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Activity Report 2012

Team URBANET

Urban Capillary Networks

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

Keywords: Cellular Networks, Network Protocols, Wireless Networks

The UrbaNet team is located at the Centre of Innovation in Telecommunications and Integration of Services (CITI), at INSA de Lyon.

Creation of the Team: February 01, 2012 .

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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 to take into account constraints on the nodes 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.

Year 2012 has been the year during which the team has been created, henceforth the scientific project of the team discussed and detailed. It has also been the time for starting projects addressing explicitly capillary network issues in the settings of urban applications. There are detailed in what follows.

2.2. Highlights of the Year

First, Quentin Lampin, Orange Labs PhD student, co-supervised by Isabelle Augé-Blum and Fabrice Valois in the settings of a bilateral contract with Orange Labs (Dominique Barthel) and contributing for Orange Labs to the ANR ARESA2 project, has been hired by Orange Labs on a permanent researcher position in december 2012.

In september 2012, Razvan Stanica has been hired Associate Professor at INSA Lyon and joined the Urbanet team. He did his PhD thesis at IRIT, Toulouse, supervised by André-Luc Beylot. Khaled Boussetta has also been awarded an Inria "delegation" temporary position and joined the Urbanet team. His permanent Associate Professor position is within University of Paris XIII.

An ARC 7 regional grant has been awarded to the team for hiring a PhD student (namely Trista Lin) and collaborating with the "Agence d'Urbanisme de Lyon" on mobility measurement and service cartography. This research is focusing on networking and software issues of smart parking applications.

Within the second phase of the Inria/Alcatel-Lucent lab, an ADR has been created on green networking issue and granted one postdoc and one PhD positions. The PhD position is dedicated to the topic we are in charge within the ADR: dynamic switch on/off mechanisms for micro-cellular network leveraging wireless sensor techniques.

3. Scientific Foundations

3.1. Capillary networks

The digital cities that evolve today need a thin and dense digitalization of their citizens and infrastructures' activities. There is hence a need for a new networking paradigm capable of providing enough capacity and quality of service. From the user point of view, there is only one network to access to data and applications, but from the point of view of operators, engineers, there are several access networks: wireless sensor networks to measure the physical world, the cellular networks (including 3G/4G) to handle mobility, mesh networks to support new applications and services.

We propose to aggregate all these networks in the concept of capillary network. A capillary network is, for the user or end device, a link to Internet, whatever the link is. For engineers and researchers, a capillary network represents all the different possible paths we have from the user terminal to the access network. Providing the support for a digital city and for a digital society requires to focus on Capillary Networking issues. These issues include classical challenges related to sensor, mesh, or user-centric networks (such as cellular or vehicular networks), but also present important components generated by the urban environment.

3.2. Characterizing urban networks

A typical urban capillary network will involve a set of different communication technologies like 3G/ LTE, IEEE 802.11, WSN, inter vehicular communications and many others. Each technology relies on a set of mechanisms that were designed to provide a dedicated set of functionalities. Typical mechanisms include resource allocation, scheduling, error detection and correction, routing etc.

Dimensioning the operating parameters of such network mechanisms in order to provide the desired services while ensuring the network efficiency is a classical and yet a difficult issue. There are many directions to address this problem. For instance, one can refer to the network dimensioning and traffic-engineering approaches. Cross layer optimization and Self-organizing networks (SON) paradigm in 3G/LTE are also other perspectives to tackle this issue. However, given the complexity of the problem, most of the efforts concentrate on the mono-technological and/or the mono-service cases.

In the urban scenario, the heterogeneity of the technologies and the particularity of the urban services bring up new network-dimensioning challenges. The optimization has to be extended to the inter-technological perspective and to the multi-services standpoint. The different technologies that compose the capillary network have to inter-operate in a seamless and optimal way so that they can provide user-centric services with the desired quality of experience. Consider, for instance, dimensioning the scheduling mechanism of a mesh network, which has to carry the traffic generated by different WSN in the city. Predicting the time and spatial distribution of the traffic generated by the different WSNs are clearly among the key elements that shall be considered. On the other side, from a downlink standpoint, consider the judicious setting of an WSN aggregation mechanism accordingly with the time varying capacity of the mesh backbone level.

It is quite clear that these questions cannot be addressed without characterizing the features of an urban capillary network. This covers the geographical properties of the networks (distribution, density, nodes degree, mobility etc.) as well as the data traffic characteristics of urban services. Understanding these proprieties and their correlation is still an uncovered area. The main challenge in this case is the production of quantitative traces from real or realistic urban mobility, networks and services. For example, in urban mobility scenarios, how long devices are in radio range of each other gives temporal constraints on the communications protocols that should be understood. In this duration, devices have to self-organize or to hang on the exiting organization and to exchange information.

A second step is to derive analytical or simulation models that will be used for network dimensioning and optimization. Many models already exist in the literature in related scientific fields and they could be considered or adapted to this purpose. This covers different models ranging from radio propagation, vehicular or pedestrian mobility, traffic pattern, etc, the difficulty being on how to mix these models and how to choose the right time magnitude and spatial scale in order to preserve the accuracy of the capillary network features while maintaining the model complexity tractable. The derived models could serve to optimize the different mechanisms involved in the urban capillary network.

The inference between different networks and services is quite complex to understand and to model, therefore a simple approach would be to decouple the models. Choosing the right decoupling technique depends on the targeted temporal and spatial level of the input and output parameters. Again, the latter shall capture for each decoupled model a selected set of significant features of the capillary network. Finally, the purpose of the constructed models is to obtain the optimal dimensioning of the network mechanisms. Several optimization techniques, from exact to heuristics ones, shall be considered to compute the best operating parameters. One of the main challenges here is to maintain the computational complexity tractable by exploiting the specific structure of the problems induced by the city.

3.3. Highly scalable protocols

The networks formed in an urban environment can sometimes be particularly challenging for the MAC layer protocols and QoS support, especially if the network is not centralized or synchronized: very high node degree, unstable and asymmetric links, etc.

MAC layer protocols are either very difficult to implement in distributed and self-organized environment or present serious scaling issues. Studies focusing on distributed TDMA showed that MAC protocols from this class can be successfully designed to accommodate channel access for a high number of contending nodes. However, scalability is always obtained following a learning phase with relatively high convergence time. This means that in a dynamic network scenario like the one encountered in most urban capillary networks, the MAC protocol spends most of the time in the learning phase, where it achieves a reduced performance. The same problem appears when trying to distribute other usually centralized schemes, such as OFDMA or CDMA. On the other hand, CSMA/CA protocols are distributed by their nature.

However, the current leading solutions in this area are based on the IEEE 802.11 Distributed Coordination Function (DCF), a channel access method designed and optimized for Wireless LANs with a central access point and a maximum of 10-20 contending stations. The DCF is well-known for its scalability issues, especially in multi-hop dynamic networks, and adding energy constraints usually existing in wireless sensor networks does not improve its performance. While multiple MAC layer congestion control solutions have been proposed in the context of mobile ad-hoc networks, the approach is usually based on the idea of reducing the number of neighbors, either through transmission power control or data rate adjustment. However, this is just a workaround and the search for a truly scalable MAC layer protocol for high density wireless networks is still open.

Regarding the network layers, in order to have multi-service platforms deployed in practice, all the requirements of telecommunication operators should be present, in particular in wireless sensor and actuators networks, within the key notion of Service Level Agreement (SLA) for traffic differentiation, quality of service support (delay, reliability, etc.). Moreover, because the world becomes more and more connected to Internet, IP should be supported in wireless sensor networks. The IETF proposes the use of RPL (Routing Protocol for low power and lossy networks), where it is clear that the support of several Destination oriented Directed Acyclic Graphs (DoDAG) is required, and a complete traffic management is needed. Moreover, RPL assumes a static topology but the classical sensor networks give way to urban sensing, where the user's smartphone give the physical measures to the operators. Therefore, the data collection becomes distributed, sometimes local, the network is now dynamic. In such a scenario, inconsistencies stemming from data collected using different calibration process raise a lot of interests. Moreover, data aggregation and data gathering is, in capillary networks, at the heart of the issues related to the limited capacity of the networks. In particular, combining local aggregation and measurement redundancy for improving data reliability is a promising approach.

3.4. 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, especially the one related to future machine-to-machine communications. Cumulated with the lack of available new radio frequency spectrum, this leads to an important challenge for mobile operators, who are looking at both licensed and unlicensed technologies for solutions.

Several approaches can be taken to tackle this problem, the most obvious being to exploit the multitude of alternative network interfaces in order to prevent data to go through the cellular network. In this perspective, taking advantage of the fact that cellular operators usually possess an important ADSL or cable infrastructure for wired services, the development of femtocell solutions has become 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 is to use IEEE 802.11 Wi-Fi (or other multi-hop 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, concluding that more than 65% of the data can be offloaded from the cellular infrastructure in high density areas. 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 hot-spot connectivity and multi-hop communications is an appealing answer to broadcasting geolocalized informations efficiently.

A complementary approach, more operator oriented, for minimizing the transmission power of cellular networks as well as increasing the network capacity, consists in a dramatic increase in the deployment of micro-cells. On the other hand, increasing the number of micro-cells multiplies the energy consumed by the cells whatever their state, idle, transmitting or receiving, which 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, which can be done by mechanisms inspired by the abundant works on WSNs and adapted to the energy models of micro-cells, and to the requirements of a cellular network, in particular the need for providing an adequate quality of service to dynamic and mobile clients.

4. Application Domains

4.1. Smart infrastructure

Unlike the communication infrastructure that went through a continuous development in the last decades, the distribution networks in our cities, whether we are talking about water, gas, or 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 becomes 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 needs of both consumers and suppliers.

Another fundamental urban infrastructure is the transportation system. The progress achieved by 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 will be obtained by 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 architectural 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 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. User-centric services

What is the most disobeyed traffic sign in your city? How does the level of pollution on your street compare with the one in other neighborhoods? How long is the queue at that exhibition you were planning to attend today? Combining location awareness and data recovered from multiple sources like social networks or sensing devices can provide answers to all these questions, making visible previously unknown characteristics of the urban environment.

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. Software

5.1. WSNet.

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.

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/ .

6. New Results

6.1. Scalable protocols for capillary networks.

Participants: Ibrahim Amadou, Quentin Lampin, Bilel Romdhani, Alexandre Mouradian, Isabelle Augé-Blum, Fabrice Valois

6.1.1. Beacon-less and opportunistic routing.

During the thesis of Ibrahim Amadou [1], we were focused on the issues of energy in WSNs through energy-efficient routing and medium access control protocols. The contributions of research work can be summarized as follows. First, we were interested on the energy issues at the routing layer for multi-hop wireless sensor networks (WSNs). We proposed a mathematical framework to model and analyze the energy consumption of routing protocols in multi-hop WSNs by taking into account the protocol parameters, the traffic pattern and the network characteristics defined by the medium channel properties, the dynamic topology behavior, the network diameter and the node density. We showed that Beacon-less routing protocol is a good candidate for energy saving in WSNs.

We investigated the performance of some existing relay selection schemes which are used by Beacon-less routing protocols. Extensive simulations were realized in order to evaluate their performance locally in terms of packet delivery ratio, duplicated packet and delay. Then, we extended the work in multi-hop wireless networks and developed an optimal solution, Enhanced Nearest Forwarding within Radius, which tries to minimize the per-hop expected number of retransmissions in order to save energy.

We presented a new Beacon-less routing protocol called Pizza-Forwarding (PF) without any assumption on the radio environment: neither the radio range nor symmetric radio links nor radio properties (shadowing, etc.) are assumed or restricted. A classical greedy mode is proposed. To overcome the hole problem, packets are forwarded to an optimal node in the two hop neighbor following a reactive and optimized neighborhood discovery.

In order to save energy due to idle listening and overhearing, we proposed to combine PF's main concepts with an energy-efficient MAC protocol to provide a joint MAC/routing protocol suitable for a real radio environment. Performance results lead to conclude to the powerful behavior of PF-MAC.

In collaboration with Orange Labs, we designed QOR, an opportunistic routing protocol for wireless sensor networks [16]. QOR first builds a stable directed acyclic logical routing structure and a prefix-based addressing plan stemming from data sinks. This addressing plan is then used to define the potential forwarders set for each source and allows a strict scheduling and an unique selection of the forwarder for each transmission thanks to a cascading acknowledgment scheme. QOR is particularly suited for sensor networks that require high delivery ratio under severe energy constraints. Extensive simulations show the benefits of QOR over an implementation of the IETF routing protocol for Lossy and Low Power networks, RPL, tailored to provide high delivery ratios. Our case studies shows that QOR saves up to 50% energy and reduces the end-to-end delay of a factor of 4 times while maintaining similar delivery ratios.

Most existing routing protocols designed for WSNs assume that links are symmetric, which is in contradiction with what is observed in the field. Indeed, many links in real-world WSNs are asymmetric. Asymmetric links can dramatically decrease the performance of routing algorithms not designed to cope with them. Quite naturally, most existing routing protocol implementations prune the asymmetric links to only use the symmetric ones. In our experience, asymmetric links are a valuable asset to improve network connectivity, capacity and overall performance [20],[2]. We therefore introduced AsymRP (Asymmetric Convergecast Routing Protocol) [21], a new routing protocol for collecting data in WSNs. AsymRP assumes 2-hop neighborhood knowledge and uses implicit and explicit acknowledgment. It takes advantage of asymmetric links to increase delivery ratio while lowering hop count and packet replication.

6.1.2. MAC and cross-layer mechanisms for QoS.

Protocols developed during the last years for Wireless Sensor Networks (WSNs) are mainly focused on energy-consumption optimization and autonomous mechanisms (e.g. self-organization, self-configuration, etc). Nevertheless, with new WSN applications appear new QoS requirements 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 focused on applications which consist in alarms that are sent to the sink node (e.g. air pollution monitoring). We proposed the Real-Time X-layer Protocol (RTXP) [27], a real-time communication protocol that integrates mechanisms for both MAC and routing layers. Our proposal aims at guaranteeing an end-to-end constraint delay, while keeping good performances on other parameters, such as energy consumption. For this purpose the protocol relies on a hop-count-based Virtual Coordinate System (VCS) which classifies nodes having the same hop-count from the sink, allows forwarder selection, and gives to the nodes an unique identifier in a 2-hop neighborhood allowing deterministic medium access. This protocol has better performances than state-of-the-art protocols, in terms of time constraints and reliability, even with unreliable radio links.

In the ARESA2 project, but also in a joint collaboration with Orange Labs, we studied receiver initiated MAC protocol to compare their performance to the more classical receiver-based MAC one [17]. We proposed the Self Adapting Receiver Initiated MAC protocol (SARI-MAC), a novel asynchronous MAC protocol for energy constrained Wireless Sensor Networks. SARI-MAC self-adapts to the traffic load to meet specified Quality of Service requirements at the lowest energy cost possible. To do so, SARI-MAC relies on traffic estimation, duty-cycle adaptation and acknowledgment mechanisms. Our performance evaluation assesses that SARI-MAC meets given QoS requirements in a energy efficient manner and outperforms the state of the art protocol RI-MAC in a broad range of traffic scenarios.

For energy constrained wireless sensor networks, lifetime is a critical issue. Several medium access control protocols have been proposed to address this issue, often at the cost of poor network capacity. To address both capacity and energy issues, we proposed a novel medium sharing protocol for Wireless Sensor Networks named Cascading Tournament (CT-MAC) [15]. CT-MAC is a synchronous, localized, dynamic, joint contention/allocation protocol. Relying on cascading iterations of tournaments, CT-MAC allocates multiple time slots to nodes that compete for accessing the medium. CT-MAC offers an unprecedented trade-off between traffic delay, network capacity and energy efficiency and stands out as a solid candidate for energy constrained sensor networks that must support heterogeneous traffic loads. Our simulations show that CT-MAC significantly outperforms the state-of-the-art SCP- MAC protocol.

6.2. Characterizing urban capillary wireless networks.

Participants: Sandesh Uppoor, Diala Naboulsi, Rodrigue Domga Komguem, Anis Ouni, Alexandre Mouradian, Isabelle Augé-Blum, Hervé Rivano, Marco Fiore, Fabrice Valois

6.2.1. Properties of urban road traffic of interest to mobile networking.

The management of mobility is commonly regarded as one of the most critical issues in large-scale telecommunication networks. The problem is exacerbated when considering vehicular mobility, which is characterized by road-constrained movements, high speeds, sudden changes of movement direction and acceleration, and significant variations of these dynamics over daytime. The understanding of the properties of car movement patterns becomes then paramount to the design and evaluation of network solutions aimed at vehicular environments.

We first analyzed how the vehicular mobility in a large-scale urban region affects a cellular infrastructure intended to support on-board users. We studied the spatial and temporal distribution of traffic load induced by vehicular users, their spatial flows, their inter-arrival and residence times at cells [22].

We then studied the topological features of a network built on moving vehicles, considering the instantaneous connectivity of the system [28]. Our results evidence the spatial and temporal diversity of road traffic, stressing the importance of a correct modeling of road traffic towards the reliable performance evaluation of network protocols. Additionally, the results outline how commonly adopted assumptions (e.g., Poisson user arrivals at the network base stations) do not hold under vehicular environments, and how the V2V-based network has low connectivity, availability, reliability and navigability properties.

6.2.2. The limits of RSSI-based localization.

Numerous localization protocols in Wireless Sensor Networks are based on Received Signal Strength Indicator. Because absolute positioning is not always available, localization based on RSSI is popular. More, no extra hardware is needed unlike solutions based on infra-red or ultrasonic. Moreover, the theory gives a RSSI as a function of distance. However, using RSSI as a distance metric involves errors in the measured values, resulting path-loss, fading, and shadowing effects. We did experimentation results from three large WSNs, each with up to 250 nodes [23]. Based on our findings from the 3 systems, the relation between RSSI and distance is investigated according to the topology properties and the radio environment. We underline the intrinsic limitations of RSSI as a distance metric, in terms of accuracy and stability. Contrary to what we assumed, collaborative localization protocol based on Spring-Relaxation algorithm can not smooth the distance-estimation errors obtained with RSSI measurements.

6.2.3. Modeling and optimization of wireless networks.

In critical real-time applications, when an event is detected, the Worst Case Traversal Time (WCTT) of the message must be bounded. However, despite this, real-time protocols for WSNs are rarely formally verified. The model checking of WSNs is a challenging problem for several reasons. First, WSNs are usually large scale so it induces state space explosion during the verification. Moreover, wireless communications produce a local broadcast behavior which means that a packet is received only by nodes which are in the radio range of the sender. Finally, the radio link is probabilistic. The modeling of those aspects of the wireless link in model checking is not straightforward and it has to be done in a way that mitigates the state space explosion problem. We are currently working on proposing a methodology adapted to WSNs, and based on Timed Automata (TA) and model-checking. First results are promising [19], but needed to be further investigated.

While the large variety of routing protocols (geographical, gradient, reactive, ...) proposed in the literature provide a set of pertinent solutions for optimizing the energy consumption for multi-hop wireless networks, they do not permit to know the conditions of use of these protocols based on parameters such as: the dynamics of topology, traffic pattern, the density and diameter of the network, the load, etc. In [12], we presented a theoretical model for evaluating the energy consumption for communication protocols taking into account both the dynamics of nodes and links, the properties of topology, the traffic pattern, the control/data packets and a realistic channel model. This model is applied successively to several protocols (GPSR, AODV, OLSR and PF) to highlight their optimum usage and it permits to conclude that Beacon-Less routing protocols are adapted for application with low traffic.

We continued developing optimization tools for building optimal solution to various problems of multi-hop wireless networks. Most of these contributions combine graph theoretical basis with Mixed Integer Linear Programming techniques, and are valuable for understanding the extremal behaviors of the systems and guide the development of efficient architectures and protocols. In this sense, we have considered a new edge coloring problem to model call scheduling optimization issues in wireless mesh networks: the proportional coloring [6]. It consists in finding a minimum cost edge coloring of a graph which preserves the proportion given by the weights associated to each of its edges. We show that deciding if a weighted graph admits a proportional coloring is pseudo-polynomial while determining its proportional chromatic index is NP-hard. We then give lower and upper bounds for this parameter that can be computed in pseudo-polynomial time. We finally identify a class of graphs and a class of weighted graphs for which the proportional chromatic index can be exactly determined.

Dealing with wireless mesh network, we have investigated the fundamental trade-off between transmitting energy consumption and network capacity [24]. The results on this trade-off have been computed using MILP models solved with column generation techniques. The main contribution relies in the ability to consider a realistic SINR model of the physical layer with a continuous power control and discrete transmission rate selection at each node. In order to model these functionalities, a strong formulation (in the sense that the linear relaxation gives relevant lower bounds) of the rate selection is introduced.

The behavior of beaconless geographic forwarding protocols for wireless sensor networks has also been modeled [9]. A realistic physical layer is taken into account by combining MILP models with simulation based inputs on the number of required retransmissions for realizing a transmission. The model is then able to compute energy efficient routings and allows for understanding the most efficient relay selection schemes, denoted Furthest Forward within Reliable neighbors (FFRe).

6.3. Solutions for cellular networks.

Participants: Anis Ouni, Fabrice Valois, Hervé Rivano, Marco Fiore

6.3.1. Content downloading through a vehicular network.

We considered a system that leverages vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication to transfer large contents to users on-board moving cars. This paradigm is intended to relieve the cellular infrastructure from the high load that such downloads would induce, once vehicles are widely equipped with infotainment devices.

We first characterized the theoretical performance limits of such a vehicular content downloading system by modeling the downloading process as an optimization problem, and maximizing the overall system throughput. Our approach allows us to investigate the impact of different factors, such as the roadside infrastructure deployment, the vehicle-to-vehicle relaying, and the penetration rate of the communication technology, even in presence of large instances of the problem [7]. We then evaluated practical protocols for vehicular downloading, devising solutions for the selection of relay vehicles and data chunks at the Road Side Units (RSUs), and evaluating them in real-world road topologies, under different infrastructure deployment strategies [8].

Our results show that V2V transfers can significantly increase the download rate of vehicular users in urban/suburban environments, and that such a result holds throughout diverse mobility scenarios, RSU placements and network loads. Also, they highlight the existence of two operational regimes at different penetration rates and the importance of an efficient, yet 2-hop constrained, V2V relaying.

6.3.2. Toward green mesh and cellular networks.

On the one hand, a promising technique for minimizing the transmission power of cellular networks seems to be a dramatic densification of micro-cells coverage. On the other hand, increasing the number of micro-cells multiplies the energy consumed by the cells whatever their state, idle, transmitting or receiving. 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 there are not absolutely needed. The densification of the cells induces the need for an autonomic control of the on/off state of cells. This has motivated a preliminary investigation on exploiting within the micro-cellular settings the manifold results of duty cycles for Wireless Sensor Networks where switching nodes on and off is done in a distributed or localized manner while coverage and connectivity properties are maintained [29].

Focusing on broadband wireless mesh networks based on OFDMA resource management, and considering a realistic SINR model of the physical layer with a continuous power control and discrete transmission rate selection at each node, we have investigated the trade-off between transmission energy consumption and network capacity [24]. Correlation between capacity and energy consumption is analyzed as well as the impact of physical layer parameters - SINR threshold and path-loss exponent. We highlight that there is no significant tradeoff between capacity and energy when the power consumption of idle nodes is important. We also show that both energy consumption and network capacity are very sensitive to the SINR threshold variation. We also highlight that power control and rate selection are not expandable to an optimal system configuration.

6.4. Miscellaneous security issues in capillary networks.

Participants: Ochirkhand Erdene-Ochir, Fabrice Valois, Marco Fiore

6.4.1. Resiliency in routing protocols.

Within the ARESA2 project, we defined the notion of resiliency for routing protocols in wireless sensor networks and we applied it to several routing strategies to provide an understandable taxonomy [3]. Efforts have been made to compare routing protocols according to their resiliency in wireless multi-hop sensor networks in the presence of packet dropping malicious insiders. In [13], we proposed a new taxonomy of routing protocols obtained by applying our resiliency metric. Several resiliency enhancing methods such as introducing a random behavior to the classical routing protocols and a new data replication method based on the distance information have been evaluated as well. Simulation results demonstrate the effectiveness of the proposed approach.

6.4.2. Verifying the positions announced by mobile nodes.

A growing number of ad hoc networking protocols and location-aware services require that mobile nodes learn the position of their neighbors. However, such a process can be easily abused or disrupted by adversarial nodes. In absence of a-priori trusted nodes, the discovery and verification of neighbor positions presents challenges that have been scarcely investigated in the literature.

We proposed a fully-distributed cooperative solution that is robust against independent and colluding adversaries. Results show that our protocol can thwart more than 99% of the attacks under the best possible conditions for the adversaries, with minimal false positive rates [5].

A centralized solution was also developed, that leverages anonymous position beacons from vehicles, and the cooperation of nearby cars collecting and reporting the beacons they hear. Such information allows an authority to verify the locations announced by vehicles, or to infer the actual ones if needed [18].

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

- Two bilateral collaborations are running since 2009 with Orange Labs, and another one since 2008. These collaborations include the supervision of Ph.D. students into a common research program (heterogeneity in wireless sensor networks, resiliency and security of routing protocols, quality of service support of WSN). These three collaborations ended in 2012.
- Two short-term bilateral collaborations, also with Orange Labs, were pursued in 2012: a 4 months project in quality of service in WSN (joint supervision of a master student), and a 2 months project on the SensORLab testbed, deployed in Orange Labs (Meylan).
- A new bilateral collaboration with Orange started in November 2012. This CRE includes the supervision of a CIFRE thesis about multi-topology routing protocol and service level agreement for wireless sensor networks.
- One short-term bilateral collaborations with Thalès was done during 4 months, as a preliminary research project for a Ph.D. student. Unfortunately, no candidate with solid/strong background applied for this position yet. This project should start in 2013.

8. Partnerships and Cooperations

8.1. Regional Initiatives

- ARC 7 PhD Grant on Urban mobility measurement for citizen-oriented services cartography.
  Participants: Trista Lin (PhD), Marco Fiore, Hervé Rivano, Fabrice Valois. In collaboration with Frédéric Le Mouel (CITI) and Lyon Urbanism Agency.
- ARC 7 animation grant for organizing the "Digital Cities days".
- BQR INSA 3 years project on "Network architecture for Buildings and Energy" (ARBRE).
  Participants: Hervé Rivano, Fabrice Valois. In collaboration with CETHIL (energetic modeling), LIRIS (database management) and EVS (social science).

8.2. National Initiatives

8.2.1. ANR

- ANR Verso ECOScells 10/2009-12/2012
  Participants: Anis Ouni, Hervé Rivano, Fabrice Valois
  The objective of ECOScells is to study energy efficient microcells networks. Hervé Rivano is leader for Inria side and of the work package focusing on energy efficient wireless backhauling.
- ANR ARESA2 03/2010-08/2013.
  Participants: Alexandre Mouradian, Isabelle Augé-Blum, Fabrice Valois
  The partners in the ANR ARESA2 project are: Orange Labs, Coronis, Inria, LIG, Télécom Bretagne, VERIMAG. Our contributions focus on: resiliency of routing protocols in WSN; how to exploit the heterogeneity in wireless multi-hop network; real-time and QoS support in routing protocols for WSN. This project will end in August 2013. Alexandre Mouradian (Ph.D student) is funded by ARESA2.

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.

8.3. International Initiatives

8.3.1. Inria International Partners

- Universidade Federal do Ceara (Brazil): Joint publication [6] with Claudia Linhares Sales on proportional coloring for wireless mesh networks.
- University of Waterloo (Canada): Collaboration with Catherine Rosenberg on optimization of wireless mesh networks.
- Politecnico di Torino (Italy): Multiple publications [4], [5], [7], [18] co-authored with members of the Telecommunication Networks Group.
- Universidade Federal de Minas Gerais (Brazil): Collaboration with Pedro Vaz de Melo on mobility analysis [26].
- Ecole Polytechnique Fédérale de Lausanne (Switzerland): Collaboration with Florian Huc on proportional coloring for wireless mesh networks [6].
- A new collaboration started with Université of Yaoundé 1 into the LIRIMA framework. Fabrice Valois works with Prof. Maurice Tchuente and a joint Ph.D. thesis started: the research topics of M. Rodrigue Domga Komguem focus on the use of wireless sensor networks for intelligent transport systems (ITS).

8.4. International Research Visitors

8.4.1. Visits of International Scientists

Delia Ciullo (04/2012)

Subject: Sleep Mode Effectiveness in Cellular Networks

Institution: Politecnico di Torino (Italy)

Catherine Rosenberg (06/2012)

Subject: Resource Allocation, Transmission Coordination and User Association in Heterogeneous Cellular Networks

Institution: University of Waterloo (Canada)

Prasan Kumar Sahoo (11/2012)

Subject: Wireless Sensor Networks: Applications and Research Issues

Institution: University Chang Gung (Taiwan)

8.4.2. Visits to International Teams

- Marco Fiore visited with monthly frequency the Telecommunication Networks Group of the Politecnico di Torino, Italy. The cooperation focused on the topics of content download in vehicular environments and mobile user position verification.
- Marco Fiore visited the Hamilton Institute, Ireland, on October 2012. He gave an invited talk and discussed possible cooperation between UrbaNet and the Hamilton Institute.
- In last August, in the frame of the "Saisons Croisées France-Afrique du Sud", with the collaboration of the French Foreign Office and with the support of the Inria foreign office, Fabrice Valois participated to a common workshop on the use of wireless sensor networks for South-African applications. This workshop was held in Stellenbosch University, and was organized jointly by the communications group of Stellenboch University and the Inria project FUN (Dr. Nathalie Mitton). In this context, Fabrice Valois gave lectures and participated to a tutorial on Senslab. In September, a project proposal was submitted with these collaborators. Last November, a new research meeting was held in Inria Lille, hosted by the FUN team.

- In November, Hervé Rivano, Fabrice Valois, Razvan Stanica and Quentin Lampin participated to the Wireless Days conference in Dublin, Ireland. As Dublin academic institutions are very active in the area of urban networking and applications, we extended our stay and met with research teams from the Hamilton Institute and Dublin City University, as well as with French Embassy staff, to discuss possible collaborative activities.

9. Dissemination

9.1. Scientific Animation

- Marco Fiore organized and co-chaired the First Workshop on Urban Networking (UrbaNe'12), held jointly with the international conference ACM CoNEXT 2012.
- Marco Fiore was co-chair of the "Wireless Networks, Access Control and Resource Management" track at the international conference IEEE VTC'13 Spring.
- Marco Fiore was the keynote speaker at the IEEE WoWMoM VTP workshop in June 2012.
- Marco Fiore is/was TPC member for a number of international conferences, including IEEE SECON 2013, IEEE/IFIP WONS 2012/2013, IEEE WoWMoM 2012/2013, IEEE ICCCN 2012.
- Hervé Rivano is a member of the Section 07 of the CoNRS (scientific committee of CNRS, section ICT).
- Hervé Rivano is a member of the scientific committee of the Rescom pole.
- Hervé Rivano is a member of the CITI laboratory council.
- Razvan Stanica was session chair for the "Energy in Ad Hoc and Sensor Networks" session at the international conference IFIP Wireless Days 2012.
- Fabrice Valois is elected in the CITI laboratory council.
- Fabrice Valois was TPC member for a number of international conferences, including IEEE ICC, IEEE GlobeCom, IEEE WiMob, IEEE PIMRC, IEEE AINA, IEEE WPMC, SensorCom, iCost, IWCMC, GIIS.
- Fabrice Valois is in charge of the foreign affairs of the CITI laboratory.
- Fabrice Valois is correspondent member for the Labex IMU.
- Marco Fiore and Hervé Rivano are members of the Labex IMU.
- Khaled Boussetta was co-chair of the Technology track at the international conference GIIS 2012.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence :

- Marco Fiore, Introduction to Computer Networking, 30h, L3, INSA Lyon, France
- Razvan Stanica, TC Informatics Passport, 30h, L3, INSA Lyon, France
- Fabrice Valois, IP Networks, 50h, L3, INSA Lyon, France

Master :

- Marco Fiore, Performance evaluation of telecom networks, 80h, M1, INSA Lyon, France
- Marco Fiore, Advanced wireless networking, 20h, M1, INSA Lyon, France
- Marco Fiore, Services and protocols for wide-area networks, 90h, M1, INSA Lyon, France
- Marco Fiore, Future networking, 8h, M2, University of Lyon, France
- Fabrice Valois, Cellular networks, 50h, M1, INSA Lyon, France

- Fabrice Valois, Wireless sensor networks, 10h, M2, University of Lyon, France

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

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 and Marco Fiore are elected members of the Telecommunications Department Council at INSA Lyon.

Marco Fiore is the responsible for all Master theses defended in the Telecommunications Department at INSA Lyon, coordinating the related administrative activities.

9.2.2. Supervision

PhD :

- Ibrahim Amadou *Protocoles de routage sans connaissance de voisinage pour réseaux radio multi-saut*, INSA Lyon, 09/2012, Advisor: Fabrice Valois
- Bilel Romdhani *Exploitation de l'hétérogénéité des réseaux de capteurs et d'actionneurs dans la conception des protocoles d'auto-organisation et de routage*, INSA Lyon, 07/2012, Advisor: Fabrice Valois

PhD in progress :

- Jin Cui *Aggregation: From data dynamics to network dynamics*, since 11/2012. Advisor: Fabrice Valois.
- Ochirkhand Erdene-Ochir *Resilient networking security for WSN*, since 10/2009. Advisors: Marine Minier and Fabrice Valois
- Guillaume Gaillard *Multi-topology routing in IP-based wireless sensor networks with SLA support*, since 12/2012. Advisor: Fabrice Valois.
- Rodrigue D. Komguem *Autonomous WSN architectures for road traffic applications*, since 11/2012. Advisors: Fabrice Valois and Maurice Tchuente (Univ. Yaoundé, Cameroun)
- Quentin Lampin *QoS constraints and time constraints in WSN*, since 10/2009. Advisors: Isabelle Augé-Blum and Fabrice Vlaois.
- Trista Lin *Urban mobility measurement and citizen-oriented services cartography*, since 10/2012. Advisors: Frédéric Le Mouel, Hervé Rivano and Fabrice Valois.
- Alexandre Mouradian *Real-time communication protocols for WSNs*, since 10/2010. Advisors: Isabelle Augé-Blum and Fabrice Vlaois.
- Diala Naboulsi *Human mobility - an urban networking perspective*, since 10/2012, Advisors: Marco Fiore, Hervé Rivano and Fabrice Valois.
- Anis Ouni *Study and optimization of capacity and energy consumption trade-off in wireless mesh networks*, since 10/2009. Advisors: Hervé Rivano and Fabrice Valois.
- Sandesh Uppoor *Understanding and exploiting mobility in wireless networks*, since 10/2010, Advisors: Marco Fiore and Fabrice Valois.

9.2.3. Juries

- Fabrice Valois was external reviewer of the following HDR defense:
  - N. Malouch, *Studying and Improving Various Control Mechanisms in Today's and Future Networks*, LIP6, Université de Paris VI, 2012
- Fabrice Valois was external reviewer of the following Ph.D. defenses:
  - B. Pavkovic, *Going towards the future Internet of Things through a cross-layer optimization of the standard protocol suite*, LIG, Universite de Grenoble, 2012

  - S. Bellahsene, *Prédiction de la mobilité pour la gestion des handovers dans les réseaux IP : modèles et algorithmes*, PRiSM, Université de Versailles, 2012
  - G. Corbellini, *Adaptative Medium Access Control for Heterogeneous Wireless Sensor Networks*, LIG, Université Joseph Fourier, 2012
  - I. Salhi, *Un codage réseau contraint pour les réseaux de capteurs sans fil*, Institut Gaspard Monge, Université de Paris-Est, 2012
  - Y. Mezali, *Algorithme de géolocalisation intérieure par différentiation de signaux WIFI*, Hipercom, Université Paris VI, 2012
- Fabrice Valois was external examiner of the following Ph.D. defense:
  - M. Iturralde, *Performance des réseaux LTE*, IRIT, Université de Toulouse, 2012
- Fabrice Valois was member of a CoS 27MCF for a position of MCF at University of Avignon.
- Fabrice Valois was president of a CoS 27MCF for a position of MCF at INSA Lyon.
- Marco Fiore was member of a CoS 27MCF for a position of MCF at INSA Lyon.

9.2.4. Internships

Florin Avram (L3)

Subject: Networking analysis of metropolitan-scale vehicular mobility

Institution: University of Oradea (Romania)

Advisor: Marco Fiore

Duration: 4 months

Calin Rares Lucaciu (L3)

Subject: Networking analysis of metropolitan-scale vehicular mobility

Institution: University of Oradea (Romania)

Advisor: Marco Fiore

Duration: 4 months

Piotr Mach (L3)

Subject: Vehicular Connectivity Graphs in Urban Environments

Institution: Warsaw University of Technology (Poland)

Advisor: Marco Fiore

Duration: 4 months

Carl Nolan (L3)

Subject: Vehicular Connectivity Graphs in Urban Environments

Institution: Dublin City University (Ireland)

Advisor: Marco Fiore

Duration: 4 months

Egert-Priit Arus (L3)

Subject: Integrating Electric Vehicles with Smart Grids

Institution: Tallin University of Technology (Estonia)

Advisor: Razvan Stanica

Duration: 4 months

Keijiro Nakagawa (L3)

Subject: Multi-commodity flow in delay tolerant networks

Institution: Tokyo University (Japan)

Advisor: Hervé Rivano
Duration: 4 months

Yesser Bouguerra (M2)
Subject: Data aggregation in multi-hop wireless networks
Institution: INSA Lyon (France)
Advisor: Fabrice Valois
Duration: 6 months

Nicolas Gaspard (M2)
Subject: Multi-service routing in urban wireless sensor networks
Institution: INSA Lyon (France)
Advisor: Fabrice Valois
Duration: 6 months

Mickael Lam (L3)
Subject: Large scale vehicular networks
Institution: INSA Lyon (France)
Advisor: Marco Fiore
Duration: 4 months

Trista Lin (M2)
Subject: Optimization of MAC layer protocols for urban wireless sensor networks
Institution: INSA Lyon (France)
Advisor: Fabrice Valois and Hervé Rivano
Duration: 6 months

Iulia Tunaru (M2)
Subject: Applying sensor networks energy efficiency solutions to mesh networks
Institution: INSA Lyon (France)
Advisor: Fabrice Valois and Hervé Rivano
Duration: 6 months

Diala Naboulsi (M2)
Subject: Large scale vehicular networks
Institution: INSA Lyon (France)
Advisor: Marco Fiore
Duration: 6 months

9.3. Popularization

- Fabrice Valois gave a seminar on the Internet of Things entitled *Etat de l'art sur les réseaux de capteurs*, organized by the ASPROM Association in Paris in October 2012.

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Publications of the year

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[11] D. Barthel, Q. Lampin, I. Augé-Blum, F. Valois. *Exploiting Long-Range Opportunistic Links to Improve Deivery, Delay and Energy Consumption in Wireless Sensor Networks*, in "IEEE International Conference on Mobile Ad hoc and Sensor Systems (IEEE MASS)", Las Vegas, Nevada, October 2012, 5, http://hal.inria.fr/hal-00759061.

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