



Activity Report 2016

Team URBANET

Réseaux capillaires urbains

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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Team URBANET

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Keywords:

Computer Science and Digital Science:

- 1.2. - Networks
 - 1.2.1. - Dynamic reconfiguration
 - 1.2.2. - Supervision
 - 1.2.3. - Routing
 - 1.2.4. - QoS, performance evaluation
 - 1.2.5. - Internet of things
 - 1.2.6. - Sensor networks
- 1.4. - Ubiquitous Systems
- 5.11. - Smart spaces
 - 5.11.1. - Human activity analysis and recognition
- 6.2.6. - Optimization
- 7.3. - Optimization
- 7.11. - Performance evaluation

Other Research Topics and Application Domains:

- 6.3.2. - Network protocols
- 6.4. - Internet of things
- 8. - Smart Cities and Territories
- 8.2. - Connected city
- 8.5.2. - Crowd sourcing

1. Members

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2. Overall Objectives

2.1. Introduction

This is the last activity report of the Inria UrbaNet team, which officially ended in December 2016. Team UrbaNet's overall objectives were to study and characterize the architectures of urban capillary wireless networks and to propose mechanisms and protocols that are designed for the specific settings of the urban environment. This required taking into account constraints on the node deployment, heterogeneous and dynamic wireless connectivity, and requirements yielded by the usage of the city and the societal trends. Our methodology consisted in combining formal verification and combinatorial optimization methods with simulation based and analytical performance assessments to guide the development of relevant mechanisms. We entered this experience in 2012, with a group of researchers with a background on generic multi-hop wireless networks and we end it now, after four great years, in which we initiated collaborations with experts in transportation, air pollution, urbanism, economics or robotics. These collaborations brought us closer to the real problem of networking in an urban environment and challenged our view of wireless multi-hop networks. We are now studying hybrid (short and long range communications) architectures, new communication technologies (RFID, VLC), and new networking paradigms (energy harvesting). We are focusing on the dense deployment of nodes and functionalities, and the challenges this brings. And, finally, we try to extract as much information as possible from real massive data, obtained from our collaborators or collected by us. If you are curious about how will this go, follow us as team Agora from January 2017.

3. Research Program

3.1. Capillary networks

The definition of Smart Cities is still constantly redefined and expanded so as to comprehensively describe the future of major urban areas. The Smart City concept mainly refers to granting efficiency and sustainability in densely populated metropolitan areas while enhancing citizens' life and protecting the environment. The Smart City vision can be primarily achieved by a clever integration of ICT in the urban tissue. Indeed, ICTs are enabling an evolution from the current duality between the "real world" and its digitalized counterpart to a continuum in which digital contents and applications are seamlessly interacting with classical infrastructures and services. The general philosophy of smart cities can also be seen as a paradigm shift combining the Internet of Things (IoT) and Machine-to-Machine (M2M) communication with a citizen-centric model, all together leveraging massive data collected by pervasive sensors, connected mobile or fixed devices, and social applications.

The fast expansion of urban digitalization yields new challenges that span from social issues to technical problems. Therefore, there is a significant joint effort by public authorities, academic research communities and industrial companies to understand and address these challenges. Within that context, the application layer, i.e., the novel services that ICT can bring to digital urban environments, have monopolized the attention. Lower-layer network architectures have gone instead quite overlooked. We believe that this might be a fatal error, since the communication network plays a critical role in supporting advanced services and ultimately in making the Smart City vision a reality. The UrbaNet project deals precisely with that aspect, and the study of network solutions for upcoming Smart Cities represents the core of our work.

Most network-related challenges along the road to real-world Smart Cities deal with efficient mobile data communication, both at the backbone and at the radio access levels. It is on the latter that the UrbaNet project is focused. More precisely, the scope of the project maps to that of capillary networks, an original concept we define next.

The capillary networking concept represents a unifying paradigm for wireless last-mile communication in smart cities. The term we use is reminiscent of the pervasive penetration of different technologies for wireless communication in future digital cities. Indeed, capillary networks represent the very last portion of the data distribution and collection network, bringing Internet connectivity to every endpoint of the urban tissue in the same exact way capillary blood vessels bring oxygen and collect carbon dioxide at tissues in the human body. Capillary networks inherit concepts from the self-configuring, autonomous, ad hoc networks so extensively studied in the past decade, but they do so in a holistic way. Specifically, this implies considering multiple technologies and applications at a time, and doing so by accounting for all the specificities of the urban environment.

3.2. Specific issues and new challenges of capillary networks

Capillary networks are not just a collection of independent wireless technologies that can be abstracted from the urban environment and/or studied separately. That approach has been in fact continued over the last decade, as technologies such as sensor, mesh, vehicular, opportunistic, and – generally speaking – M2M networks have been designed and evaluated in isolation and in presence of unrealistic mobility and physical layer, simplistic deployments, random traffic demands, impractical application use cases and non-existent business models. In addition, the physical context of the network has a significant impact on its performances and cannot be reduced to a simple random variable. Moreover, one of the main element of a network never appears in many studies: the user. To summarize, networks issues should be addressed from a user- and context-centric perspective.

Such abstractions and approximations were necessary for understanding the fundamentals of wireless network protocols. However, real world deployments have shown their limits. The finest protocols are often unreliable and hardly applicable to real contexts. That also partially explains the marginal impact of multi-hop wireless technologies on today's production market. Industrial solutions are mostly single-hop, complex to operate, and expensive to maintain.

In the UrbaNet project we consider the capillary network as an ensemble of strongly intertwined wireless networks that are expected to coexist and possibly co-operate in the context of arising digital cities. This has three major implications:

- Each technology contributing to the overall capillary network should not be studied apart. As a matter of fact, mobile devices integrate today a growing number of sensors (e.g., environment sensing, resource consumption metering, movement, health or pollution monitoring) and multiple radio interfaces (e.g., LTE, WiFi, ZigBee, . . .), and this is becoming a trend also in the case of privately owned cars, public transport vehicles, commercial fleets, and even city bikes. Similarly, access network sites tend to implement heterogeneous communication technologies so as to limit capital expenses. Enabling smart-cities needs a dense sensing of its activities, which cannot be achieved without multi-service sensor networks. Moreover, all these devices are expected to inter-operate so as to make the communication more sustainable and reliable. Thus, the technologies that build up the capillary network shall be studied as a whole in the future.

- The capillary network paradigm necessarily accounts for actual urban mobility flows, city land-use layouts, metropolitan deployment constraints, and expected activity of the citizens. Often, these specificities do not arise from purely networking features, but relate to the study of city topologies and road layouts, social acceptability, transportation systems, energy management, or urban economics. Therefore, addressing capillary network scenarios cannot but rely on strong multidisciplinary interactions.
- Digital and smart cities are often characterized by arising M2M applications. However, a city is, before all, the gathering of citizens, who use digital services and mobile Internet for increasing their quality of life, empowerment, and entertainment opportunities. Some data flows should be gathered to, or distributed from, an information system. Some other should be disseminated to a geographically or time constrained perimeter. Future usage may induce peer-to-peer like traffics. Moreover these services are also an enabler of new usages of the urban environment. Solutions built within the capillary network paradigm have to manage this heterogeneity of traffic requirements and user behaviors.

By following these guidelines, the UrbaNet ambition is to go one step beyond traditional approaches discussed above. The capillary network paradigm for Smart Cities is tightly linked to the specificities of the metropolitan context and the citizens' activity. Our proposal is thus to re-think the way capillary network technologies are developed, considering a broader and more practical perspective.

3.3. Characterizing urban networks

Our first objective is to understand and model those properties of real-world urban environments that have an impact on the design, deployment and operation of capillary networks. It means to collect and analyze data from actual deployments and services, as well as testbeds experiments. These data have then to be correlated with urban characteristics, e.g. topography, density of population and activities. The objective is to deduce analytical models, simulations and traces of realistic scenarios that can be leveraged afterward. We structure the axis into three tasks that correspond to the three broad categories of networking aspects affected by the urban context.

- **Topological characteristics.** Nowadays, the way urban wireless network infrastructures are typically represented in the literature is dissatisfying. As an example, wireless links are mostly represented as symmetric, lossless channels whose signal quality depends continuously on the distance between the transmitter and the receiver. No need to say, real-world behaviors are very far from these simplified representations. Another example, topologies are generally modeled according to deterministic (e.g., regular grids and lattices, or perfect hexagonal cell coverages) or stochastic (e.g., random uniform distributions over unbound surfaces) approaches. These make network problems mathematically tractable and simulations easier to set up, but are hardly representative of the layouts encountered in the real world. Employing simplistic models helps understanding some fundamental principles but risks to lead to unreliable results, both from the viewpoint of the network architecture design and from that of its performance evaluation. It is thus our speculation that the actual operations and the real-world topologies of infrastructured capillary networks are key to the successful deployment of these technologies, and, in this task, we aim at characterizing them. To that end, we leverage existing collaborations with device manufacturers (Alcatel-Lucent, HiKob) and operators (Orange), as well as collaboration such as the Sense City project and testbed experiments, in order to provide models that faithfully mimic the behavior of real world network devices. The goal is to understand the important features of the topologies, including, e.g., their overall connectivity level, spatial density, degree distribution, regularity, etc. Building on these results, we try to define network graph models that reproduce such major features and can be employed for the development and evaluation of capillary network solutions.
- **Mobilities.** We aim at understanding and modeling the mobile portion of capillary networks as well as the impact of the human mobility on the network usage. Our definition of "mobile portion" includes traditional mobile users as well as all communication-enabled devices that autonomously

interact with Internet-based servers and among themselves. There have been efforts to collect real-world movement traces, to generate synthetic mobility dataset and to derive mobility models. However, real-world traces remain limited to small scenarios or circumstantial subsets of the users (e.g., cabs instead of the whole road traffic). Synthetic traces are instead limited by their scale and by their level of realism, still insufficient. Finally, even the most advanced models cannot but provide a rough representation of user mobility in urban areas, as they do not consider the street layout or the human activity patterns. In the end, although often deprecated, random or stochastic mobility models (e.g., random walks, exponential inter-arrivals and cell residence times) are still the common practice. We are well aware of the paramount importance of a faithful representation of device and user mobility within capillary networks and, in order to achieve it, we leverage a number of realistic sources, including Call Detail Records (CDR) collected by mobile operators, Open Data initiatives, real-world social network data, and experiments. We collect data and analyze it, so as to infer the critical properties of the underlying mobility patterns.

- **Data traffic patterns.** The characterization of capillary network usages means understanding and modeling when, where and how the wireless access provided by the diverse capillary network technologies is exploited by users and devices. In other words, we are interested in learning which applications are used at different geographical locations and day times, which urban phenomena generate network usage, and which kind of data traffic load they induce on the capillary network. Properly characterizing network usages is as critical as correctly modeling network topology and mobility. Indeed, the capillary networks being the link directly collecting the data from end devices, we cannot count on statistical smoothing which yields regular distributions. Unfortunately, the common practice is to consider, e.g., that each user or device generates a constant data traffic or follows on/off models, that the offered load is uniform over space and does not vary over time, that there is small difference between uplink and downlink behaviors, or that source/destination node pairs are randomly distributed in the network. We plan to go further on the specific scenarios we address, such as smart-parking, floating car data, tele-metering, road traffic management of pollution detection. To that end, we collect real-world data, explore it and derive properties useful to the accurate modeling of content consumption.

3.4. Autonomic networking protocols

While the capillary networks concept covers a large panel of technologies, network architectures, applications and services, common challenges remain, regardless the particular choice of a technology or architecture. Our record of research on spontaneous and multi-hop networks let us think that autonomic networking appears as the main issue: the connectivity to Internet, to cyber-physical systems, to Information Systems should be transparent for the user, context-aware and location-aware. To address these challenges, a capillary network model is required. Unfortunately, very few specific models fit this task today. However, a number of important, specific capillary networks properties can already be inferred from recent experiments: distributed and localized topologies, very high node degree, dynamic network diameter, unstable / asymmetric / non-transitive radio links, concurrent topologies, heterogeneous capabilities, etc. These properties can already be acknowledged in the design of networking solutions, and they are particularly challenging for the functioning of the MAC layer and QoS support. Clearly, capillary networks provide new research opportunities with regard to networking protocols design.

- **Self-* protocols.** In this regard, self-configuration, self-organization and self-healing are some of the major concerns within the context of capillary networks. Solving such issues would allow spontaneous topologies to appear dynamically in order to provide a service depending of the location and the context, while also adapting to the interactions imposed by the urban environment. Moreover, these mechanisms have the capacity to alleviate the management of the network and the deployment engineering rules, and can provide efficient support to the network dynamics due to user mobility, environment modifications, etc. The designed protocols have to be able to react to traffic requests and local node densities. We address such self-adaptive protocols as a transversal solution to several scenarios, e.g. pollution monitoring, smart-services depending on human activities, vehicle

to infrastructure communications, etc. In architectures where self-* mechanisms govern the protocol design, both robustness and energy are more than ever essential challenges at the network layer. Solutions such as energy-harvesting can significantly increase the network lifetime in this case, therefore we investigate their impact on the mechanisms at both MAC and network layers.

- **Quality of service issues.** The capillary networks paradigm implies a simultaneous deployment of multiple wireless technologies, and by different entities (industry, local community, citizens). This means that some applications and services can be provided concurrently by different parts of the capillary network, while others might require the cooperation of multiple parties. The notion of Service Level Agreement (SLA) for traffic differentiation, quality of service support (delay, reliability, etc.) is a requirement in these cases for scalability purposes and resource sharing. We contribute to a proper definition of this notion and the related network mechanisms in the settings of low power wireless devices. Because of the urban context, but also because of the wireless media itself, network connectivity is always temporary, while applications require a delivery ratio close to 100%. We investigate different techniques that can achieve this objective in an urban environment.
- **Data impact.** Capillary networks suffer from low capacity facing the increasing user request. In order to cope with network saturation, a promising strategy is to consider the nature of the transmitted data in the development of the protocols. Data aggregation and data gathering are two concepts with a major role to play in this context of limited capacity. In particular, combining local aggregation and measurement redundancy for improving on data reliability is a promising idea, which can also be important for energy saving purposes. Even if the data flow is well known and regular, e.g. temperature or humidity metering, developing aggregation schemes tailored to the constraints of the urban environment is a challenge we address within the UrbaNet team. Many urban applications generate data which has limited spatial and temporal perimeters of relevance, e.g. smart-parking applications, community information broadcasting, etc. When solely a spatial range of relevance is considered, the underlying mechanisms are denoted “geocasting”. We also address these spatio-temporal constraints, which combine geocasting approaches with real-time techniques.

3.5. Optimizing cellular network usage

The capacity of cellular networks, even those that are now being planned, does not seem able to cope with the increasing demands of data users. Moreover, new applications with high bandwidth requirements are also foreseen, for example in the intelligent transportation area, and an exponential growth in signaling traffic is expected in order to enable this data growth. Cumulated with the lack of available new spectrum, this leads to an important challenge for mobile operators, who are looking at both licensed and unlicensed technologies for solutions. The usual strategy consists in a dramatic densification of micro-cells coverage, allowing both to minimize the transmission power of cellular networks as well as to increase the network capacity. However, this solution has obvious physical limits, which we work on determining, and we propose exploiting the capillarity of network interfaces as a complementary solution.

- **Green cellular network.** Increasing the density of micro-cells means multiplying the energy consumption issues. Indeed, the energy consumption of actual LTE eNodeBs and relays, whatever their state, idle, transmitting or receiving, is a major and growing part of the access network energy consumption. For a sustainable deployment of such micro-cell infrastructures and for a significant decrease of the overall energy consumption, an operator needs to be able to switch off cells when they are not absolutely needed. The densification of the cells induces the need for an autonomic control of the on/off state of cells. One solution in this sense can be to adapt the WSN mechanisms to the energy models of micro-cells and to the requirements of a cellular network. The main difficulty here is to be able to adapt and assess the proposed solutions in a realistic environment (in terms of radio propagation, deployment of the cells, user mobility and traffic dynamics).
- **Offloading.** Offloading the cellular infrastructure implies taking advantage of the wealth of connectivity provided by capillary networks instead of relying solely on 4G connectivity. Cellular operators usually possess an important ADSL or cable infrastructure for wired services, the development of

femtocell solutions thus becomes very popular. However, while femtocells can be an excellent solution in zones with poor coverage, their extensive use in areas with a high density of mobile users leads to serious interference problems that are yet to be solved. Taking advantage of capillarity for offloading cellular data relies on using IEEE 802.11 Wi-Fi (or other similar technologies) access points or direct device-to-device communications. The ubiquity of Wi-Fi access in urban areas makes this solution particularly interesting, and many studies have focused on its potential. However, these studies fail to take into account the usually low quality of Wi-Fi connections in public areas, and they consider that a certain data rate can be sustained by the Wi-Fi network regardless of the number of contending nodes. In reality, most public Wi-Fi networks are optimized for connectivity, but not for capacity, and more research in this area is needed to correctly assess the potential of this technology. Direct opportunistic communication between mobile users can also be used to offload an important amount of data. This solution raises a number of major problems related to the role of social information and multi-hop communication in the achievable offload capacity. Moreover, in this case the business model is not yet clear, as operators would indeed offload traffic, but also lose revenue as direct ad-hoc communication would be difficult to charge and privacy issues may arise. However, combining hotspot connectivity and multi-hop communications is an appealing answer to broadcasting geo-localized informations efficiently.

4. Application Domains

4.1. Smart urban infrastructure

Unlike the communication infrastructure that went through a continuous development in the last decades, the distribution networks in our cities including water, gas and electricity are still based on 19th century infrastructure. With the introduction of new methods for producing renewable but unpredictable energy and with the increased attention towards environmental problems, modernizing distribution networks became one of the major concerns in the urban world. An essential component of these enhanced systems is their integration with information and communications technology, the result being a smart distribution infrastructure, with improved efficiency and reliability. This evolution is mainly based on the increased deployment of automatic equipment and the use of machine-to-machine and sensor-to-actuator communications that would allow taking into account the behavior and necessities of both consumers and suppliers

Another fundamental urban infrastructure is the transportation system. The progress made in the transportation industry over the last century has been an essential factor in the development of today's urban society, while also triggering the birth and growth of other economic branches. However, the current transportation system has serious difficulties coping with the continuous growth in the number of vehicles, especially in an urban environment. As a major increase in the capacity of a city road infrastructure, already in place for tens or even hundreds of years, would imply dissuasive costs, the more realistic approach is to optimize the use of the existing transportation system. As in the case of distribution networks, the intelligence of the system can be achieved through the integration of information and communication capabilities. However, for smart transportation the challenges are somehow different, because the intelligence is no longer limited to the infrastructure, but propagates to vehicles themselves. Moreover, the degree of automation is reduced in transportation systems, as most actions resulting in reduced road congestion, higher reliability or improved safety must come from the human driver (at least in the foreseeable future)

Finally, smart spaces are becoming an essential component of our cities. The classical architecture tools used to design and shape the urban environment are more and more challenged by the idea of automatically modifying private and public spaces in order to adapt to the requirements and preferences of their users. Among the objectives of this new urban planning current, we can find the transformation of the home in a proactive health care center, fast reconfigurable and customizable workplaces, or the addition of digital content in the public spaces in order to reshape the urban scene. Bringing these changing places in our daily lives is conditioned by a major shift in the construction industry, but it also involves important advancements in digital infrastructure, sensing, and communications

4.2. Urban participatory sensing

Urban sensing can be seen as the same evolution of the environment digitalization as social networking has been for information flows. Indeed, besides dedicated and deployed sensors and actuators, still required for specific sensing operations such as the real-time monitoring of pollution levels, there is a wide range of relevant urban data that can be collected without the need for new communication infrastructures, leveraging instead on the pervasiveness of smart mobile terminals. With more than 80% of the population owning a mobile phone, the mobile market has a deeper penetration than electricity or safe drinking water. Originally designed for voice transmitted over cellular networks, mobile phones are today complete computing, communication and sensing devices, offering in a handheld device multiple sensors and communication technologies.

Mobile devices such as smartphones or tablets are indeed able to gather a wealth of informations through embedded cameras, GPS receivers, accelerometers, and cellular, WiFi and bluetooth radio interfaces. When collected by a single device, such data may have small value per-se, however its fusion over large scales could prove critical for urban sensing to become an economically viable mainstream paradigm.

This is even more true when less traditional mobile terminals are taken into account: privately-owned cars, public transport means, commercial fleets, and even city bikes are starting to feature communication capabilities and the Floating Car Data (FCD) they generate can bring a dramatic contribution to the cause of urban sensing. Indeed, other than enlarging the sensing scope even further, e.g., through Electronic Control Units (ECUs), these mobile terminals are not burdened by strong energy constraints and can thus significantly increase the granularity of data collection. This data can be used by authorities to improve public services, or by citizens who can integrate it in their choices. However, in order to kindle this hidden information, important problems related to data gathering, aggregation, communication, data mining, or even energy efficiency need to be solved.

4.3. Human-centric networks

Combining location awareness and data recovered from multiple sources like social networks or sensing devices can surface previously unknown characteristics of the urban environment, and enable important new services. As a few examples, one could think of informing citizens about often disobeyed (and thus risky) traffic signs, polluted neighborhoods, or queue waiting times at current exhibitions in the urban area.

Beyond letting their own devices or vehicles autonomously harvest data from the environment through embedded or onboard sensors, mobile users can actively take part in the participatory sensing process because they can, in return, benefit from citizen-centric services which aim at improving their experience of the urban life. Crowdsourcing applications have the potential to turn citizens into both sources of information and interactive actors of the city. It is not a surprise that emerging services built on live mobile user feedback are rapidly meeting a large success. In particular, improving everyone's mobility is probably one of the main services that a smart city shall offer to its inhabitants and visitors. This implies providing, through network broadcast data or urban smart-furniture, an accurate and user-tailored information on where people should head in order to find what they are looking for (from a specific kind of shop to a free parking slot), on their current travel time estimates, on the availability of better alternate means of transport to destination. Depending on the context, such information may need to be provided under hard real-time constraints, e.g., in presence of road accidents, unauthorized public manifestations, or delayed public transport schedules.

In some cases, information can also be provided to mobile users so as to bias or even enforce their mobility: drivers can be alerted of the arrival of an emergency vehicle so that they leave the leftmost lane available, or participants leaving vast public events can be directed out of the event venue through diverse routes displayed on their smartphones so as to dynamically balance the pedestrian flows and reduce their waiting times.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

The paper by A. Boubrima *et al.* - "Cost-Precision Tradeoffs in 3D Air Pollution Mapping using WSN" received the Best Paper Award at the 2nd International Symposium on Ubiquitous Networking (UNET 2016).

Ahmed Boubrima was awarded the third place in the Best MS Thesis competition by IEEE ComSoc Chapter France for his work on optimal deployment of wireless sensor networks to monitor urban pollution (supervised by Walid Bechkit and Hervé Rivano).

BEST PAPER AWARD:

[13]

A. BOUBRIMA, W. BECHKIT, H. RIVANO, L. SOULHAC. *Cost-Precision Tradeoffs in 3D Air Pollution Mapping using WSN*, in "UNET 2016 - 2nd International Symposium on Ubiquitous Networking", Casablanca, Morocco, May 2016, Best Paper Award, <https://hal.inria.fr/hal-01312940>

6. New Software and Platforms

6.1. PrivaMovApp

FUNCTIONAL DESCRIPTION

UrbaNet 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: Razvan Stanica and Hervé Rivano.
- Contact: Razvan Stanica
- URL: <http://liris.cnrs.fr/privamov/project/>

6.2. TAPASCologne

Travel and Activity PAtterns Simulation Cologne

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: Razvan Stanica
- URL: <http://kolntrace.project.citi-lab.fr/>

6.3. Platforms

6.3.1. *Sense in the City*

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: Khaled Boussetta, Hervé Rivano.
- Contact: Khaled Boussetta

6.3.2. *Extention of the FIT IoT Lab Equipex in Tech La Doua Campus*

This testbed is located in an experimentation room which belongs to the CITI laboratory and the Telecommunications Department of INSA Lyon, Villeurbanne. The target usages of this room are quite diverse: practical works with students, robots/drones testing, wireless sensor networks experimentation, Wi-Fi security evaluation, services deployment, etc. During an experimentation, this room could be shared with others practical works. Basically, we claim that this room is useful to observe the behavior of nodes with this dense interactivity. 18 M3 open nodes, 11 A8 nodes and 12 mobile on robots are available for experimentation.

- Participants: Romain Pujol, Hervé Rivano, Fabrice Valois.
- Contact: Fabrice Valois
- URL: <https://www.iot-lab.info/deployment/lyon/>

7. New Results

7.1. Network deployment and characterization

Participants: Ahmed Boubrima, Angelo Furno, Walid Bechkit, Khaled Boussetta, Hervé Rivano, Razvan Stanica.

7.1.1. *Deployment of Wireless Sensor Networks for Pollution Monitoring*

Monitoring air quality has become a major challenge of modern cities, where the majority of population lives, 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. Wireless sensor networks seem to be a good solution to this problem, thanks to sensors' low cost and autonomy, as well as their fine-grained deployment. A careful deployment of sensors is therefore necessary to get better performances, while ensuring a minimal financial cost.

We have tackled the issue of WSN deployment for air pollution monitoring in a series of papers this year. In [10], we tackled the optimization problem of sensor deployment and we proposed an integer programming model, which allows to find the optimal network topology while ensuring air quality monitoring with a high precision and the minimum financial cost. Most of existing deployment models of wireless sensor networks are generic and assume that sensors have a given detection range. This assumption does not fit pollutant concentrations sensing. Our model takes into account interpolation methods to place sensors in such a way that pollution concentration is estimated with a bounded error at locations where no sensor is deployed. This solution was further tested and evaluated on a data set of the Lyon city [9], giving insights on how to establish a good compromise between the deployment budget and the precision of air quality monitoring.

In practice, multiple pollution sources can be present in an area. For this reason, in [11] we propose to apply a spatial clustering algorithm to the air pollution data in order to determine pollution zones that are due to the same pollutant sources and group them together to find candidate sites for the deployment of sensors. This approach was tested on real world data, namely the Paris pollution data, which was recorded in March 2014.

A very important deployment parameter is the height at which the sensor is placed. In [12], we demonstrate the impact of this parameter, usually neglected in the literature. This pushed us to study a 3D deployment model, based on an air pollution dispersion model issued from real experiments, performed in wind tunnels emulating the pollution emitted by a steady state traffic flow in a typical street canyon.

7.1.2. Access Point Deployment

The problem of designing wireless local networks (WLANs) involves deciding where to install the access points (APs), and assigning frequency channels to them with the aim to cover the service area and to guarantee enough capacity to users. In [5], we propose different solutions to the problems related to the WLAN design. In the first part, we focus on the problem of designing a WLAN by treating separately the AP positioning and the channel assignment problems. For the AP positioning issue, we formulate it as a set covering problem. Since the computation complexity limits the exact solution, we propose two heuristics to offer efficient solutions. On the other hand, for the channel assignment, we define this issue as a minimum interference frequency assignment problem and propose three heuristics: two of them aim to minimize the interference at AP locations, and the third one minimizes the interference at the TPs level. In the second part, we treat jointly the two aforementioned issues based on the concept of virtual forces. In this case, we start from an initial solution provided by the separated approach and try to enhance it by adjusting the APs positions and reassigning their operating frequencies.

7.1.3. Mobile Traffic Analysis

The analysis of operator-side mobile traffic data is a recently emerged research field, and, apart a few outliers, relevant works cover the period from 2005 to date, with a sensible densification over the last four years. In [8], we provided a thorough review of the multidisciplinary activities that rely on mobile traffic datasets, identifying major categories and sub-categories in the literature, so as to outline a hierarchical classification of research lines and proposing a complete introductory guide to the research based on mobile traffic analysis.

The usage of these datasets in the design of new networking solutions, in order to achieve the so-called cognitive networking paradigm, is one of the most important applications of these analytics methods. In fact, 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 and realize a more dynamic management of network resources, that adapts to the significant spatiotemporal fluctuations of the mobile demand. In [6], 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.

7.2. Data Collection in Multi-hop Networks

Participants: Jin Cui, Jad Oueis, Hervé Rivano, Razvan Stanica, Fabrice Valois.

7.2.1. Data Aggregation in Wireless Sensor Networks

Wireless Sensor Networks (WSNs) have been regarded as an emerging and promising field in both academia and industry. Currently, such networks are deployed due to their unique properties, such as self-organization and ease of deployment. However, there are still some technical challenges needed to be addressed, such as energy and network capacity constraints. Data aggregation, as a fundamental solution, processes information at sensor level as a useful digest, and only transmits the digest to the sink. The energy and capacity consumptions are reduced due to less data packets transmission.

As a key category of data aggregation, aggregation function, solving how to aggregate information at sensor level, was investigated in the Ph.D. thesis of Jin Cui [1]. In this work, we make four main contributions: firstly, we propose two new networking-oriented metrics to evaluate the performance of aggregation function: aggregation ratio and packet size coefficient. Aggregation ratio is used to measure the energy saving by data aggregation, and packet size coefficient allows to evaluate the network capacity change due to data aggregation. Using these metrics, we confirm that data aggregation saves energy and capacity whatever the routing or MAC protocol is used. Secondly, to reduce the impact of sensitive raw data, we propose a data-independent aggregation method which benefits from similar data evolution and achieves better recovered fidelity. This solution, named Simba, is detailed in [15] as well. Thirdly, a property-independent aggregation function is proposed to adapt the dynamic data variations. Comparing to other functions, our proposal can fit the latest raw data better and achieve real adaptability without assumption about the application and the network topology. Finally, considering a given application, a target accuracy, we classify the forecasting aggregation functions by their performance. The networking-oriented metrics are used to measure the function performance, and a Markov Decision Process is used to compute them. Dataset characterization and classification framework are also presented to guide researcher and engineer to select an appropriate functions under specific requirements.

7.2.2. Energy Harvesting in Wireless Sensor Networks

Energy harvesting capabilities are challenging our understanding of wireless sensor networks by adding recharging capacity to sensor nodes. This has a significant impact on the communication paradigm, as networking mechanisms can benefit from these potentially infinite renewable energy sources. In [23], we study photovoltaic energy harvesting in wireless sensor networks, by building a harvesting analytical model, linking three components: the environment, the battery, and the application. Given information on two of the components, limits on the third one can be determined. To test this model, we adopt several use cases with various indoor and outdoor locations, battery types, and application requirements. Results show that, for predefined application parameters, we are able to determine the acceptable node duty cycle given a specific battery, and vice versa. Moreover, the suitability of the deployment environment (outdoor, well lighted indoor, poorly lighted indoor) for different application characteristics and battery types is discussed.

In a second contribution [22], we study the consequences of implementing photovoltaic energy harvesting on the duty cycle of a wireless sensor node, in both outdoor and indoor scenarios. We show that, for the static duty cycle approach in outdoor scenarios, very high duty cycles, in the order of tens of percents, are achieved. This further eliminates the need for additional energy conservation schemes. In the indoor case, our analysis shows that the dynamic duty cycle approach based solely on the battery residual energy does not necessarily achieve better results than the static approach. We identify the main reasons behind this behavior, and test new design considerations by adding information on the battery level variation to the duty cycle computation. We demonstrate that this approach always outperforms static solutions when perfect knowledge of the harvestable energy is assumed, as well as in realistic deployments, where this information is not available.

7.2.3. Data Collection with Moving Nodes

Patrolling with mobile nodes (robots, drones, cars) is mainly used in situations where the need of repeatedly visiting certain places is critical. In [24], we consider a deployment of a wireless sensor network (WSN) that cannot be fully meshed because of the distance or obstacles. Several robots are then in charge of getting close enough to the nodes in order to connect to them, and perform a patrol to collect all the data in time. We discuss the problem of multi-robot patrolling within the constrained wireless networking settings. We show that this is fundamentally a problem of vertex coverage with bounded simple cycles (CBSC). We offer a formalization of the CBSC problem and prove it is NP-hard and at least as hard as the Traveling Salesman Problem (TSP). Then, we provide and analyze heuristics relying on clusterings and geometric techniques. The performances of our solutions are assessed in regards to robot limitations (storage and energy), networking parameters, but also to random and particular graph models.

Also related to data collection, in [3], we advocate the use of conventional vehicles equipped with storage devices as data carriers whilst being driven for daily routine journeys. The road network can be turned into a large-capacity transmission system to offload bulk transfers of delay-tolerant data from the Internet. The

challenges we address include how to assign data to flows of vehicles and while coping with the complexity of the road network. We propose an embedding algorithm that computes an offloading overlay where each logical link spans over multiple stretches of road from the underlying road infrastructure. We then formulate the data transfer assignment problem as a novel linear programming model we solve to determine the optimal logical paths matching the performance requirements of a data transfer. We evaluate our road traffic allocation scheme using actual road traffic counts in France. The numerical results show that 20% of vehicles in circulation in France equipped with only one Terabyte of storage can offload Petabyte transfers in a week.

7.2.4. Network Resilience

The notion of Shared Risk Link Groups (SRLG) captures survivability issues when a set of links of a network may fail simultaneously. The theory of survivable network design relies on basic combinatorial objects that are rather easy to compute in the classical graph models: shortest paths, minimum cuts, or pairs of disjoint paths. In the SRLG context, the optimization criterion for these objects is no longer the number of edges they use, but the number of SRLGs involved. Unfortunately, computing these combinatorial objects is NP-hard and hard to approximate with this objective in general. Nevertheless some objects can be computed in polynomial time when the SRLGs satisfy certain structural properties of locality which correspond to practical ones, namely the star property (all links affected by a given SRLG are incident to a unique node) and the span 1 property (the links affected by a given SRLG form a connected component of the network). The star property is defined in a multi-colored model where a link can be affected by several SRLGs while the span property is defined only in a mono-colored model where a link can be affected by at most one SRLG. In [4], we extend these notions to characterize new cases in which these optimization problems can be solved in polynomial time. We also investigate the computational impact of the transformation from the multi-colored model to the mono-colored one. Experimental results are presented to validate the proposed algorithms and principles.

7.3. Networks in the Internet of Things

Participants: Soukaina Cherkaoui, Alexis Duque, Guillaume Gaillard, Hervé Rivano, Razvan Stanica, Fabrice Valois.

7.3.1. Service Level Agreements in the Internet of Things

With the growing use of distributed wireless technologies for modern services, the deployments of dedicated radio infrastructures do not enable to ensure large-scale, low-cost and reliable communications. The Ph.D. thesis of Guillaume Gaillard [2] aims at enabling an operator to deploy a radio network infrastructure for several client applications, hence forming the Internet of Things (IoT). We evaluate the benefits earned by sharing an architecture among different traffic flows, in order to reduce the costs of deployment, obtaining a wide coverage through efficient use of the capacity on the network nodes. We thus need to ensure a differentiated Quality of Service (QoS) for the flows of each application.

We propose to specify QoS contracts, namely Service Level Agreements (SLAs), in the context of the IoT. SLAs include specific Key Performance Indicators (KPIs), such as the transit time and the delivery ratio, concerning connected devices that are geographically distributed in the environment. The operator agrees with each client on the sources and amount of traffic for which the performance is guaranteed. Secondly, we describe the features needed to implement SLAs on the operated network, and we organize them into an SLA management architecture. We consider the admission of new flows, the analysis of current performance and the configuration of the operator's relays. Based on a robust, multi-hop technology, IEEE Std 802.15.4-2015 TSCH mode, we provide two essential elements to implement the SLAs : a mechanism for the monitoring of the KPIs [19], and KAUSA, a resource allocation algorithm with multi-flow QoS constraints [18]. The former uses existing data frames as a transport medium to reduce the overhead in terms of communication resources. We compare different piggybacking strategies to find a tradeoff between the performance and the efficiency of the monitoring. With the latter, KAUSA, we dedicate adjusted time-frequency resources for each message, hop by hop. KAUSA takes into account the interference, the reliability of radio links and the expected load to improve the distribution of allocated resources and prolong the network lifetime [17]. We show the gains and the validity of our contributions with a simulation based on realistic traffic scenarios and requirements.

7.3.2. Channel Access in Machine-to-Machine Communications

The densification of the urban population and the rise of smart cities applications foster the need for capillary networks collecting data from sensors monitoring the cities. Among the multiple networking technologies considered for this task, cellular networks, such as LTE-A, bring an ubiquitous coverage of most cities. It is therefore necessary to understand how to adapt LTE-A, and what should be the future 5G architecture, in order to provide efficient connectivity to Machine-to-Machine (M2M) devices alongside the main target of mobile networks, Human-to-Human devices. Indeed, cellular random access procedures are known to suffer from congestion in presence of a large number of devices, while smart cities scenarios expect huge density of M2M devices. Several solutions have been investigated for the enhancement of the current LTE-A access management strategy. In [14], we contribute to the modeling and computation of the capacity of the LTE-A Random Access Channel (RACH) in terms of simultaneous successful access. In particular, we investigate the hypothesis of piggybacking the payload of Machine Type Communications from M2M devices within the RACH, and show that M2M densities considered realistic for smart cities applications are difficult to sustain by the current LTE-A architecture.

7.3.3. Visible Light Communications in the Internet of Things

The Internet of Things connects devices, such as everyday consumer objects, enabling information gathering and improved user experience. Also, this growing and dynamic market makes that consumers nowadays expect electronic products, even the cheapest, to include wireless connectivity. However, despite the fact that radio based solutions exist, such as Bluetooth Low Energy, the manufacturing costs introduced by these radio technologies are non-negligible compared to the initial product price. As most of the home electronics already integrate small light emitting diodes, Visible Light Communication appears as a competitive alternative. However, its broad adoption is suffering from a lack of integration with smartphones, which represent the communication hubs for most of the users. To overcome this issue, in [16], we propose a line of sight LED-to-camera communication system based on a small color LED and a smartphone. We design a cheap prototype as proof of concept of a near communication framework for the Internet of Things. We evaluate the system performance, its reliability and the environment influence on the LED-to-camera communication, highlighting that a throughput of a few kilobits per second is reachable. Finally, we design a real time, efficient LED detection and image processing algorithm to leverage the specific issues encountered in the system.

7.3.4. Radio Frequency Identification in Dense Environments

Radio Frequency Identification (RFID) is another cheap technology shaping the Internet of Things. The rapid development of RFID has allowed its large adoption and led to increasing deployments of RFID solutions in diverse environments under varying scenarios and constraints. The nature of these constraints ranges from the amount to the mobility of the readers deployed, which in turn highly affects the quality of the RFID system, causing reading collisions. However, the technology suffers from a recurring issue: the reader-to-reader collisions. Numerous protocols have been proposed to attempt to reduce them, but remaining reading errors still heavily impact the performance and fairness of dense RFID deployments.

In order to ensure collision-free reading, a scheduling scheme is needed to read tags in the shortest possible time. In [25], we study this scheduling problem in a stationary setting and the reader minimization problem in a mobile setting. We show that the optimal schedule construction problem is NP-complete and provide an approximation algorithm that we evaluate our techniques through simulation. Moving closer to practical solutions, [20] introduces a new Distributed Efficient & Fair Anticollision for RFID (DEFAR) protocol. DEFAR reduces both monochannel and multichannel collisions, as well as interference, by a factor of almost 90% in comparison with the best state of the art protocols. The fairness of the medium access among the readers is improved to a 99% level. Such improvements are achieved by applying a TDMA-based "serverless" approach and assigning different priorities to readers depending on their behavior over precedent rounds. A distributed reservation phase is organized between readers with at least one winning reader afterwards. Then, multiple reading phases occur within a single frame in order to obtain fast coverage and high throughput. The use of different reader priorities based on reading behaviors of previous frames also contributes to improve both fairness and efficiency.

Another type of collisions appears when the RFID tags are not only dense, but also mobile. mDEFAR [21] is an adaptation of DEFAR, while CORA [7] 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 the state of the art, 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.

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 Green.
Urbanet is part of the ADR Green of the common laboratory Inria/Nokia Bell Labs. This ADR provides the PhD grant of Soukaina Cherkaoui on the channel access capacity evaluation in 5G networks.
- Spie - INSA Lyon IoT Chaire.
Urbanet is involved in the SPIE INSA Lyon IoT Chaire, launched in November 2016. The PhD thesis work of Alexis Duque and Abderrahman Ben Khalifa are our main contributions in this structure.
- Volvo - INSA Lyon Chaire.
Urbanet 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

- BQR INSA CROME 12/2013-12/2016
Participants: Fabrice Valois
The partners in this project are the CITI DynaMid team and LIRIS. The project studies the coordination of a fleet of mobile robots for the multi-view analysis of complex scenes.
- Labex IMU Priva'Mov 10/2013-10/2016
Participants: Stéphane D'Alu, Hervé Rivano, Razvan Stanica
The partners in this project are DRIM LIRIS, Inria Privatics, INSA EVS, and LET ENTPE. The aim of this project is to develop and deploy a crowdsensing platform to collect mobility traces from a sample of real users equipped with android devices, while carrying research on privacy preservation issues. Our contribution consists on developing the platform and using the collected data to analyze cellular network offloading strategies.

- **Labex IMU UrPolSens 10/2015-10/2018**
Participants: 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 Urbanet 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.
- **Capt-PolAir 01/2016-12/2016**
PEPS project CNRS and Université de Lyon
Participants: Ahmed Boubrima, Leo Le Taro, Walid Bechkit, Hervé Rivano
The partners in this project are Ifsttar, LMFA, EVS, and TUBA, with Inria Urbanet leading the project. This project deals with the practical issues of the low cost wireless sensor deployment for air pollution monitoring. This projet complete the experimental part of UrPolSens.
- **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.

9.2. National Initiatives

9.2.1. ANR

- **ANR ABCD 10/2013-04/2017.**
Participants: Angelo Furno, Anh-Dung Nguyen, Razvan Stanica
The partners in the ANR ABCD project are: Orange Labs, Ucopia, Inria UrbaNet, 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 UrbaNet, Socrate and Dyogene.

9.2.2. DGA

- **DGA CLOTHO 10/2016-03/2018.**
Participants: 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.**
Participants: 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. Urbanet 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 under construction and should be finalized in 2017.

9.2.6. Inria Project lab

- CityLab
Urbanet 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.

9.4. International Research Visitors

9.4.1. Visits of International Scientists

- Catherine Rosenberg, Professor, University of Waterloo, Canada: invited professor at INSA Lyon (Spring semester, 2016).
- Michele Nogueira, Professor, University of Parana, Brazil : visiting professor (one week, February 2016).
- Wei Wennie Shu, Professor, University of New Mexico, USA : visiting professor (one month, December 2016).

- Min-You Wy, Professor, University of Shanghai Jiao Tong, China : visiting professor (one month, December 2016).

9.4.2. Visits to International Teams

9.4.2.1. Research Stays Abroad

- Alexis Duque visited the group of Dr. Domenico Giustinano, at IMDEA Networks, Madrid, Spain (one week, Nov. 2016).
- Alexis Duque visited the group of Prof. Josep Paradells Aspas, at Universitat Politecnica de Catalunya, Barcelona, Spain (one week, Nov. 2016).

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 CoRes 2016, the first French national conference on protocol design, performance evaluation and experimentation, held in Bayonne in May 2016.

10.1.2. Scientific Events Selection

10.1.2.1. Chair of Conference Program Committees

- Razvan Stanica was the co-chair of the track "Vehicular and Delay Tolerant Networks" at the Wireless Days 2016 conference, held in Toulouse in March 2016.

10.1.2.2. Member of the Conference Program Committees

- Walid Bechkit was in the TPC of IEEE ICC and IEEE GlobeCom.
- Razvan Stanica was in the TPC of the following conferences: IEEE ICC, IEEE GlobeCom, IEEE VTC Spring/Fall, AdHoc-Now, GIIS, IEEE ISC2, IEEE UIC, WF-IoT.
- Fabrice Valois was in the TPC of the following conferences: IEEE Globecom, IEEE ICC, IEEE ICT, IEEE WCNC, IEEE WCMC, WiSARN.

10.1.2.3. Reviewer

- Razvan Stanica was a reviewer for IEEE Infocom and IEEE WoWMoM.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

- Razvan Stanica was Guest Editor for the Elsevier Computer Communication special issue on Mobile Traffic Analytics.
- Fabrice Valois is Associated Editor for Annals of Telecommunications.

10.1.3.2. Reviewer - Reviewing Activities

- Walid Bechkit was a reviewer for ACM Transactions on Sensor Networks, Journal of Network and Computer Applications (Elsevier), Journal of Network and Systems Management, Telecommunication Systems.
- Razvan Stanica was a reviewer for the following journals: IEEE Transactions on Mobile Computing, IEEE Communications Magazine, IEEE Transactions on Big Data, IEEE Transactions on Vehicular Technology, Vehicular Communications, Wireless Networks, China Communications, Frontiers of Information Technology & Electronic Engineering.

10.1.4. Invited Talks

- Hervé Rivano was an invited speaker at the Intelligent Internet of Things Showroom (SIDO), Lyon, April 2016.
- Hervé Rivano gave an invited talk at the inauguration of the Sense City EquipEx, Paris, April 2016.
- Hervé Rivano gave an invited talk at the UCN@Sophia Labex seminar, Sophia Antipolis, April 2016.
- Hervé Rivano was an invited speaker at the Inria Alumni jam session on IoT, Paris, November 2016.
- Fabrice Valois gave a talk on the “Scientific Challenges of IoT: the viewpoint of the CITI Lab.”, CA Foundation INSA Lyon, September 2016.

10.1.5. Leadership within the Scientific Community

- 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 Scientific Council of the Labex IMU (Intelligence des Mondes Urbains).
- Fabrice Valois is in the steering committee of the Fédération d’Information de Lyon (FR 2000 CNRS).

10.1.6. Scientific Expertise

- Walid Bechkit was a reviewer for ANRT for Cifre PhD thesis.
- Hervé Rivano was a reviewer for the Sino-French call for project of the Joint Research Institute for Science and Society.
- Razvan Stanica was a reviewer for the following calls: ANR appel générique (France), ANRT Cifre (France), CETIC (Cameroun).
- Fabrice Valois was a reviewer for ANRT for Cifre PhD thesis.

10.1.7. Research Administration

- Walid Bechkit is responsible for seminar organization and scientific animation within the CITI laboratory.
- 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 is director of the CITI research laboratory of INSA Lyon.
- Fabrice Valois is in the steering committee of the SPIE INSA Lyon IoT Chaire.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Licence : Isabelle Augé-Blum, Operating Systems, 70h, L3, Telecom. Dpt. INSA Lyon.

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

Licence : Hervé Rivano, IP Networks, 34h, L3, Telecom. Dpt. INSA Lyon.

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

Licence : Razvan Stanica, Advanced Wireless Networks, 20h, L3, IST / Telecom. Dpt. INSA Lyon (lectures given in english).

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 : Isabelle Augé-Blum, Innovation project, 30h, M1, Telecom. Dpt. INSA Lyon.

Master : Isabelle Augé-Blum, Bibliographical study, 30h, M1, Telecom. Dpt. INSA Lyon.

Master : Isabelle Augé-Blum, Real-Time Networks, 25h, M2, Telecom. Dpt. INSA Lyon.

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 multihop networks, 10h, M2, University of Lyon.

Master : Walid Bechkit, Wireless networks: architecture and security, 18h, M2, INSA Lyon.

Master: Hervé Rivano, Wireless multihop networks, 10h, M2, University of Lyon.

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

Master: Hervé Rivano, Smart Cities and IoT, 48h, 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.

Isabelle Augé-Blum is in charge of the foreign affairs of the Telecommunications department at INSA Lyon, coordinating all incoming and outgoing student exchange programs.

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

Razvan Stanica is responsible for the administrative part related to all Master projects prepared by INSA Lyon Telecommunications department students.

Razvan Stanica is responsible of the research option at the Telecommunications department of INSA Lyon.

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 : Jin Cui, Data aggregation in wireless sensor networks, INSA Lyon, 06/2016. Advisor: Fabrice Valois.

PhD : Guillaume Gaillard, Opérer les réseaux de l'Internet des Objets à l'aide de contrats de qualité de service (Service Level Agreements), INSA Lyon, 12/2016. Advisors: Dominique Barthel (Orange Labs), Fabrice Theoleyre (I-Cube CNRS), Fabrice Valois.

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

PhD in progress: Abderrahman Ben Khalifa, Cognitive mechanisms for IoT networks. 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 : Soukaina Cherkaoui, Energy-saving strategies for backhaul networks, since 11/2013. Advisor: Hervé Rivano.

PhD in progress : Rodrigue Domga Komguem, Autonomous WSN architectures for road traffic applications, since 11/2012. Advisors: Razvan Stanica, Maurice Tchente (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 : Leo Le Taro, Recalibration of wireless sensors for pollution monitoring, since 11/2015. Advisor: Hervé Rivano.

PhD in progress: Abdul Aziz Mack, 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, Systèmes PMR très haut débit fédérateurs, since 10/2015. Advisors: Razvan Stanica, Fabrice Valois.

PhD in progress: Mihai Popescu, Mobilité au sein de flottes de robots sous contrainte de maintien de la connectivité, since 11/2015. Advisors: Olivier Simonin (Inria CHROMA), Anne Spalanzani (Inria CHROMA), Fabrice Valois.

MS thesis: T.Alias, Univ. Bretagne Sud, Resource Allocation in Cloud RAN, 07/2016. Advisors: Hervé Rivano, Razvan Stanica.

MS thesis: M Biteau, Data Gathering in Linear WSN, 01/2016. Advisors: Isabelle Augé-Blum, Walid Bechkit.

MS thesis: L. Bontemps, INSA Lyon, Anonymization of Mobile Traffic Datasets, 10/2016. Advisors: Razvan Stanica.

MS thesis: N. Chovelon, INSA Lyon, Control Traffic Model for LTE Core Networks, 06/2016. Advisors: Razvan Stanica, Fabrice Valois.

MS thesis: A. Mermouri, INSA Lyon, User Mobility in Virtualized Cellular Networks, 10/2016. Advisors: Razvan Stanica.

10.2.3. Juries

- Hervé Rivano was reviewer in the following PhD defense committee:
 - L. Wang, Facilitating Mobile Crowdsensing from both Organizers' and Participants' Perspectives, Télécom SudParis and Université Pierre et Marie Curie – Paris 6, 05/2016.
- Razvan Stanica was member in the following PhD defense committee:
 - M. Abualhoul, Visible Light and Radio Communication for Cooperative Autonomous Driving, Mines Paris Tech, Université Paris Sciences et Lettres, 12/2016.
- Fabrice Valois was reviewer in the following PhD defense committee:
 - M. G. Chalhoub, Enhanced Communication in Data Collection Multihop WSN, LIMOS, Univ. Clermont Ferrand, 07/2016.
- Fabrice Valois was member in the following PhD defense committee:
 - M. B. Tian, Data Dissemination Protocols and Mobility Model for VANETs, LIMOS, Univ. Clermont Ferrand, 10/2016.

10.3. Popularization

- Hervé Rivano has been involved in several popularization actions, in particular with the Grand Lyon metropolis (on air quality monitoring, smart cities infrastructure), SPL Lyon Part Dieu (on sensors networks), the TUBA (on sensors, mobility, networking), and Cité du Design et de l'Industrie.
- Hervé Rivano was a panelist at a public debate on "revolutions in education, culture, thinking and public space".

11. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

- [1] J. CUI. *Data Aggregation in Wireless Sensor Networks*, INSA Lyon, June 2016, <https://hal.inria.fr/tel-01428983>
- [2] G. GAILLARD. *Manage IoT networks using service level agreements*, INSA Lyon, December 2016, <https://hal.inria.fr/tel-01429025>

Articles in International Peer-Reviewed Journals

- [3] B. BARON, P. SPATHIS, H. RIVANO, M. DIAS DE AMORIM. *Offloading Massive Data onto Passenger Vehicles: Topology Simplification and Traffic Assignment*, in "IEEE/ACM Transactions on Networking", 2016, vol. PP, n^o 99, 14 p. [DOI : 10.1109/TNET.2016.2518926], <http://hal.upmc.fr/hal-01247713>
- [4] D. COUDERT, S. PÉRENNES, H. RIVANO, M.-E. VOGÉ. *Combinatorial optimization in networks with Shared Risk Link Groups*, in "Discrete Mathematics and Theoretical Computer Science", May 2016, vol. Vol. 18, no 3, 25 p. . <https://hal.inria.fr/hal-01053859>
- [5] A. FARSI, N. ACHIR, K. BOUSSETTA. *WLAN Planning: Separate and Joint Optimization of Both Access Point Placement and Channel Assignment*, in "Annals of Telecommunications - annales des télécommunications", January 2016, vol. 70, n^o 5-6, pp. 263–274 [DOI : 10.1007/s12243-014-0447-2], <https://hal.inria.fr/hal-01251971>
- [6] A. FURNO, D. NABOULSI, R. STANICA, M. FIORE. *Mobile Demand Profiling for Cellular Cognitive Networking*, in "IEEE Transactions on Mobile Computing", 2016 [DOI : 10.1109/TMC.2016.2563429], <https://hal.inria.fr/hal-01402487>
- [7] A. A. MBACKÉ, N. MITTON, H. RIVANO. *RFID Reader Anticollision Protocols for Dense and Mobile Deployments*, in "MDPI Electronics Special Issue "RFID Systems and Applications"", December 2016, <https://hal.inria.fr/hal-01402639>
- [8] D. NABOULSI, M. FIORE, S. RIBOT, R. STANICA. *Large-scale Mobile Traffic Analysis: a Survey*, in "Communications Surveys and Tutorials, IEEE Communications Society", January 2016, vol. 18, n^o 1, pp. 124-161 [DOI : 10.1109/COMST.2015.2491361], <https://hal.inria.fr/hal-01132385>

International Conferences with Proceedings

- [9] A. BOUBRIMA, W. BECHKIT, H. RIVANO. *Error-Bounded Air Quality Mapping Using Wireless Sensor Networks*, in "LCN 2016 - The 41st IEEE Conference on Local Computer Networks", Dubai, United Arab Emirates, November 2016, <https://hal.inria.fr/hal-01361868>
- [10] A. BOUBRIMA, W. BECHKIT, H. RIVANO. *Optimal Deployment of Dense WSN for Error Bounded Air Pollution Mapping*, in "DCOSS 2016 - International Conference on Distributed Computing in Sensor Systems", Washington, DC, United States, May 2016, <https://hal.inria.fr/hal-01315221>

- [11] A. BOUBRIMA, W. BECHKIT, H. RIVANO. *A New WSN Deployment Approach for Air Pollution Monitoring*, in "The 14th IEEE Consumer Communications & Networking Conference - CCNC 2017", Las Vegas, United States, January 2017, <https://hal.inria.fr/hal-01392863>
- [12] A. BOUBRIMA, W. BECHKIT, H. RIVANO, A. RUAS. *Wireless Sensor Networks Deployment for Air Pollution Monitoring*, in "TAP 2016 - 21st International Transport and Air Pollution Conference", Lyon, France, May 2016, <https://hal.inria.fr/hal-01315182>
- [13] *Best Paper*
A. BOUBRIMA, W. BECHKIT, H. RIVANO, L. SOULHAC. *Cost-Precision Tradeoffs in 3D Air Pollution Mapping using WSN*, in "UNET 2016 - 2nd International Symposium on Ubiquitous Networking", Casablanca, Morocco, May 2016, Best Paper Award, <https://hal.inria.fr/hal-01312940>.
- [14] S. CHERKAoui, I. KESKES, H. RIVANO, R. STANICA. *LTE-A Random Access Channel Capacity Evaluation for M2M Communications*, in "WD 2016 - 8th IFIP Wireless Days", Toulouse, France, March 2016 [DOI : 10.1109/WD.2016.7461480], <https://hal.inria.fr/hal-01312768>
- [15] J. CUI, F. VALOIS. *Simba: Similar-evolution based Aggregation in Wireless Sensor Networks*, in "WD 2016 - 8th IFIP Wireless Days", Toulouse, France, March 2016 [DOI : 10.1109/WD.2016.7461483], <https://hal.inria.fr/hal-01312748>
- [16] A. DUQUE, R. STANICA, H. RIVANO, A. DESPORTES. *Unleashing the Power of LED-to-Camera Communications for IoT Devices*, in "VLCS 2016 - ACM 3rd International Workshop on Visible Light Communication Systems", New York, United States, October 2016 [DOI : 10.1145/2981548.2981555], <https://hal.inria.fr/hal-01351146>
- [17] G. GAILLARD, D. BARTHEL, F. THEOLEYRE, F. VALOIS. *High-Reliability Scheduling in Deterministic Wireless Multi-hop Networks*, in "PIMRC 2016 - IEEE 27th Annual International Symposium on Personal, Indoor and Mobile Radio Communications", Valencia, Spain, September 2016, <https://hal.inria.fr/hal-01344792>
- [18] G. GAILLARD, D. BARTHEL, F. THEOLEYRE, F. VALOIS. *Kausa: KPI-aware Scheduling Algorithm for Multi-flow in Multi-hop IoT Networks*, in "AdHoc-Now 2016 - 15th International Conference on Ad Hoc Networks and Wireless", Lille, France, July 2016, <https://hal.inria.fr/hal-01306628>
- [19] G. GAILLARD, D. BARTHEL, F. THEOLEYRE, F. VALOIS. *Monitoring KPIs in Synchronized FTDMA Multi-hop Wireless Networks*, in "WD 2016 - 8th IFIP Wireless Days", Toulouse, France, March 2016, <https://hal.inria.fr/hal-01279719>
- [20] A. A. MBACKÉ, N. MITTON, H. RIVANO. *Distributed Efficient & Fair Anticollision for RFID Protocol*, in "WiMob 2016 - IEEE 12th International Conference on Wireless and Mobile Computing, Networking and Communications", New York, United States, October 2016, <https://hal.inria.fr/hal-01351350>
- [21] A. A. MBACKÉ, N. MITTON, H. RIVANO. *RFID anticollision in dense mobile environments*, in "IEEE Wireless Communications and Networking Conference", San Francisco, United States, March 2017, <https://hal.inria.fr/hal-01418170>

- [22] J. OUEIS, R. STANICA, F. VALOIS. *Energy Harvesting Wireless Sensor Networks: From Characterization to Duty Cycle Dimensioning*, in "MASS 2016 - IEEE 13th International Conference on Mobile Ad hoc and Sensor Systems", Brasilia, Brazil, October 2016, <https://hal.inria.fr/hal-01342974>
- [23] J. OUEIS, R. STANICA, F. VALOIS. *Linking the Environment, the Battery, and the Application in Energy Harvesting Wireless Sensor Networks*, in "AdHoc-Now 2016 - 15th International Conference on Ad Hoc Networks and Wireless", Lille, France, July 2016, <https://hal.inria.fr/hal-01306198>
- [24] M.-I. POPESCU, H. RIVANO, O. SIMONIN. *Multi-robot Patrolling in Wireless Sensor Networks using Bounded Cycle Coverage*, in "ICTAI 2016 28th International Conference on Tools with Artificial Intelligence", San Jose, United States, IEEE, November 2016, <https://hal.archives-ouvertes.fr/hal-01357866>
- [25] A. SEN, A. DAS, C. ZHOU, A. MAZUMDER, N. MITTON, A. A. MBACKÉ. *Reader Scheduling for Tag Access in RFID Systems*, in "NoF 2016 - 7th International Conference on Network of the Future", Buzios, Rio de Janeiro, Brazil, November 2016, <https://hal.inria.fr/hal-01372697>

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- [26] G. GAILLARD, D. BARTHEL, F. THEOLEYRE, F. VALOIS. *Enabling Flow-level Reliability on FTDM Schedules with efficient Hop-by-hop Over-provisioning*, Inria Grenoble - Rhône-Alpes, February 2016, n° RR-8866, <https://hal.inria.fr/hal-01278077>