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Activity Report 2014

Team URBANET

Réseaux capillaires urbains

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

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Networks and Telecommunications

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Team URBANET

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2. Overall Objectives

2.1. Introduction

Team UrbaNet's overall objectives are 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. It requires 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 consists in combining formal verification and combinatorial optimization methods with simulation based and analytical performance assessments to guide the development of relevant mechanisms.

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 significative 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. New Software and Platforms

5.1. WSNet

Participants: Rodrigue Domga Komguem, Quentin Lampin, Trista Lin, Alexandre Mouradian, Fabrice Valois (contact).

UrbaNet is an active contributor to WSnet (http://wsnet.gforge.inria.fr/), a discrete event simulator dedicated to large scale wireless networks developed and maintained by members of Inria and CITI lab. A major part of this contribution is represented by the implementation of state of the art protocols for medium access control and routing.

The WSNet simulation results obtained following this process are sometimes used as an input for another part of our development effort, which consists in prototype software based on the combination of CPLEX and AMPL for solving mixed integer linear programming problems with column generation.

5.2. TAPASCologne vehicular mobility dataset

Participants:Marco Fiore (contact), Diala Naboulsi, Razvan Stanica.

Based on the data made available by the Institute of Transportation Systems at the German Aerospace Center (ITS-DLR), the dataset aims at reproducing, with a high level of realism, car traffic in the greater urban area of the city of Cologne, 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.

The resulting synthetic trace of the car traffic in a the city of Cologne covers a region of 400 square kilometers for a period of 24 hours, comprising more than 700.000 individual car trips. More information is available on the project website at http://kolntrace.project.citi-lab.fr/ .

5.3. PrivaMovApp

Participants:Djamel Benferhat, Patrice Raveneau, Hervé Rivano, Razvan Stanica (contact).

UrbaNet is leading the development of an Android application for user data collection purposes. The application is based on the Funf (http://www.funf.org/) framework, and is currently available on Google Play. A first deployment of the application, on 25 users, took place in December, at the ACM Middleware 2014 conference, in Bordeaux.

5.4. Sense in the City

Participants:Khaled Boussetta (contact), Hervé Rivano, Hamadoun Tall.

We are developing a lightweight experimentation platform for wireless sensor networks. 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. First practical deployments of the platform will be used to showcase some protocols developed in the team in 2015.

6. New Results

6.1. Highlights of the Year

Two scientific results can be distinguished in UrbaNet activity this year. First of all, the work did in collaboration with Orange Labs during the PhD thesis of O. Erdene-Ochir (defended in 2013) led to a patent [38] related to routing in wireless sensor networks under resiliency constraints.

A second important result is represented by the book chapter "Wireless Access Networks for Smart Cities" [31], a common contribution of all the permanent members of the team. We hope that this chapter will become the reference on wireless networking within the new and dynamic smart cities community.

6.2. Characterizing and measuring urban networks

Participants: R. Domga Komguem, M. Fiore, D. Naboulsi, P. Raveneau, R. Stanica, F. Valois

6.2.1. Collection and Analysis of Mobile Phone Data

Cellular communications are undergoing significant evolutions in order to accommodate the load generated by increasingly pervasive smart mobile devices. At the same time, recent generations of mobile phones, embedding a wide variety of sensors, have fostered the development of open sensing applications, such as network quality or weather forecast applications.

In this sense, we contributed with a novel privacy-preserving mobile data collection platform [21], leveraging the dynamic deployment of crowdsourcing tasks across a pouplation of mobile phones.

Using such data, or other datasets coming from network operators, we can propose dynamic access network mechanisms that adapt to customers' demands. To that end, one must be able to process large amount of mobile traffic data and outline the network utilization in an automated manner. In [28], we propose a framework to analyze broad sets of Call Detail Records (CDRs) so as to define categories of mobile call profiles and classify network usages accordingly. We evaluated our framework on a CDR dataset including more than 300 million calls recorded in an urban area over 5 months. We showed how our approach allows to classify similar network usage profiles and to tell apart normal and outlying call behaviors.

6.2.2. Generation and Analysis of Vehicular Mobility Datasets

The surge in vehicular network research has led, over the last few years, to the proposal of countless network solutions specifically designed for vehicular environments. A vast majority of such solutions has been evaluated by means of simulation, since experimental and analytical approaches are often impractical and intractable, respectively. The reliability of the simulative evaluation is thus paramount to the performance analysis of vehicular networks, and the first distinctive feature that has to be properly accounted for is the mobility of vehicles, i.e., network nodes. Notwithstanding the improvements that vehicular mobility modeling has undergone over the last decade, no vehicular mobility dataset was publicly available that captures both the macroscopic and microscopic dynamics of road traffic over a large urban region.

In [12], we present a realistic synthetic dataset, covering 24 hours of car traffic in a 400-km2 region around the city of Ko¨ln, in Germany. We describe the generation process and outline how the dataset improves the traces currently employed for the simulative evaluation of vehicular networks. We also show the potential impact that such a comprehensive mobility dataset has on the network protocol performance analysis, demonstrating how incomplete representations of vehicular mobility may result in over-optimistic network connectivity and protocol performance.

Moreover, using a similar methodology we contribute to the ongoing effort to define such mobility scenarios by introducing a second set of traces for vehicular network simulation, this time focusing on a highway environment. Our traces are derived from high-resolution real-world traffic counts, and describe the road traffic on two highways around Madrid, Spain, at several hours of different working days. We provide a thorough discussion of the real-world data underlying our study, and of the synthetic trace generation process [20] [35] [29]. Finally, we assess the potential impact of our dataset on networking studies, by characterizing the connectivity of vehicular networks built on the different traces. Our results underscore the dramatic impact that relatively small communication range variations have on the network. Also, they unveil previously unknown temporal dynamics of the topology of highway vehicular networks, and identify their causes.

6.2.3. Characterizing Novel Wireless Networks for Urban Intelligent Transportation Solutions

Vehicular networks are not the only contribution communication technologies can bring in the field of Intelligent Transportation Systems. Two other examples have been studied this year in the team.

The first example is related to traffic light control in an urban environment [17]. A traffic light controller takes as input an estimation of the number of vehicles entering the intersection and produces as output a light plan, with the objective to reduce the traffic jam. The quality of the input traffic estimation is a key consideration on the performance of the traffic light controller. The advent of Wireless Sensor Networks, with their relatively low deployment and operation price, led to the development of several sensor-based architectures for intersection monitoring. We show in this work that the solutions proposed in the literature are unrealistic in terms of communication possibilities and that they do not allow a measure of the vehicular queue length at a lane level. Based on extensive experimental results, we propose an energy efficient, low cost and lightweight multi-hop wireless sensor network architecture to measure with a good accuracy the vehicle queue length, in order to have a more precise vision of traffic at the intersection.

On a second example, these last years have witnessed the rise of the smart cities and several mechanisms to render the cities more sustainable and more energy-efficient. Among all different aspects, a noteworthy one is urban bike development. Besides the growing enthusiast provoked by bicycles and the benefit for health they bring, there still exists some reluctance in using bikes because of safety, road state, weather, etc. To counter-balance these feelings, there is a need to better understand bicycle users habits, path, road utilization rate in order to improve the bicycle path quality. In this perspective, in [25], we propose to deploy a set of mobile sensors on bicycles to gather this different data and to exploit them to make the bike easier and make people want to ride bicycles more often. Such a network will also be useful for several entities like city authorities for road maintenance and deployment, doctors and environment authorities, etc. Based on such a framework, we propose a first basis model that help to dimension the network infrastructure and the kind of data to be real time gathered from bikes. More specifically, we present a theoretical model that computes the quantity of data a bike will be able to send along a travel and the quantity of data a base station should be able to absorb.

We have based our study on real data to provide first numerical results and be able to draw some preliminary conclusions and open new research directions.

6.3. Technology specific solutions

Participants: I. Augé-Blum, W. Bechkit, J. Cui, A. Mouradian, T. Lin, H. Rivano, R. Stanica, F. Valois

6.3.1. Medium Access Control in Wireless Sensor Networks

Protocols developed during the last years for Wireless Sensor Networks (WSNs) are mainly focused on energy efficiency and autonomous mechanisms (e.g. self-organization, self-configuration, etc.). Nevertheless, with new WSN applications, new QoS requirements appear, such as time constraints. Real-time applications require the packets to be delivered before a known time bound which depends on the application requirements. We particularly focus on applications which consist in alarms sent to the sink node. We propose Real-Time X-layer Protocol (RTXP) [8], a real-time communication protocol. RTXP is a MAC and routing real-time communication protocol that is not centralized, but instead relies only on local information. To the best of our knowledge, it is the first real-time protocol for WSNs using an opportunistic routing scheme in order to increase the packet delivery ratio. In the paper above, we describe the protocol mechanisms. We give theoretical bounds on the end-to-end delay and the capacity of the protocol. Intensive simulation results confirm the theoretical predictions and allow to compare RTXP with a real-time scheduled solution. RTXP is also simulated under harsh radio channel, in which case the radio link introduces probabilistic behavior. Nevertheless, we show that RTXP performs better than a non-deterministic solution. It thus advocates for the usefulness of designing real-time (deterministic) protocols even for highly unreliable networks such as WSNs.

Continuing on the idea of WSN applications with strict temporal constraints, these critical applications require correct behavior, reliability, and, of course, the respect of time constraints. Otherwise, if they fail, consequences on human life and the environment could be catastrophic. For this reason, we argue that the WSN protocols used in these applications must be formally verified. Unfortunately the radio link is unreliable, it is thus difficult to give hard guarantees on the temporal behavior of the protocols (on wired systems the link error probability is very low, so they are considered reliable). Indeed, in WSN a message may experience a very high number of retransmissions. The temporal guarantee has thus to be given with a probability that it is achieved. This probability must meet the requirements of the application. Network protocols have been successfully verified on a given network topology without taking into account unreliable links. Nevertheless, the probabilistic nature of radio links may change the topology (links which appear and disappear). Thus, instead of a single topology we have a set of possible topologies, each topology having a probability to exist. In this paper, we propose a method that produces the set of topologies, checks the property on every topology, and gives the probability that the property is verified. This technique is independent from the verification technique, i.e. each topology can be verified using any formal method which can give a “yes” or “no” answer to the question: “Does the model of the protocol respect the property?”. In [27], we apply this method on the previously proposed f-MAC protocol, a real-time medium access protocol for WSNs. We use UPPAAL model checker as verification tool, and we perform simulations to observe the difference between average and worst case behaviors.

One WSN application gaining a lot of importance in the team in the last few years targets Intelligent Transportation Systems (ITS), as also explained in the previous section. In this ITS field, parking sensor networks are rapidly deploying around the world and are also regarded as one of the first implemented urban services in smart cities. To provide the best network performance in this context, the MAC protocol shall be adaptive enough in order to satisfy the traffic intensity and variation of parking sensors. In this sense, in [24] and [36], we compare the performance of two off-the-shelf medium access control protocols on two different kinds of traffic models, and then evaluate their application-end information delay and energy consumption while varying traffic parameters and network density. From the simulation results, we highlight some limits induced by network density and occurrence frequency of event-driven applications. When it comes to real-time urban services, a protocol selection shall be taken into account - even dynamically - with a special attention to the energy-delay trade-off. In a follow-up study [23], we use real world data, more precisely the heavy-tailed parking and vacant time models from the SmartSantander platform, and then we apply the traffic model in the simulation with four different kinds of MAC protocols, that is, contention-based, schedule-based and two hybrid versions of these. The result shows that the packet inter-arrival time is no longer heavy-tailed while collecting a group of parking sensors, and then choosing an appropriate MAC protocol highly depends on the network configuration. Also, the information delay is bounded by traffic and MAC parameters which are important criteria while the timely message is required.

6.3.2. Routing in Wireless Sensor Networks

Routing represents another major challenging issue in WSN, because of the application diversity and energy efficiency constraints. Gradient broadcast routing is a robust scheme for data gathering in WSNs. At each hop, the sender broadcasts the packet to its neighbors and one or more nodes among its neighbors closer to the sink forward it. As long as a node has at least one neighbor with a smaller hop-count, it can route packets. Nevertheless, nodes can disappear because of energy depletion, hardware failure, etc. In this case, it cannot be ensured that a packet reaches the sink. Usually this issue is addressed by updating the gradient with a periodical flooding. Nevertheless, it consumes an important amount of energy, moreover, parts of the network may not need to be updated. In [26], we propose GRABUP (GRAdient Broadcast UPdate), a traffic-based gradient maintenance algorithm which updates the gradient thanks to the data packets. We simulate the proposition and compare it with the classic gradient broadcast routing.

Another specific application that we target is smart metering, which heavily rely on the communication network for efficient data gathering, thus eliminating manual meter reading. Smart electronic devices are deployed in open, unattended and possibly hostile environment such as consumer's home and office areas, making them particularly vulnerable to physical attacks. Resilience is needed in this case to mitigate such inherent vulnerabilities and risks related to security and reliability. In [18], a general overview of the resilience including definition, metric and resilient techniques relevant for smart metering is presented. A quantitative metric, visual and meaningful, based on the graphical representation is adopted to compare routing protocols in the sense of resilience against active insider attacks. Five well-known routing protocols from the main categories have been studied through simulations and their resilience is evaluated according to the given metric. Resilient techniques introduced to these protocols have enhanced significantly the resilience against attacks providing route diversification.

6.3.3. Other Research Issues Related to Wireless Sensor Networks

Important features of WSNs, such as low battery consumption, changing topology awareness, open environment, non reliable radio links, raise other research issues than classical MAC and routing problems. For example, in [32], we investigate the benefits of Network Coding in WSN, especially with respect to resiliency. We have seen in our previous work that resiliency could be described as a multi dimensional metric, taking parameters such as Average Delivery Ratio, Delay Efficiency, Energy Efficiency, Average Throughput and Delivery Fairness into account. Resiliency can then be graphically represented as a kiviat diagram created by the previous weighted parameters. In order to introduce these metrics, previous works have been leaded on the Random Gradient Based Routing, which proved good resiliency in malicious environment. We look for seeing the improvements in term of resiliency, when adding network coding in the Random Gradient Based Routing with malicious nodes.

Another challenge is represented by the deployment of sensor nodes, which can take into account the impact of multiple parameters. For example, temperature variations have a significant effect on low power WSNs as wireless communication links drastically deteriorate when temperature increases. A reliable deployment should take temperature into account to avoid network connectivity problems resulting from poor wireless links when temperature increases. A good deployment needs also to adapt its operation and save resources when temperature decreases and wireless links improve. Taking into account the probabilistic nature of the wireless communication channel, we develop [4] a mathematical model that provides the most energy efficient deployment in function of temperature without compromising the correct operation of the network by preserving both connectivity and coverage. We use our model to design three temperature-aware algorithms that seek to save energy (i) by putting some nodes in hibernate mode as in the SO (Stop-Operate) algorithm, or

(ii) by using transmission power control as in PC (Power-Control), or (iii) by doing both techniques as in SOPC (Stop-Operate Power-Control). All proposed algorithms are fully distributed and solely rely on temperature readings without any information exchange between neighbors, which makes them low overhead and robust. Our results identify the optimal operation of each algorithm and show that a significant amount of energy can be saved by taking temperature into account.

Finally, the notion of Shared Risk Link Groups (SRLG) captures survivability issues when a set of links of a network may fail simultaneously, such as a WSN where link conditions are extremely dynamic. 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, for example a battery depleted sensor) and the span 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 [33], we extend these notions to characterize new cases in which these optimization problems can be solved in polynomial time or are fixed parameter tractable. We also investigate on 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.

6.3.4. Data Aggregation and Gathering

In the data gathering problem, a particular network node, the base station or the sink, aims at receiving messages from some other network nodes. In [5], we model this network as a graph, and we consider that, at each step, a node can send one message to one of its neighbors (such an action is called a call). However, a node cannot send and receive a message during the same step. Moreover, the communication is subject to interference constraints, more precisely, two calls interfere in a step, if one sender is at distance below a certain threshold from the other receiver. Given a graph with a base station and a set of nodes having some messages, the goal of the gathering problem is to compute a schedule of calls for the base station to receive all messages as fast as possible, i.e., minimizing the number of steps (called makespan). The gathering problem is equivalent in this case to the personalized broadcasting problem where the base station has to send messages to some nodes in the graph, with same transmission constraints. We focus on the gathering and personalized broadcasting problem in grids (regular networks, with nodes deployed in a grid-like shape, e.g. parking or intersection monitoring WSNs). Moreover, we consider the non-buffering model: when a node receives a message at some step, it must transmit it during the next step. In this setting, though the problem of determining the complexity of computing the optimal makespan in a grid is still open, we present linear (in the number of messages) algorithms that compute optimal schedules for data gathering.

Data aggregation is a particular solution for the data gathering problem, which reduces the amount of data sent to the base station. In [16], we show that data aggregation can effectively reduce the energy consumption and improve the network capacity. Moreover, we present the state-of-the-art aggregation functions, including compressing-based and forecasting-based method; compressing-based aggregation focuses on compressing the data packets accompanied with transmitting based on spatial correlation, while forecasting aggregation tends to use mathematical models to fit the time series and predict the new value due to highly temporal correlation. We detail these two methods and characterize them respectively. We propose comparison between A-ARMA and Compressing Sensing, which are noteworthy examples of forecasting aggregation and compressing aggregation respectively.

6.3.5. Safety Vehicular Ad Hoc Networks

Vehicular ad hoc networks can play an important role in enhancing transportation efficiency and improving road safety. Therefore, direct vehicle-to-vehicle communications are considered as one of the main building blocks of a future Intelligent Transportation System. The success and availability of IEEE 802.11 radios made this technology the most probable choice for the medium access control layer in vehicular networks. However, IEEE 802.11 was originally designed in a wireless local area network context and it is not optimized for a dynamic, ad hoc vehicular scenario. In [11], we investigate the compatibility of the IEEE 802.11 medium access control protocol with the requirements of safety vehicular applications. As the protocols in this family are well-known for their scalability problems, we are especially interested in high density scenarios, quite frequent on today's roads. Using an analytical framework, we study the performance of the back-off mechanism and the role of the contention window on the control channel of a vehicular network. Based on these findings, we propose a reverse back-off mechanism, specifically designed with road safety applications in mind. Extensive simulations are carried out to prove the efficiency of the proposed enhancement scheme and to better understand the characteristics of vehicular communications.

One of the major roles of vehicular communication is the dissemination of information on the road in order to increase the awareness of the drivers. The facilities layer is a recently standardized component in the vehicular communication architecture, with an important role to play in the process of information dissemination. In [22], we propose facilities layer-based mechanisms for information propagation and we show they outperform classical network layer solutions. We also demonstrate that previous studies that do not consider the cohabitation of different types of safety messages on the vehicular control channel highly under-estimate the dissemination delay, which can lead to unrealistic assumptions in the design of safety applications.

6.4. Capillary solutions

Participants: M. Fiore, G. Gaillard, D. Naboulsi, H. Rivano, R. Stanica, F. Valois

6.4.1. Connected Vehicles

Bandwidth availability in the cellular backhaul is challenged by ever-increasing demand by mobile users. Vehicular users, in particular, are likely to retrieve large quantities of data, choking the cellular infrastructure along major thoroughfares and in urban areas. It is envisioned that alternative roadside network connectivity can play an important role in offloading the cellular infrastructure. We investigate [7] the effectiveness of vehicular networks in this task, considering that roadside units can exploit mobility prediction to decide which data they should fetch from the Internet and to schedule transmissions to vehicles. Rather than adopting a specific prediction scheme, we propose a fog-of-war model that allows us to express and account for different degrees of prediction accuracy in a simple, yet effective, manner. We show that our fog-of-war model can closely reproduce the prediction accuracy of Markovian techniques. We then provide a probabilistic graph-based representation of the system that includes the prediction information and lets us optimize content prefetching and transmission scheduling. Analytical and simulation results show that our approach to content downloading through vehicular networks can achieve a 70% offload of the cellular network.

Vehicles also produce large quantities of Floating Car Data (FCD), which consist of information generated by moving vehicles and uploaded to Internet-based control centers for processing and analysis. As upcoming mobile services based on or built for networked vehicles largely rely on uplink transfers of small-sized but high-frequency messages, FCD traffic is expected to become increasingly common in the next few years. Presently, FCD are managed through a traditional cellular network paradigm: however, the scalability of such a model is unclear in the face of massive FCD upload, involving large fractions of the vehicles over short time intervals. In [13], we explore the use of vehicle-to-vehicle (V2V) communication to partially relieve the cellular infrastructure from FCD traffic. Specifically, we study the performance boundaries of such a FCD offloading approach in presence of best- and worst-case data aggregation possibilities at vehicles. We show the gain that can be obtained by offloading FCD via vehicular communication, and propose a simple distributed heuristic that has nearly optimal performance under any FCD aggregation model.

We also advocate the use of a data shuttle service model to offload bulk transfers of delay-tolerant data from the Internet onto standard vehicles equipped with data storage capabilities [14]. We first propose an embedding algorithm that computes an offloading overlay on top of the road infrastructure. The goal is to simplify the representation of the road infrastructure as raw maps are too complex to handle. In this overlay, each logical link maps multiple stretches of road from the underlying road infrastructure. We formulate then the data transfer assignment problem as a novel linear programming model that determines the most appropriate logical paths in the offloading overlay for a data transfer request. We evaluate our proposal using actual road traffic counts in France. Numerical results show that we can satisfy weekly aggregate requests in the petabyte range while achieving cumulative bandwidth above 10 Gbps with a market share of 20% and only one terabyte of storage per vehicle.

6.4.2. Energy Consumption in Communication Networks

Providing high data rates with minimum energy consumption is a crucial challenge for next generation wireless networks. There are few papers in the literature which combine these two issues. The work we propose in [10] focuses on multi-hop wireless mesh networks using a MAC layer based on S-TDMA (Spatial Time Division Multiple Access). We develop an optimization framework based on linear programming to study the relationship between throughput and energy consumption. Our contributions are twofold. First, we formulate and solve, using column generation, a new MILP to compute offline energy-throughput tradeoff curve. We use a physical interference model where the nodes can perform continuous power control and can use a discrete set of data rates. Second, we highlight network engineering insights. We show, via numerical results, that power control and multirate functionalities allow optimal throughput to be reached, with lower energy consumption, using a mix of single hop and multihop routes.

Another strategy with regard to energy consumption is switching off some network nodes that are not carrying any data or control traffic. In [37], we tackle the problem of on-grid energy saving in cellular networks based on switch-on/off techniques for base stations and the usage of renewable energy. We aim to evaluate how much power can be saved in the network and dimension the renew able energy system according to the consumptions in real-world networks.

6.4.3. Service Level Agreements

The era of the Internet of Things (IoT) brings complexity and deployment costs in smart cities, particularly in WSNs. Utilities such as gas or water providers are keen on delegating the management of the communications to specialized firms, namely WSN Operators, that will share the WSN resource among their various clients. For this reason, in [34] we provide a guideline to write Service Level Agreements (SLAs) for IoT operation, borrowing a well studied concept from the web services domain. We extend the SLA definition with specific items that integrate the WSN constraints, and we facilitate the construction of complex metrics that express the performance of the WSN.

Furthermore. WSN operators will need a robust and reliable technology in order to guarantee QoS constraints in a wireless environment, as in the industrial world. IEEE 802.15.4e Time Slotted Channel Hopping (TSCH) is one good candidate. Moreover, the IETF experience in IP networks management is an important input for monitoring and QoS control over WSNs. In [19], we give formal guidelines for the implementation of a SLA architecture for operated WSNs. We distinguish the various formal algorithms that are necessary to operate a WSN according to SLAs, and determines which functional entities are necessarily technology-dependent. Detailed examples of such entities are developed in an IPv6 over IEEE 802.15.4e TSCH context, such as advocated in the IETF 6TiSCH Working Group.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

- We have contracted bilateral cooperation with some industrial partners that are under non disclosure agreements and cannot be mentioned here.

8. Partnerships and Cooperations

8.1. 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: Djamel Benferhat, Patrice Raveneau, 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.

8.2. National Initiatives

8.2.1. ANR

- ANR ABCD 10/2013-04/2017.
  Participants: Diala Naboulsi, Marco Fiore, 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.

8.2.2. Pôle ResCom

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

8.2.3. Common Laboratory Inria/Alcatel-Lucent Bell Labs

- ADR Green
  UrbaNet is part of the ADR Green of the common laboratory Inria/Alcatel-Lucent Bell Labs. This ADR provides the PhD grant of Soukaina Cherkaoui on the adaptation of wireless sensor network control protocols for optimizing the energy consumption of heterogeneous cellular LTE networks.

8.2.4. 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. The first deployment is scheduled early 2015.

8.2.5. Inria Project lab

- CityLab
  Urbanet is involved in the CityLab Inria Project Lab lead by Valérie Issarny. Within this project, Hervé Rivano is the networking referent for the PhD thesis of Raphael Ventura, advised by Vivien Mallet, in the Clime Inria team.

8.3. European Initiatives

8.3.1. FP7 & H2020 Projects

- ReFleX 04/2014-03/2018.
  Participants: Marco Fiore
  ReFleX (http://www.wcsg.ieiit.cnr.it/Reflex/website/) is a European Union-funded project, within the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme (FP7/2007-2013) under Research Executive Agency grant agreement n.630211. ReFleX aims at characterizing in a comprehensive manner the topological features of large-scale urban vehicular networks built on top of DSRC-based V2V and V2I communication technologies. To that end, the project adopts a multidisciplinary approach, bringing together tools from vehicular networking, wireless communications, transportation theory, and complex network science.

8.4. International Initiatives

8.4.1. Inria International Partners

8.4.1.1. Informal International Partners

- **Politecnico di Torino (Italy)**. Multiple publications co-authored with members of the Telecommunication Networks Group.
- **University of Waterloo (Ontario, Canada)**. Cooperation and joint publications on the optimization of wireless mesh networks.

8.5. International Research Visitors

8.5.1. Internships

- S. Ancona, MS thesis, Politecnico di Bari, Italy: Offloading Cellular Networks through Residential Wi-Fi Access Points (4 months).
- A. Hadji, MS thesis, SupCom, Tunis, Tunisia: Coordination Model for Fleets of Mobile Robots (5 months).
- O. Jimenez Hidalgo, intern, Simon Bolivar University, Caracas, Venezuela: Visualization of Mobile Data Statistics (3 months).
- I. Keskes, MS thesis, ENIT Tunis, Tunisia: Floating Car Data Resource Allocation in Mobile Vehicular Networks (5 months).
- D. Martella, intern, Politecnico di Torino, Italy: Performance Evaluation of Coordinated Mobility Algorithms with Connectivity Constraints (3 months).
- P. Mikulski, intern, University of Lodz, Poland: Combining DSRC and VLC in Safety Vehicular Networks (3 months).
- B. Mordzak, intern, University of Lodz, Poland: Offloading Capacity of Residential Wi-Fi Networks (3 months)
- C. Ortegon Barajas, intern, University Icesi, Cali, Colombia: Performance Evaluation of Coordinated Mobility Algorithms with Connectivity Constraints (3 months).

- A. Vaidya, intern, Nanyang Technological University, Singapore: Simulation of Vehicular Networks (5 months).

8.5.2. Visits to International Teams

8.5.2.1. Research stays abroad

- **Razvan Stanica** and **Fabrice Valois** were visiting researchers at University of Yaoundé 1 (Cameroon), in June 2014 (one week).
- **Diala Naboulsi** was a visiting scholar within the Telecommunication Networks Group at Politecnico di Torino (Italy), between Sep 2013 and Jan 2014, under the CMIRA Explora'Doc programme.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Administrative responsibilities

- Fabrice Valois was elected (02/2014) and nominated (09/2014) as director of the CITI research laboratory of INSA Lyon.
- Hervé Rivano is responsible with the Economic and Strategic Intelligence affairs of the CITI research laboratory, in charge with setting up ZRRs withing the lab.
- Hervé Rivano and Razvan Stanica are members in the CITI laboratory council.

9.1.2. Scientific events organization

9.1.2.1. Session chair

- Marco Fiore was a panelist at the *Complex Network Science: the next big thing* Panel at IEEE NetSciCom, May 2014.
- Marco Fiore was Session chair for two sessions at IEEE SECON 2014.
- Hervé Rivano was an invited panelist at the Labex IMU Workshop.
- Razvan Stanica was Session chair for the "Sensing, Vising and Perception VII" session at IEEE ITSC 2014.

9.1.3. Scientific events selection

9.1.3.1. Member of the conference program committee

- The Urbanet team members are/were members of the technical program committee for a number of international conferences, including IEEE SECON 2014, IEEE WoWMoM 2014/2015, IEEE Globecom 2014, IEEE ICC 2014/2015, IEEE VTC-Spring 2014, IEEE WCNC 2014, IEEE VNC 2014, WD 2014, ICCVE 2014, IEEE AINA 2014, IWCMC 2014.

9.1.4. Journal

9.1.4.1. Member of the editorial board

- Marco Fiore is member of the Technical Committee of Elsevier Computer Communications.

9.1.4.2. Reviewer

- The Urbanet team members are/were reviewers for a number of international journals, including IEEE Transactions on Mobile Computing, IEEE Communications Magazine, IEEE Transactions on Vehicular Technology, IEEE Wireless Communication Letters, Ad Hoc Networks Journal, Vehicular Communications Journal, Transportation Research Part C.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

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

Licence : Walid Bechkit, IP Networks, 10h, L3, Telecom. Dpt. INSA Lyon, France.

Licence : Hervé Rivano, IP Networks, 20h, L3, Telecom. Dpt. INSA Lyon, France.

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

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

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

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

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

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

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

Master : Isabelle Augé-Blum, Networks of the Future, 10h, M2, University of Lyon.

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

Master : Walid Bechkit, Performance evaluation of telecom networks, 60h, M1, Telecom. Dpt. INSA Lyon, France.

Master : Walid Bechkit, Wireless Multihop networks, 10h, M2, University of Lyon.

Master : Razvan Stanica, Wireless local area networks, 8h, M2, University of Lyon.

Master : Razvan Stanica, Mobile Networks, 10h, M1, Telecom. Dpt. INSA Lyon, France.

Master : Fabrice Valois, Cellular Networks, 40h, M1, Telecom. Dpt. INSA Lyon, France.

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.

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

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

Since 2006, Fabrice Valois is the head of an international teaching program focused on Internet of Things, established between INSA Lyon and Shanghai Jiao Tong University.

Fabrice Valois is an elected member of the Telecommunications Department Council at INSA Lyon.

9.2.2. Supervision

HdR : Hervé Rivano, Modélisation et optimisation du partage de ressources dans les réseaux radio multi-sauts, INSA Lyon, 06/2014.

HdR : Marco Fiore, Vehicular networking: from fundamental properties to network solutions, INSA Lyon, 07/2014.

PhD : Quentin Lampin, Réseaux urbains de capteurs sans fil: Applications, caractérisation et protocoles, INSA Lyon, 01/2014. Advisors: Isabelle Auge´-Blum, Fabrice Valois.

PhD in progress : Soukaina Cherkaoui, Energy-saving strategies for backhaul networks, since 11/2013. Advisors: Hervé Rivano, Fabrice Valois.

PhD in progress : Jin Cui, Aggregation: From data dynamics to network dynamics, since 11/2012. Advisor: Fabrice Valois.

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

PhD in progress : Guillaume Gaillard, SLA pour réseaux de capteurs multi-services, since 12/2012. Advisor: Fabrice Valois.

PhD in progress : Trista Lin, Urban mobility measurement and citizen-oriented services cartography, since10/2012. Advisors: Frédéric Le Mouel (CITI DynaMid), Hervé Rivano.

PhD in progress : Diala Naboulsi, Human mobility - an urban networking perspective, INSA Lyon, since 10/2012. Advisors: Razvan Stanica, Marco Fiore, Hervé Rivano.

MS thesis: P. Brunisholz, INSA Lyon, The Gain of Network Coding in Wireless Sensor Networking. Advisors: Fabrice Valois, Marine Minier (Inria Privatics).

MS thesis: A. Caballero, INSA Lyon, Collection and Analysis of Mobile Phone Data. Advisors: Razvan Stanica, Hervé Rivano.

MS thesis: R. Chaabouni, INSA Lyon, Capacity of a Bike Mobile Sensor Network. Advisor: Hervé Rivano.

MS thesis: S. Feng, INSA Lyon, GPS Data Collection using Android Smartphones. Advisors: Razvan Stanica, Hervé Rivano.

MS thesis: F. Hou, INSA Lyon, Resource Allocation in Cloud Radio Access Networks. Advisor: Razvan Stanica.

MS thesis: H. Kahoul, INSA Lyon, Autonomous RPL An IPV6 Routing Protocol For Wireless Sensor Networks. Advisor: Fabrice Valois.

MS thesis: C. Lamé, INSA Lyon, Analytical Models of IEEE 802.11 Networks. Advisor: Razvan Stanica.

MS thesis: F. Matigot, INSA Lyon, Deployment of Wireless Sensor Networks for Urban Pollution Monitoring. Advisors: Walid Bechkit, Hervé Rivano.

MS thesis: S. Mokhtari, INSA Lyon, Performance Evaluation of Line Wireless Sensor Networks. Advisors: Walid Bechkit, Hervé Rivano.

MS thesis: A. Tessilimi, INSA Lyon, Human Mobility Analysis from Call Detail Records. Advisors: Razvan Stanica, Marco Fiore.

MS thesis: M. Yu, INSA Lyon: Characterization of WSN For Traffic Flow Control. Advisor: Fabrice Valois.

9.2.3. Juries

- Marco Fiore was external reviewer of the following Ph.D. defense:
  - S. Faye, Contrôle et gestion du trafic routier urbain par un réseau de capteurs sans fil, Telecom ParisTech, 10/2014.
- Marco Fiore was external examiner of the following Ph.D. defense:
  - N. Haddadou, Réseaux ad hoc véhiculaires : vers une dissémination de données efficace, coopérative et fiable, Université Paris-Est, 06/2014.
- Marco Fiore was external examiner of the following mid-term Ph.D. defense:
  - L. Gallo, Next Generation Mobile Vehicular Networking for Public Transportation Systems, EURECOM, 10/2014.
- Hervé Rivano was external reviewer of the following Ph.D. defense:
  - A. Kodjo, Design and Optimization of Wireless Backhaul Networks, I3S, Université de Nice Sophia Antipolis, 12/2014.

- Razvan Stanica was a member of one CoS (selection committee) for an associate professor position at INSA Lyon.
- Fabrice Valois was external reviewer of the following Ph.D. defenses:
  - K. El Gholami, La Gestion de la Qualité de Service Temps-Réel dans les Réseaux de Capteurs Sans Fil, LIMOS, Université Blaise Pascal, Clermont-Ferrand (France) and STIC, Université Chouaib Doukkali, El Jadida (Maroc), 12/2014.
  - D. D. Khanh, Performance Analysis of Wireless Technologies for New Generation Avionics Embedded Systems, ISAE, Université de Toulouse, 12/2014.
- Fabrice Valois was member in the following HdR defense committee:
  - F. Theoleyre, Medium Access and Efficient Use of Multihop Wireless Networks (HDR), ICube, Université de Strasbourg, 06/2014.
- Fabrice Valois was a member of two CoS (selection committee) for associate professor positions at Telecom ParisTech and INSA Lyon.

9.3. Popularization

- Hervé Rivano gave a popularization talk for ISN teachers on smart cities and wireless networking issues in June 2014.
- Razvan Stanica gave an invited talk, titled *Data Collection and Analysis using Mobile Phone Sensors*, in the wireless sensor network training organized for industrial partners at the Ecole Polytechnique de Yaoundé in June 2014.
- Fabrice Valois gave an invited talk, titled *Introduction to Wireless Sensor Networks*, in the wireless sensor network training organized for industrial partners at the Ecole Polytechnique de Yaoundé in June 2014.

10. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] P. DEVANT, Q. LAMPIN. *Urban wireless sensor networks: from applications to protocols*, INSA de Lyon, January 2014, https://hal.inria.fr/tel-01095797

[2] M. FIORE. *Vehicular networking: from fundamental properties to network solutions*, INSA Lyon ; Universite Claude Bernard Lyon 1, July 2014, Habilitation à diriger des recherches, https://hal.inria.fr/tel-01090951

[3] H. RIVANO. *Linear Programming techniques for modeling capacity and energy issues in wireless multi-hop networks*, INSA Lyon, June 2014, Habilitation à diriger des recherches, https://hal.inria.fr/tel-01084608

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[4] A. BACHIR, W. BECHKIT, Y. CHALLAL, A. BOUABDALLAH. *Joint Connectivity-Coverage Temperature-Aware Algorithms for Wireless Sensor Networks*, in "IEEE Transactions on Parallel and Distributed Systems", 2014, pp. 1-14, https://hal.archives-ouvertes.fr/hal-01006039

[5] J.-C. BERMOND, B. LI, N. NISSE, H. RIVANO, M.-L. YU. *Data gathering and personalized broadcasting in radio grids with interference*, in "Journal of Theoretical Computer Science (TCS)", October 2014, 23 p. [*DOI :* 10.1016/J.TCS.2014.10.029], https://hal.inria.fr/hal-01084996

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[10] A. OUNI, H. RIVANO, F. VALOIS, C. ROSENBERG. *Energy and Throughput Optimization of Wireless Mesh Networks with Continuous Power Control*, in "IEEE Transactions on Wireless Communications", October 2014, n^o 99, 12 p. [*DOI :* 10.1109/TWC.2014.2364815], https://hal.inria.fr/hal-01085013

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[13] S. ANCONA, R. STANICA, M. FIORE. *Performance Boundaries of Massive Floating Car Data Offloading*, in "WONS - 11th IEEE/IFIP Annual Conference on Wireless On-demand Network Systems and Services", Obergurgl, Austria, April 2014, pp. 89 - 96 [*DOI :* 10.1109/WONS.2014.6814727], https://hal.inria.fr/hal-01005015

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[14] B. BARON, P. SPATHIS, H. RIVANO, M. DIAS DE AMORIM. *Vehicles as Big Data Carriers: Road Map Space Reduction and Efficient Data Assignment*, in "VTC2014-Fall - IEEE 80th Vehicular Technology Conference", Vancouver, Canada, September 2014, http://hal.upmc.fr/hal-00994848

[15] B. BARON, P. SPATHIS, H. RIVANO, M. DIAS DE AMORIM, Y. VINIOTIS, J. CLARKE. *Software-Defined Vehicular Backhaul*, in "Wireless Days 2014", Rio de Janeiro, Brazil, IEEE and IFIP, November 2014, http://hal.upmc.fr/hal-01074558

[16] J. CUI, F. VALOIS. *Data aggregation in Wireless Sensor Networks: Compressing or Forecasting?*, in "WCNC - IEEE Wireless Communications and Networking Conference", Istanbul, Turkey, April 2014, https://hal.inria.fr/hal-01003835

[17] R. DOMGA KOMGUEM, R. STANICA, M. TCHUENTE, F. VALOIS. *WARIM: Wireless Sensor Network Architecture for a Reliable Intersection Monitoring*, in "ITSC - IEEE 17th International Conference on Intelligent Transportation Systems", Qingdao, China, October 2014, https://hal.inria.fr/hal-01057864

[18] O. ERDENE-OCHIR, M. ABDALLAH, K. QARAQE, M. MINIER, F. VALOIS. *Routing Resilience Evaluation for Smart Metering: Definition, Metric and Techniques*, in "PIMRC - IEEE 25th International Symposium on Personal, Indoor and Mobile Radio Communications", Washington DC, United States, September 2014, https://hal.inria.fr/hal-01015801

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[20] M. GRAMAGLIA, O. TRULLOLS-CRUCES, D. NABOULSI, M. FIORE, M. CALDERON. *Vehicular Networks on Two Madrid Highways*, in "SECON - IEEE 11th International Conference on Sensing, Communication, and Networking", Singapore, June 2014, https://hal.inria.fr/hal-01003163

[21] N. HADERER, V. PRIMAULT, P. RAVENEAU, C. RIBEIRO, R. ROUVOY, S. BEN MOKHTAR. *Towards a Practical Deployment of Privacy-preserving Crowd-sensing Tasks*, in "Middleware Posters and Demos '14", Bordeaux, France, December 2014 [*DOI :* 10.1145/2678508.2678530], https://hal.archives-ouvertes.fr/hal-01095787

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[28] D. NABOULSI, R. STANICA, M. FIORE. *Classifying Call Profiles in Large-scale Mobile Traffic Datasets*, in "INFOCOM - 33rd Annual IEEE International Conference on Computer Communications", Toronto, Canada, April 2014, https://hal.inria.fr/hal-01005050

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[29] M. GRAMAGLIA, O. TRULLOLS-CRUCES, D. NABOULSI, M. FIORE, M. CALDERON. *Connectivity of Highway Vehicular Networks*, in "ALGOTEL - 16èmes Rencontres Francophones sur les Aspects Algorithmiques des Télécommunications", Le Bois Plage en Ré, France, June 2014, pp. 1-4, https://hal.archives-ouvertes.fr/hal-00986007

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