9], we propose a distributed and iterative centroid-based algorithm to address this problem. At each iteration, the algorithm selects two virtual anchors and finds the order of a subset of nodes, placed between these two anchors. The proposed algorithm requires local node connectivity knowledge and the identifier of the first sensor node of the network, which is the only manually configured parameter. This solution, scalable and lightweight from the deployment and maintenance point of view, is shown to be robust to connectivity degradation, correctly ordering more than 95% of the nodes, even under very low connectivity conditions.

7.1.3. Function Placement in Public Safety Networks

In response to the growing demand in the public safety community for broadband communication systems, LTE is currently being adopted as the base technology for next generation public safety networks. In parallel, notable efforts are being made by the 3GPP to enhance the LTE standard in order to offer public safety oriented services. In the recent Release 13, the Isolated E-UTRAN Operation for Public Safety (IOPS) concept was introduced. IOPS aims at maintaining a level of communication between public safety users, offering them local mission-critical services even when the backhaul connectivity to the core network is not fully functional. Isolated operation is usually needed in mission-critical situations, when the infrastructure is damaged or completely destroyed, and in out of coverage areas. In [6], we present a detailed technical overview on the IOPS specifications, and then identify several research prospects and development perspectives opened up by IOPS.

An isolated base station is a base station having no connection to a traditional core network. To provide services to users, an isolated base station is co-located with an entity providing the same functionalities as the traditional core network, referred to as Local EPC. In order to cover wider areas, several base stations are interconnected, forming a network that should be served by a single Local EPC. In [20], [24], we tackle the Local EPC placement problem in the network, to determine with which of the base stations the Local EPC must be co-located. We propose a novel centrality metric, flow centrality, which measures the capacity of a node to receive the total amount of flows in the network. We show that co-locating the Local EPC with the base station having the maximum flow centrality maximizes the total amount of traffic the Local EPC can receive from all base stations, under certain capacity and load distribution constraints. We compare the flow centrality to other state of the art centrality metrics, and emphasize its advantages.

7.1.4. User Association in Public Safety Oriented Mobile Networks

In many disaster scenarios, communication infrastructure fails to provide network services for both civilians and first responders. One solution is to have rapidly deployable mobile networks formed by interconnected base stations, that are easy to move, deploy, and configure. Such public safety-oriented networks are different from classical mobile networks in terms of scale, deployment, and architecture.

In this context, we revisit the user association problem [21], for two main reasons. First, the backhaul, formed by the links interconnecting the base stations, must be accounted for when deciding on the association, since it may present a bottleneck with its limited bandwidth. Second, the mission-critical nature of the traffic imposes strict guaranteed bit rate constraints, that must be respected when associating users. Therefore, we propose a network-aware optimal association that minimizes the bandwidth consumption on the backhaul, while still respecting the stringent performance requirements.

7.2. Wireless data collection

Participants: Yosra Bahri Zguira, Alexis Duque, Junaid Ahmed Khan, Abdoul-Aziz Mbacké, Romain Pujol, Hervé Rivano, Razvan Stanica, Fabrice Valois.

7.2.1. Smart Parking Systems

Considering the increase of urban population and traffic congestion, smart parking is always a strategic issue to work on, not only in the research field but also from economic interests. Thanks to information and communication technology evolution, drivers can more efficiently find satisfying parking spaces with smart parking services. The existing and ongoing works on smart parking are complicated and transdisciplinary. While deploying a smart parking system, cities, as well as urban engineers, need to spend a very long time to survey and inspect all the possibilities. Moreover, many varied works involve multiple disciplines, which are closely linked and inseparable.

To give a clear overview, we introduce a smart parking ecosystem and propose a comprehensive and thoughtful classification by identifying their functionalities and problematic focuses [5]. We go through the literature over the period of 2000-2016 on parking solutions as they were applied to smart parking development and evolution, and propose three macro-themes: information collection, system deployment, and service dissemination. In each macro-theme, we explain and synthesize the main methodologies used in the existing works and summarize their common goals and visions to solve current parking difficulties. Lastly, we give our engineering insights and show some challenges and open issues.

7.2.2. Data Offloading

Mobile users in an urban environment access content on the Internet from different locations. It is challenging for the current service providers to cope with the increasing content demand from a large number of collocated mobile users. In-network caching to offload content at nodes closer to users alleviates the issue, though efficient cache management is required to find out who should cache what, when and where in an urban environment, given nodes limited computing, communication and caching resources. To address this [14], we first define a novel relation between content popularity and availability in the network and investigate a node eligibility to cache content based on its urban reachability. We then allow nodes to self-organize into mobile fogs to increase the distributed cache and maximize content availability in a cost-effective manner. However, to cater rational nodes, we propose a coalition game for the nodes to offer a maximum virtual cache assuming a monetary reward is paid to them by the service/content provider. Nodes are allowed to merge into different spatio-temporal coalitions in order to increase the distributed cache size at the network edge. Results obtained through simulations using realistic urban mobility trace validate the performance of our caching system showing a ratio of 60 - 85% of cache hits compared to the 30 - 40% obtained by the existing schemes and 10% in case of no coalition.

Another option for data offloading is represented by vehicular traffic. With over 300 billion vehicle trips made in the USA and 64 billion in France per year, network operators have the opportunity to utilize the existing road and highway network as an alternative data network to offload large amounts of delay-tolerant traffic. To enable the road network as a large-capacity transmission system, we exploit the existing mobility of vehicles equipped with wireless and storage capacities together with a collection of offloading spots [1]. An offloading spot is a data storage equipment located where vehicles usually park. Data is transloaded from a conventional data network to the closest offloading spot and then shipped by vehicles along their line of travel. The subsequent offloading spots act as data relay boxes where vehicles can drop off data for later pickups by other vehicles, depending on their direction of travel. The main challenges of this offloading system are how to compute the road path matching the performance requirements of a data transfer and how to configure the sequence of offloading spots involved in the transfer. We propose a scalable and adaptive centralized architecture built on SDN that maximizes the utilization of the flow of vehicles connecting consecutive offloading spots. We simulate the performance of our system using real roads traffic counts for France. Results show that the centralized controlled offloading architecture can achieve an efficient and fair allocation of concurrent data transfers between major cities in France.

7.2.3. Hybrid Short/Long Range Networks

Despite the success of dedicated IoT networks, such as Sigfox or LoRa, several use cases can not be accommodated by these new technologies, mainly because of capacity constraints. For example, mobile sensing and proximity-based applications require smart devices to find other nodes in vicinity, though it is challenging for a device to find neighbors in an energy efficient manner, while also running on low duty cycles.

Neighbor discovery schemes allow nodes to follow a schedule to become active and send beacons or listen for other active nodes in order to discover each other with a bounded latency. However, a trade-off exists between the energy consumption and the time a node takes to discover neighbors using a given activity schedule. Moreover, energy consumption is not the only bottleneck, as theoretically perfect schedules can result in discovery failures in a real environment. In [12], we provide an in-depth study on neighbor discovery, by first defining the relation between energy efficiency, discovery latency and the fraction of discovered neighbors. We evaluate existing mechanisms using extensive simulations for up to 100 nodes and testbed implementations for up to 15 nodes, with no synchronization between nodes and using duty cycles as low as 1% and 5%. Moreover, the literature assumes that multiple nodes active simultaneously always result in neighbor discovery, which is not true in practice as this can lead to collisions between the transmitted messages. Our findings reveal such scalability issues in existing schemes, where discovery fails because of collisions between beacons from multiple nodes active at the same time. Therefore, we show that energy efficient discovery schemes do not necessarily result in successful discovery of all neighbors, even when the activity schedules are computed in a deterministic manner.

A second use-case requiring a combination of long range and short range communications is related to intelligent transportation systems. As a matter of fact, communication is essential to the coordination of public transport systems. Nowadays, cities are facing an increasing number of bikes used by citizens therefore the need of monitoring and managing their traffic becomes crucial. Public bike sharing system has been introduced as an urban transportation system that can collect data from mobile devices. In this context, we introduce IoB-DTN [29], a protocol based on the Delay/Disruption Tolerant Network (DTN) paradigm adapted for an IoT-like applications running on bike sharing system based sensor network. We present simulation results obtained by evaluating the Binary Spray and Wait inspired variant of IoB-DTN with four buffer management policies and by comparing three variants of IoB-DTN by varying the number of packet copies sprayed in the network.

7.2.4. Visible Light Communications in IoT Networks

With the increasing consumer demand for smart objects, Visible Light Communications (VLC), and especially LED-to-Camera communication, appears as a low-cost alternative to radio to make any conventional device smart. Since LEDs are already on most electronics devices, that is achieved at the cost of negligible hardware modifications. However, as these LEDs are very different from the widely studied ceiling ones, several challenges need to be addressed to make this happen. In our work [31], we propose a line of sight bi-directional communication system between an ordinary LED and an off-the-shelf smartphone. We designed a cheap multi sensors device as a proof of concept of a near communication module for the IoT.

Among the issues we observed experimenting with this platform, we note the constrained physical layer data unit (PHY-SDU) length that complicates the use of coding strategies to cope with bits or packets erasure. To break this limitation, we present SeedLight [8], a coding scheme designed to face the inherent packet losses and enhance line-of-sight LED-to-Camera communication goodput. SeedLight leverages random linear coding to provide an efficient redundancy mechanism that works even on PHY-SDU of tens of bits. The key idea of SeedLight is to reduce the code overhead by replacing the usual coding coefficients by a seed. Since this work addresses IoT devices with low computational resources, SeedLight encoding algorithm complexity remains low. We develop an implementation of SeedLight on a low-cost MCU and a smartphone to evaluate both the communication and algorithmic performances. Experimental results show that SeedLight introduces a negligible overhead and can be implemented even on the cheapest MCU, such as the ones used in many IoT devices. The achievable goodput can be up to 2.5kbps, while the gain compared to a trivial retransmissions scheme is up to 100%.

To ease the evaluation of VLC systems, we present CamComSim [28], the first simulator for development and rapid prototyping of LED-to-Camera communication systems. Our event driven simulator relies on a standalone Java application that is easily extensible through a set of interfaces. A range of low and high-level parameters, such as the camera characteristics, the PHY-SDU size, or the redundancy mechanism can be chosen. CamComSim uses empirically validated models for the LED-to-Camera channel and the broadcast protocols, configurable with a finely grained precision. To validate CamComSim implementation and accuracy, we use the previously discussed testbed, based on a color LED and a smartphone, and compare the performance reached by the testbed with the results given by our simulator. We illustrate with a real use case the full usage of CamComSim, tuning a broadcast protocol that implements the transmission of 1 kbyte of information. The results highlight that our simulator is very precise and predicts the performance of a real LED-to-Camera system with less than 10% of error in most cases.

7.2.5. Data Collection with RFID Devices

The popularization of Radio Frequency Identification (RFID) systems has conducted to large deployments of RFID solutions in various areas under different criteria. However, such deployments, specially in dense environments, can be subject to RFID collisions which in turn affect the quality of readings. In [17], [18], we propose two distributed and efficient solutions for dense mobile deployments of RFID systems. mDEFAR is an adaptation of a previous work highly performing in terms of collisions reduction, efficiency and fairness in dense static deployments. CORA is more of a locally mutual solution where each reader relies on its neighborhood to enable itself or not. Using a beaconing mechanism, each reader is able to identify potential (non-)colliding neighbors in a running frame and as such chooses to read or not. Performance evaluation shows high performance in terms of coverage delay for both proposals quickly achieving 100% coverage depending on the considered use case while always maintaining consistent efficiency levels above 70%. Compared to GDRA, our solutions proved to be better suited for highly dense and mobile environments, offering both higher throughput and efficiency. The results reveal that depending on the application considered, choosing either mDEFAR or CORA helps improve efficiency and coverage delay.

RFID solutions encounter two main issues: the first one is inherent to the technology itself which is readers collisions, the second one being the gathering of read data up to a base station, potentially in a multihop fashion. While the first one has been a main research subject in the late years, the second one has not been investigated for the sole purpose of RFID, but rather for wireless adhoc networks. This multihop tag information collection must be done in regards of the application requirements but it should also care for the deployment strategy of readers to take advantage of their relative positions, coverage, reading activity and deployment density to avoid interfering between tag reading and data forwarding. To the best of our knowledge, the issue for a joint scheduling between tag reading and forwarding has never been investigated so far in the literature, although important. In [17], we propose two new distributed, cross-layer solutions meant for the reduction of collisions and better efficiency of the RFID system, but also serving as a routing solution towards a base station. Simulations show high levels of throughput while not lowering on the fairness on medium access staying above 85% in the highest deployment density with up to 500 readers, also providing a 90% increase in data rate.

7.3. Network data exploitation

Participants: Panagiota Katsikouli, Elli Zavou, Stéphane D'Alu, Hervé Rivano, Razvan Stanica.

7.3.1. Spatio-temporal Characterization of Mobile Data Traffic

Mobile traffic data collected by network operators is a rich source of information about human habits, and its analysis provides insights relevant to many fields, including urbanism, transportation, sociology and networking. Urban landscapes present a variety of socio-topological environments that are associated to diverse human activities. As the latter affect the way individuals connect with each other, a bound exists between the urban tissue and the mobile communication demand. In [3], we investigate the heterogeneous patterns emerging in the mobile communication activity recorded within metropolitan regions. To that end, we introduce an original technique to identify classes of mobile traffic signatures that are distinctive of different urban fabrics. Our proposed technique outperforms previous approaches when confronted to ground-truth information, and allows characterizing the mobile demand in greater detail than that attained in the literature to date. We apply our technique to extensive real-world data collected by major mobile operators in ten cities. Results unveil the diversity of baseline communication activities across countries, but also evidence the existence of a number of mobile traffic signatures that are common to all studied areas and specific to particular land uses.

Similarly to mobile phone data, GPS traces of vehicles convey information on transportation demand and human activities that can be related to the land use of the neighborhood where they take place. In [10], we investigate the land use patterns that emerge when studying simultaneously GPS traces of probe vehicles and mobile phone data collected by network providers. To this end, we extend previous definitions of mobile phone traffic signatures for land use detection, so as to incorporate additional information on human presence and mobility conveyed by GPS traces of vehicles. Leveraging these extended signatures, we exploit an unsupervised learning technique to identify classes of signatures that are distinctive of different land use. We apply our technique to real-world data collected in French and Italian cities. Results unveil the existence of signatures that are common to all studied areas and specific to particular land uses. The combined use of mobile phone data and GPS traces outperforms previous approaches when confronted to ground-truth information, and allows characterizing land use in greater detail than in the literature to date.

The spatial and temporal profiles of mobile phone traffic can be studied simultaneously. In [11], we present an original approach to infer both spatial and temporal structures hidden in the mobile demand, via a first-time tailoring of Exploratory Factor Analysis (EFA) techniques to the context of mobile traffic datasets. Casting our approach to the time or space dimensions of such datasets allows solving different problems in mobile traffic analysis, i.e., network activity profiling and land use detection, respectively. Tests with real-world mobile traffic datasets show that, in both its variants above, the proposed approach (i) yields results whose quality matches or exceeds that of state-of-the-art solutions, and (ii) provides additional joint spatiotemporal knowledge that is critical to result interpretation.

7.3.2. Using Mobile Phone Data in Cognitive Networking

In the next few years, mobile networks will undergo significant evolutions in order to accommodate the ever-growing load generated by increasingly pervasive smartphones and connected objects. Among those evolutions, cognitive networking upholds a more dynamic management of network resources that adapts to the significant spatiotemporal fluctuations of the mobile demand. Cognitive networking techniques root in the capability of mining large amounts of mobile traffic data collected in the network, so as to understand the current resource utilization in an automated manner. In [4], we take a first step towards cellular cognitive networks by proposing a framework that analyzes mobile operator data, builds profiles of the typical demand, and identifies unusual situations in network-wide usages. We evaluate our framework on two real-world mobile traffic datasets, and show how it extracts from these a limited number of meaningful mobile demand profiles. In addition, the proposed framework singles out a large number of outlying behaviors in both case studies, which are mapped to social events or technical issues in the network.

7.3.3. Study of Wi-Fi Localization from Crowdsourced Datasets

The wide adoption of mobile devices has created unprecedented opportunities to collect mobility traces and make them available for the research community to conduct interdisciplinary research. However, mobility traces available in the public domain are usually restricted to traces resulting from a single sensor (e.g., either GPS, GSM or WiFi). In [26], we present the PRIVA'MOV dataset, a novel dataset collected in the city of Lyon, France on which user mobility has been collected using multiple sensors. More precisely, this dataset contains mobility traces of about 100 persons including university students, staff and their family members over 15 months collected through the GPS, WiFi, GSM, and accelerometer sensors. We provide both a quantitative and a preliminary qualitative analysis of this dataset. Specifically, we report the number of visited points of interests, GSM antennas and WiFi hotspots and their distribution across the various users. We finally analyse the uniqueness of human mobility by considering the various sensors.

Thanks to this collected data, it is possible to combine information from several probes. A very common use case is the collection of network scans with location to help the localisation feature of these devices. Nevertheless, most users are not aware of this spying. The collected data might represent infringements of privacy. One possible solution to keep gathering these data while maintaining privacy would consist in device-to-device communications in order to break the links between data and users. In [22], we propose an approach to test the feasibility of such a system. We collected data from mobile users to combine location and network scans data. With this data, we test the accuracy level we can reach while using Wi-Fi localisation. We analyse how a new measure should be pushed and how many scans should be realised to provide location-based Wi-Fi. We analyse the minimal dataset to cover the set of locations covered by users and prove that a multiuser gathering system can benefit the users.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

- We have contracted bilateral cooperation with Rtone, an SME focusing on the connected objects area. This collaboration is associated with the CIFRE PhD grant for Alexis Duque, on the subject of Visible Light Communication.
- We have contracted bilateral cooperation with industrial and academic partners in the context of the PSPC Fed4PMR project (2015-2018). 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 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. The PhD thesis work of Alexis Duque and Amjed Belkhiri are also contributing in this structure.
- 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

- Labex IMU UrPolSens 10/2015-10/2018
  Participants: Amjed Belkhiri, Ahmed Boubrima, Leo Le Taro, Walid Bechkit, Hervé Rivano
  The partners in this project are Ifsttar, LMFA, EVS, TUBA, and Air Rhone-Alpes, with Inria Agora leading the project. UrPolSens deals with the monitoring of air pollution using low-cost sensors interconnected by a wireless networks. Although they are less accurate than the high-end sensors used today, low-cost autonomous air quality sensors allow to achieve a denser spatial granularity and, hopefully, a better monitoring of air pollution. The main objectives of this project are to improve the modeling of air pollution dispersion; propose efficient models to optimize the deployment the sensors while considering the pollution dispersion and the impact of urban environment on communications; deploy a small-scale network for pollution monitoring as a proof of concept; compare the measured and estimated levels of exposure; study the spatial disparities in exposure between urban areas.
- ARC6 “Robot fleet mobility under communication constraints” 10/2016-09/2019
  Participants: 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 patroll autonomously.The other partners in this project are University of Grenoble and Viameca.

- Labex IMU Veleval 10/2017-10/2019
  Participants: Hervé Rivano
  This pluridisciplinary project is leaded by the LAET and gathers researchers from EVS, LIRIS, LLSETI and CITI. The goal 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 informations 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 ABCD 10/2013-04/2017.
  Participants: Razvan Stanica
  The partners in the ANR ABCD project are: Orange Labs, Ucopia, Inria Agora, UPMC LIP6 PHARE, Telecom ParisTech. The objective of ABCD is to characterize large-scale user mobility and content consumption in urban areas via mobile data mining, so as to achieve efficient deployment and management of cloud resources via virtual machines. Our contribution in the project consists on the characterization of human mobility and service consumption at a city scale, and the design of appropriate resource allocation techniques at the cellular network level.
- ANR IDEFIX 10/2013-04/2017.
  Participants: Soukaina Cherkaoui, Hervé Rivano, Fabrice Valois
  The partners in the ANR IDEFIX project are: Orange Labs, Alcatel Lucent - Bell Labs, Telecom Paris Tech, Inria Agora, Socrate and Dyogene.

9.2.2. DGA

- DGA CLOTHO 10/2016-03/2018.
  Particpants: Junaid Khan, Romain Pujol, Razvan Stanica, Fabrice Valois
  The partners in the DGA CLOTHO project are Traqueur and Sigfox. The objective of the project is to reduce the energy consumption of the device tracking functionality, by taking profit of short-range communications between the tracked objects.

9.2.3. PIA

- PIA ADAGE 07/2016-06/2018.
  Particpants: Elli Zavou, Razvan Stanica
  The partners in the PIA ADAGE project are Orange, LAAS-CNRS and Inria Privatics. The objective of the ADAGE project is to design and evaluate anonymization algorithms for the specific case of mobile traffic data. Our role in the project is focused on evaluating whether the anonymized data is still usable for adaptive networking mechanisms.

9.2.4. Pôle ResCom

- Ongoing participation (since 2006)
  Communication networks, working groups of GDR ASR/RSD, CNRS (http://rescom.inrialpes.fr).
  Hervé Rivano is member of the scientific committee of ResCom.

9.2.5. EquipEx

- SenseCity
  We have coordinated the participation of several Inria teams to the SenseCity EquipEx. Within the SenseCity project, several small reproduction 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 tests 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 build, the information system is being finalized and the equipment will be inaugurated in April 2018.

9.2.6. Inria Project lab

- CityLab
  Agora is involved in the CityLab Inria Project Lab lead by Valérie Issarny. Within this project, Hervé Rivano co-advises, with Nathalie Mitton (FUN team, Inria Lille-Nord-Europe), the PhD thesis of Abdoul Aziz Mbacke on "Data gathering in sensor and passive RFID with energy harvesting for urban infrastructure monitoring".

9.3. International Initiatives

9.3.1. Inria International Partners

9.3.1.1. Informal International Partners

- **University of Waterloo, ON, Canada**. Joint publications and visits to/from the group of Prof. Catherine Rosenberg.
- **CNR-IEIIT, Turin, Italy**. Joint publications and projects with Dr. Marco Fiore.
- **IMDEA Networks, Madrid, Spain**. Collaboration around the OpenVLC platform with the group of Dr. Domenico Giustiniano.

9.3.2. Participation in Other International Programs

9.3.2.1. PHC Campus France

- **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.

9.4. International Research Visitors

9.4.1. Visits of International Scientists

- Abdelmalik Bachir, Professor, Biskra University, Algeria: invited professor at INSA Lyon (Spring semester, 2017).
- Ramona Marfievici, Senior Researcher, Cork University of Technology, Ireland: visiting professor (one week, November 2017).

9.4.2. Visits to International Teams

9.4.2.1. Research Stays Abroad

- Jad Oueis visited the group of Prof. Catherine Rosenberg, at University of Waterloo, ON, Canada (3 months, Sep-Dec 2017).
- Mihai Popescu visited the group of Prof. Gabriela Czibula, at University of Cluj-Napoca, Romania (3 periods of 1 month duration: April, July and November 2017).
- Razvan Stanica visited the group of Prof. Catherine Rosenberg, at University of Waterloo, ON, Canada (1 month, Sep-Oct 2017).

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. General Chair, Scientific Chair

- Razvan Stanica was general co-chair of the 1st International Workshop on Data Analytics for Mobile Networking, DAMN! 2017, held together with IEEE PerCom in Kona, Hawaii, in March 2017.
- Fabrice Valois was general co-chair of the 2nd French National Conference CoRes 2017 (Rencontres Francophones sur la Conception de Protocoles, l'Evaluation de Performance et l'Expérimentation des Réseaux de Communication), May 2017, Quiberon, France.

10.1.1.2. Member of the Organizing Committees

- Walid Bechkit and Razvan Stanica organized the 1st French National Workshop on Smart Cities Communications and Networking, in Sophia Antipolis, in January 2017.

10.1.2. Scientific Events Selection

10.1.2.1. Member of the Conference Program Committees

- Walid Bechkit was in the TPC of IEEE ICC and MobiSPC.
- Khaled Boussetta was in the TPC of the following conferences: IEEE CCNC, IEEE GlobeCom, GIIS, IEEE ICC, Med-Hoc-Net, IEEE VTC Fall, IFIP Wireless Days.
- Oana Iova was in the TPC of the following conferences: FailSafe, IEEE GlobalSIP, Grace Hopper Conference, AlgoTel.
- Razvan Stanica was in the TPC of the following conferences: IEEE ICC, IEEE GlobeCom, IEEE CCNC, IEEE WCNC, IEEE PIMRC, IEEE VTC Spring/Fall, IEEE ISC2.
- Fabrice Valois was in the TPC of the following conferences: IEEE GlobeCom, WiSARN, IEEE IWCMC, IEEE PIMRC, IEEE ICT, IEEE ISC.

10.1.2.2. Reviewer

- Walid Bechkit was a reviewer for IEEE IWCMC.
- Oana Iova was a reviewer for the following conferences: IEEE WCNC, IEEE ICC.

10.1.3. Journal

10.1.3.1. Reviewer - Reviewing Activities

- Walid Bechkit was a reviewer for IEEE Transactions on Parallel and Distributed Systems.
- Oana Iova was a reviewer for the following journals: ACM Transactions on Sensor Networks, IEEE Access, Elsevier Ad Hoc Networks, Elsevier Future Generation Computer Systems, MDPI Sensors, Springer International Journal of Wireless Information Networks.
- Razvan Stanica was a reviewer for the following journals: IEEE Transactions on Mobile Computing, IEEE Journal on Selected Areas in Communications, IEEE Communications Magazine, IEEE Communications Letters, IEEE Transactions on Intelligent Transportation Systems, Elsevier Computer Networks, Springer Wireless Networks, IEEE Access, IET Intelligent Transport Systems.

10.1.4. Invited Talks

- Razvan Stanica was an invited speaker at the School of Informatics at the University of Edinburgh, Scotland, UK (Oct. 2017).

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 awards co-chair for Networking Networking Women (N2Women) since 2016, an ACM SIGMOBILE program whose goal is to foster connections among the under-represented women in computer networking and related research fields.
- Hervé Rivano is member of the steering committee of the ResCom axis of the RSD CNRS GdR.
- Hervé Rivano is a member of the Scientific Council of TUBA Lyon.
- Fabrice Valois is a member of the Scientific Council of the LIMOS-UMR6158 laboratory, Clermont Ferrand.
- Fabrice Valois is member of the Scientifc Council of the Labex IMU (Intelligence des Mondes Urbains).
- Fabrice Valois is in the steering committee of the Féderation d'Information de Lyon (FR 2000 CNRS).

10.1.6. Scientific Expertise

- Hervé Rivano gave expertise on JORISS international projects.
- Hervé Rivano is member of the Metropole de Lyon [R] Challenge board of experts.
- Hervé Rivano is member of the Scientific Committee of the Digital League Regional Cluster.
- Razvan Stanica was a member in the recruitment committee of an Associate Professor in Computer Science at INSA Lyon.
- Fabrice Valois was a member in the recruitment committee of a Full Professor in Computer Science at INSA Lyon.
- Fabrice Valois was a member in the recruitment committee of an Associate Professor in Computer Science at INSA Lyon.

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 member of the Administration Council of the EquipEx Sense City as representative of Inria.
- Hervé Rivano is member in 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.
- Fabrice Valois was director of the CITI research laboratory of INSA Lyon until Oct. 2017.
- Fabrice Valois is in the steering committee of the SPIE INSA Lyon IoT Chaire.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Licence : Walid Bechkit, Fundamentals of wireless sensor networks, 60h, L2, INSA Lyon.

Licence : Walid Bechkit, IP Networks, 40h, L3, Telecom. Dpt. INSA Lyon.

Licence : Oana Iova, IP Networks, 2h, L3, Telecom. Dpt. INSA Lyon.

Licence : Hervé Rivano, IP Networks, 8h, L3, Telecom. Dpt. INSA Lyon.

Licence : Hervé Rivano, DB, Algorithms and programming, 79h, L1 - L2, INSA Lyon.

Licence : Hervé Rivano, Discovering digital tools, 21h, L1, INSA Lyon.

Licence : Razvan Stanica, Network Programming, 90h, L3, Telecom. Dpt. INSA Lyon.

Licence : Fabrice Valois, IP Networks, 100h, L3, Telecom. Dpt. INSA Lyon.

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

Master : Walid Bechkit, Network architectures, protocols and services, 12h, M1, Telecom. Dpt. INSA Lyon.

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

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

Master : Oana Iova, Network architectures, protocols and services, 20h, M1, INSA Lyon.

Master : Hervé Rivano, Smart Cities, 2h, M1-M2, Master Geography Lyon St Etienne.

Master : Hervé Rivano, Smart Cities, 4h, M2, Polytech Perpignan.

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

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

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

Master : Fabrice Valois, Mobile Networks, 30h, M1, Telecom. Dpt. INSA Lyon.

Master : Fabrice Valois, Wireless Sensor Networks, 6h, M2, University of Grenoble.

MOOC : Hervé Rivano, Smart Cities, 3rd season of the french version and production of the english version.

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.

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.

Herve´ Rivano is responsible for the coordination of the 1st cycle of INSA Lyon and the DSI administration.

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 responsible of the networking teaching team in the Telecommunications department at INSA Lyon, coordinating all the courses in the networking domain.

Fabrice Valois and Walid Bechkit are elected members of the Telecommunications Department Council at INSA Lyon.

10.2.2. Supervision

PhD in progress : Yosra Bahri Zguira, DTN for IoT, since 05/2015. Advisors: Aref Meddeb (Univ. Sousse, Tunisia), Hervé Rivano.

PhD in progress : Amjed Belkhiri, Optimisation of wireless sensor networks mobility for a better characterization of atmospheric pollution, since 10/2017. Advisors: Walid Bechkit, Hervé Rivano.

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

PhD in progress: Ahmed Boubrima, Optimal deployment of wireless sensor networks for air pollution monitoring, since 10/2015. Advisors: Walid Bechkit, Hervé Rivano.

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 : Alexis Duque, Use of visible light communication in a smart city context, since 10/2015. Advisors: Hervé Rivano, Razvan Stanica.

PhD in progress: Abdul Aziz Mbacke, Data gathering in sensor and passive RFID with energy harvesting for urban infrastructure monitoring, since 10/2016. Advisors: Nathalie Mitton (FUN team), Hervé Rivano.

PhD in progress: Jad Oueis, Self organization in professional mobile radio networks, since 10/2015. Advisors: Razvan Stanica, Fabrice Valois.

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.

10.2.3. Juries

- Khaled Boussetta was a member in the following PhD defense committees:
  - R. Sorokin, Video Conference based on Enterprise Desktop Grid, Telecom ParisTech, 2017
  - A. Aissioui, The Path towards Future Mobile Service Architectures: from Follow Me Cloud (FMC) to Follow Me edge Cloud (FMeC), University Of Versailles, 2017.
- Hervé Rivano was a reviewer in the following PhD defense committees:
  - V. Toldov, Adaptative MAC layers for interference limited WSN, University of Lille 1, 01/2017.
  - R.B. Messaoud, Towards efficient mobile crowd sensing assignment and uploading schemes, University of La Rochelle, 09/2017.
  - B. Mbarek, Efficient Authentication Approaches for Wireless Sensor Networks, University of Tunis El-Manar, 09/2017.
  - M.A. Messous, UAVs network: Towards an optimal exploration and an efficient computation, University of Burgundy, 10/2017.
  - C. Lopez, Dynamic modeling of traffic and urban freight: toward a combined approach, Ecole Nationale des Travaux Publics d'Etat, 10/2017.
  - C. Dorffer, Informed matrix factorization methods for mobile sensor networks calibration and pollution mapping, University of Littoral Côte d'Opale, 12/2017.
- Hervé Rivano was a reviewer in the following HDR defense committee:
  - N. Chiabaut, Dynamic modeling of multimodal transportation networks, University Claude Bernard Lyon 1, 05/2017.
- Razvan Stanica was a reviewer in the following PhD defense committee:
  - P. Katsikouli, Distributed and Privacy Preserving Algorithms for Mobility Information Processing, University of Edinburgh, 10/2017.
- Razvan Stanica was a member in the following PhD defense committee:
  - C. Razafimandimby, Toward Internet of Heterogeneous Things : Wireless Communication Maintenance and Efficient Data Sharing among Devices, Mines Paris Tech, Inria FUN, Université Lille 1, 10/2017.
- Fabrice Valois was a reviewer in the following PhD defense committees:

  - S. Hamdoun, Adaptive and Efficient Radio Resource Sharing Schemes for Machine Type Communcations underlying Cellular Networks, Institut Gaspard Monge, Université Paris-Est, 2017.
  - D. H. Nguyen, Enhancing and improving voice transmission quality over LTE networks: Challenges and Solutions, Télécom Sud Paris, 2017.
- Fabrice Valois was a member in the following PhD defense committee:
  - L. Reynaud, Stratégies de mobilité optimisées pour la tolérances aux perturbations dans les réseaux sans fil, Université de Lyon, 2017.
- Fabrice Valois was a reviewer in the following HDR defense committees:
  - A. Gallais, Contributions to Low Power Listening in Dynamic Internet of Things, I-Cube, Université de Strasbourg, 11/2017.
  - E. Natalizio, Mobility as a primitive to improve communications in wireless network, Heudiasyc, Université Technologique de Compiègne, 11/2017.
- Fabrice Valois was a member in the following HDR defense committee:
  - R. Dhaou, IoT composé de réseaux terrestres et par satellite au service des Smart Cities : mobilité et hétérogénéité, IRIT, INP Toulouse, 2017.

10.3. Popularization

- Walid Bechkit participated in the "Rencontres Inria Industrie 2017" - https://www.youtube.com/watch?v=qKzubSkpvSk
- Walid Bechkit, Ahmed Boubrima and Hervé Rivano participated in the documentary "Métropole intelligente" projected as part of the 1st edition of "Thematix - Les rencontres de la Métropole Intelligente".
- Walid Bechkit, Ahmed Boubrima and Hervé Rivano participated in the "Forum des interconnectés" - http://www.interconnectes.com/
- Hervé Rivano was interviewed by the press about future of IoT 04/17 and the Sense City EquipEx 08/17
- Hervé Rivano was animating the Twitter account of « En direct du Labo » for a week, 06/17
- Hervé Rivano gave a talk on IoT for sensing the environment at the Entretiens Jacques Cartier, Montreal, 10/17.
- Hervé Rivano gave a talk on Smart Cities to a workshop of sustainable urban spaces, Ministère Enseignement Supérieure, Recherche et Innovation, 10/2017

11. Bibliography

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Articles in International Peer-Reviewed Journals

[1] B. Baron, P. Spathis, H. Rivano, M. Dias De Amorim, Y. Viniotis, M. Ammar. *Centrally-Controlled Mass Data Offloading Using Vehicular Traffic*, in "IEEE Transactions on Network and Service Management", June 2017, vol. 14, n^{o} 2, pp. 401-415 [*DOI :* 10.1109/TNSM.2017.2672878], http://hal.upmc.fr/hal-01495055

[2] A. Boubrima, W. Bechkit, H. Rivano. *Optimal WSN Deployment Models for Air Pollution Monitoring*, in "IEEE Transactions on Wireless Communications", January 2017, vol. 16, n^{o} 5, pp. 2723 - 2735 [*DOI :* 10.1109/TWC.2017.2658601], https://hal.inria.fr/hal-01473393

[3] A. FURNO, M. FIORE, R. STANICA, C. ZIEMLICKI, Z. SMOREDA. *A Tale of Ten Cities: Characterizing Signatures of Mobile Traffic in Urban Areas*, in "IEEE Transactions on Mobile Computing", October 2017, vol. 16, n^{o} 10, pp. 2682-2696 [*DOI :* 10.1109/TMC.2016.2637901], https://hal.inria.fr/hal-01514398

[4] A. FURNO, D. NABOULSI, R. STANICA, M. FIORE. *Mobile Demand Profiling for Cellular Cognitive Networking*, in "IEEE Transactions on Mobile Computing", 2017, vol. 16, n^{o} 3, pp. 772-786 [*DOI :* 10.1109/TMC.2016.2563429], https://hal.inria.fr/hal-01402487

[5] T. LIN, H. RIVANO, F. LE MOUËL. *A Survey of Smart Parking Solutions*, in "IEEE Transactions on Intelligent Transportation Systems", December 2017, vol. 18, n^{o} 12, pp. 3229-3253 [*DOI :* 10.1109/TITS.2017.2685143], https://hal.inria.fr/hal-01501556

[6] J. OUEIS, V. CONAN, D. LAVAUX, R. STANICA, F. VALOIS. *Overview of LTE Isolated E-UTRAN Operation for Public Safety*, in "IEEE Communications Standards Magazine", 2017, vol. 1, n^{o} 2, pp. 98-105 [*DOI :* 10.1109/MCOMSTD.2017.1600875], https://hal.archives-ouvertes.fr/hal-01573383

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[7] A. BOUBRIMA, W. BECHKIT, H. RIVANO. *A New WSN Deployment Approach for Air Pollution Monitoring*, in "CCNC 2017 - 14th IEEE Consumer Communications & Networking Conference", Las Vegas, United States, January 2017, https://hal.inria.fr/hal-01392863

[8] A. DUQUE, R. STANICA, H. RIVANO, A. DESPORTES. *SeedLight: Hardening LED-to-Camera Communication with Random Linear Coding*, in "VLCS 2017 - 4th ACM Workshop on Visible Light Communication Systems", Snowbird, UT, United States, October 2017, pp. 15-20 [*DOI :* 10.1145/3129881.3129889], https://hal.inria.fr/hal-01571530

[9] R. DOMGA KOMGUEM, R. STANICA, M. TCHUENTE, F. VALOIS. *Node Ranking in Wireless Sensor Networks with Linear Topology*, in "WD 2017 - 9th IFIP Wireless Days", Porto, Portugal, March 2017, pp. 1-6, https://hal.inria.fr/hal-01466468

[10] A. FURNO, N.-E. EL FAOUZI, M. FIORE, R. STANICA. *Fusing GPS Probe and Mobile Phone Data for Enhanced Land-Use Detection*, in "MT-ITS 2017 - 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems", Naples, Italy, June 2017 [*DOI :* 10.1109/MTITS.2017.8005601], https://hal.inria.fr/hal-01576866

[11] A. FURNO, M. FIORE, R. STANICA. *Joint Spatial and Temporal Classification of Mobile Traffic Demands*, in "INFOCOM 2017 – 36th Annual IEEE International Conference on Computer Communications", Atlanta, United States, May 2017, pp. 1-9, https://hal.inria.fr/hal-01514402

[12] J. A. KHAN, R. PUJOL, R. STANICA, F. VALOIS. *On the Energy Efficiency and Performance of Neighbor Discovery Schemes for Low Duty Cycle IoT Devices*, in "ACM PE-WASUN'17 - 14th ACM International Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks", Miami Beach, FL, United States, November 2017 [*DOI :* 10.1145/3134829.3134835], https://hal.inria.fr/hal-01577845

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[16] L. LE TARO, H. RIVANO. *Simulating Collaborative Sensor Calibration: Convergence and Cost*, in "SENSORCOMM 2017 - 11th International Conference on Sensor Technologies and Applications", Roma, Italy, September 2017, pp. 1-5, https://hal.inria.fr/hal-01654371

[17] A. A. MBACKÉ, N. MITTON, H. RIVANO. *Data Gathering Solutions for Dense RFID Deployments*, in "UIC 2017 - 14th International Conference on Ubiquitous Intelligence and Computing", San Francisco, United States, August 2017, https://hal.inria.fr/hal-01521113

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[19] A. A. MBACKÉ, N. MITTON, H. RIVANO. *RFID Anticollision in Dense Mobile Environments*, in "WCNC 2017 - IEEE Wireless Communications and Networking Conference", San Francisco, United States, March 2017, https://hal.inria.fr/hal-01418170

[20] J. OUEIS, V. CONAN, D. LAVAUX, R. STANICA, F. VALOIS. *Core Network Function Placement in Mobile Networks*, in "PIMRC 2017 - IEEE International Symposium on Personal, Indoor and Mobile Radio Communications", Montreal, Canada, October 2017, 5 p. , https://hal.archives-ouvertes.fr/hal-01573380

[21] J. OUEIS, R. STANICA, F. VALOIS, C. ROSENBERG. *Network-aware User Association in Public Safety Oriented Mobile Networks*, in "I-TENDER 2017 - 1st Workshop on ICT Tools for Emergency Networks and Disaster Relief", Seoul, South Korea, December 2017, pp. 1-6, https://hal.archives-ouvertes.fr/hal-01625595

[22] P. RAVENEAU, S. D 'ALU, H. RIVANO. *Localisation based on Wi-Fi Fingerprints: A Crowdsensing Approach with a Device-to-Device Aim*, in "DAMN! 2017 - 1st Workshop on Data Analytics for Mobile Networking", Kauna, Big Island, Hawaii, United States, March 2017, https://hal.inria.fr/hal-01483696

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[24] J. OUEIS, V. CONAN, D. LAVAUX, R. STANICA, F. VALOIS. *Placement du coeur d'un réseau mobile autonome*, in "ALGOTEL 2017 - 19èmes Rencontres Francophones sur les Aspects Algorithmiques des Télécommunications", Quiberon, France, May 2017, https://hal.archives-ouvertes.fr/hal-01516180

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[29] Y. ZGUIRA, H. RIVANO. *Evaluation of IoB-DTN protocol for mobile IoT Application*, INSA Lyon, November 2017, n^{o} RR-9113, 18 p. , https://hal.inria.fr/hal-01627670

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[30] A. BOUBRIMA, W. BECHKIT, H. RIVANO, L. SOULHAC. *Poster: Toward a Better Monitoring of Air Pollution using Mobile Wireless Sensor Networks*, October 2017, pp. 1-3, MobiCom 2017 - The 23rd Annual International Conference on Mobile Computing and Networking, Poster [*DOI :* 10.1145/3117811.3131249], https://hal.inria.fr/hal-01651734

[31] A. DUQUE, R. STANICA, H. RIVANO, A. DESPORTES. *Demo: Off-the-Shelf Bi-Directional Visible Light Communication Module for IoT Devices and Smartphones*, February 2017, EWSN 2017 - 13th International Conference on Embedded Wireless Systems and Networks, Poster, https://hal.inria.fr/hal-01473706