



Activity Report 2018

Team ADOPNET

Advanced Technologies for Operated
Networks

D2 – RESEAUX, TELECOMMUNICATIONS et
SERVICES



1 Team composition

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2 Overall objectives

2.1 Overview

To access the Internet, end-users can use various types of network access technologies (e.g., optical, cellular, and WiFi). This variety of technologies is one of today's approaches to cope with two sustained trends:

- The growing heterogeneity of terminals that are connected to the Internet, driven, in part, by the increasing adoption of Machine to Machine (M2M) communication. For example a home media center with a fiber connection differs from a connected drone on multiple aspects, including mobility, energy constraints, and availability.
- The growing heterogeneity of applications that rely on the Internet to communicate. For example, a Ultra High Definition (UHD) video service requires a bandwidth greater than 20 megabits per second (Mbps) while uploading measurements from a sensor can require only a few bytes per minute.

Very different transmission technologies are required on the access to cope with this heterogeneity. Even though the IP protocol has been widely adopted, leading to a widespread *connectivity*, by itself it is not enough to offer *seamless communications*. For instance, somebody using a smart phone connected to a WiFi network will have to restart most of his communications (e.g., downloading a file, a VoIP call) when switching to a 4G interface.

Operators, motivated by reducing capital expenditures, are interested in using the same physical infrastructure to consolidate different access and aggregation networks, a process often referred to as *network convergence*. One of the key problems that has not yet been addressed by the research community is to unify the control planes of the different networks. Such a solution can offer several advantages, including energy efficiency, reliability, availability, privacy, security, and ease of configuration. It is however still an open challenge.

To deal with heterogeneous applications and terminals, network operators also have to design new content delivery systems. Although the research community has worked on increasing the transmission rate for years, the demand of content providers has changed. In particular, the next generation content delivery systems are expected to be more adaptive (to deal with heterogeneous terminals), and more reactive (to support interactive services). The new architectures and protocols will rely in particular on the availability of computing and storage resources at the edge of the network, and on the widespread adoption of software-based solutions, especially service virtualization. The research is still in its infancy in the area, despite a growing attention in recent years, especially with the intensive work on 5G.

The higher degree of heterogeneity leads to an increased variability of the behavior of the network, over time and over space. The availability of services, some of them being central for the resilience of the network, is also under threat because of the increasing complexity and intensity of attacks against infrastructures. Thus, network monitoring is a key function for operators in order to enable the network to detect anomalies, to

take counter-measures to mitigate them and to adapt to the behavior of end users and applications.

The ADOPNET team will contribute to the specification of architectures, protocols, control mechanisms, and monitoring mechanisms for the next generation access and aggregation networks. Our goal is to build networks that are flexible, adaptive, energy-efficient, secure, and able to deliver content on a large scale to various types of terminals. The ADOPNET project will in particular address the convergence of access networks, the combination of radio and optical technologies, and adaptive software-based content delivery networks.

The focus of the ADOPNET project is on the access and aggregation networks. The core networks will be only marginally addressed and the field of ad-hoc networks and home networks is clearly excluded from the project. We distinguish three main research axis: (i) content delivery, (ii) network control, and (iii) network monitoring.

2.2 Scientific foundations

Since the objective of a network is to interconnect various types of devices and to share different types of resource (information, storage capacity, computing power), studying network is by nature a multi-disciplinary activity. Furthermore, it requires an holistic approach because the global optimization of network must take into account several criteria (including transmission bit rate, latency, energy) and various types of constraints (*e.g.*, robustness and simplicity of the protocols, and scalability). In many cases, simulations and implementations on test beds are required to analyze the global performance. However, when the analysis is focused on a particular mechanism, several scientific tools can be used like stochastic analysis or discrete optimization.

2.2.1 Mathematical methods and models

Keywords: decision theory, estimation theory, classification, data stream mining, queuing systems analysis, Markov chains, large deviation theory, game theory, linear programming.

Traffic is an object of studies in itself and as such it can be analyzed in order to discover interesting properties such as long range dependence, non stationarities, non-gaussianity, or heavy tailed distributions. It is necessary to produce accurate traffic models in order to predict, for example, the utilization of resources or the quality of service. Very often traffic models are of stochastic nature. They can be very simple such as a Poisson process or more sophisticated such as Markov modulated models or, for example, fractional Brownian motions. These models are often parametric and their parameters must be estimated by the analysis of traffic captures.

The theory of queuing systems is used in order to predict the performance offered to the applications. It can be used to analyse the cost of mobility management in mobile networks as signalling related to mobility management represents a more and more important part of the total traffic. It is also useful for the analysis of the performance of complex link layer protocols in radio networks.

2.2.2 Discrete Optimization

Keywords: optimization, integer linear programs, approximate algorithms, exact algorithms, heuristics.

Operations research is a scientific area that has developed a special relation with network. The network resource (memory, processing, data rate, radio spectrum) is inherently limited. However, network operators should provide a quality of service (QoS) as good as possible. It is thus common that network scientists formulate optimization problems with an objective function to minimize (or maximize) subject to various constraints.

For example, network design relies on minimizing the cost of the resources requested to support a given traffic matrix. The traffic matrix is based on "busy hour" traffic flow predictions by the operator. Supporting the traffic on the network can often be expressed as a set of linear equations, involving traffic flows and sets of resources. Linear programming is then used to minimize the cost of resources. For small networks, an exact solution can be identified, thanks to mathematical solvers whereas large network design often relies on various heuristics.

2.2.3 Hardware and software traffic processing

Keywords: traffic analysis, commodity hardware, Linux, DPDK, Lua, hardware acceleration, FPGA, SDN.

A major challenge for network operators is to be able to process traffic at very high bit rates. They have to face an exponential increase in the traffic because of the deployment of optic fiber based technologies in the access and because of the rise of video traffic demand. On the other hand one has to implement more and more sophisticated treatments in order to optimize bandwidth usage, to offer a good quality of service and to guarantee the security of the network. In order to deal with high bit rate traffic several approaches must be used. One can leverage on the capabilities offered by parallelization on multi-core architectures or even on GPU. Optimized commodity hardware based traffic capture and analysis can scale up to dozens of Gb/sec without packet loss. Another solution is to use hardware acceleration on FPGA boards in order to speed up some treatments. Software defined networking (SDN) with OpenFlow is an innovating technology to permit a centralized control of network resources and to implement with a software approach various traffic management protocols.

2.2.4 Protocol Design for Optical Networks

Keywords: Medium Access Control, Label Based Switching, Reservation, Scheduling, GMPLS, SDN, POADM, TWIN.

Introducing optical technologies into network architecture implies designing new protocols for both transfer and control planes. This is mostly true for *transparent* or *translucent* optical technologies, that do not rely at all (or rely only partially) on Optical

to Electronic (OE) conversions.

Optical circuits build upon the sets of wavelengths made available by WDM are commonly used in the backbone's transport layer. However, a wavelength granularity may be too coarse in many situations where some small flows have to be supported as e.g. in metro/aggregation networks. In that case, a finer (sub-wavelength) granularity is requested, that can be delivered by Optical Packet Switching (OPS) or Optical Burst Switching (OBS). Both OPS and OBS offer an optical packet-based transfer but differ by the method used to carry control information; in OPS, a header is appended to each data packet on the wavelength uses to carry client data whereas in OBS, a separate wavelength is used to carry control-related information.

Optical transfer plane significantly differs from existing electronic transfer planes. One major difference is the lack of easily implemented buffering facilities in the optical domain, which precludes implementing buffering as the major contention control mechanism. Therefore, contention has to be avoided in other manners, e.g. by designing complex scheduling mechanisms, as in the upstream direction of Passive Optical Networks. Static or dynamic reservation schemes can also be implemented in the control plane in order to avoid contention in the transfer plane. Another difference between electronic and optical networks is that the transfer rate of a given optical channel can be dynamically controlled; this feature is very useful e.g. to activate backup resources in case of failures.

2.3 Application domains

2.3.1 Content Delivery

Participants: Bernard Cousin, Annie Gravey, Gwendal Simon, Bruno Stévant, Sandrine Vaton, Mariem Ben Yahia, Xavier Corbillon, Hristina Hristova, Kuhn He.

The traffic related to multimedia content, and in particular video, has increased significantly over the past few years. This growth is expected to continue with the advent of new video formats (e.g., HEVC, multi-view, and Ultra High Definition) and the integration of multimedia into our daily lives (e.g., video in education). More generally, the world is switching from TV with a handful of broadcasters to OTT (Over-The-Top) video services with thousands of broadcasters. And even bigger challenge is presented by the new features of multimedia services, such as interactivity, personalization, and adaptability.

Today's multimedia services offer some interactive features, where the end-users can control the video consumption to some extent. Multimedia services have more stringent requirements related to interactivity. For example, cloud gaming requires an overall response time below 120 ms for an acceptable Quality of Experience (QoE). This trend is expected to be even stronger in the next years due to the popularity of haptic controllers. The latency of today's cloud architecture is not low enough to guarantee QoE for users of such interactive services. To address the needs in content delivery with ultra-low response time, the most appealing architecture is a Content Delivery Network (CDN) with servers that are very close to the end-users, in other words at the edges of the network. It is thus natural that network operators develop their ability to leverage

devices close to the end-users.

In the meantime, the personalization of multimedia services is also a major, sustainable trend. With the wide adoption of HTTP Adaptive Streaming technologies, the servers propose several representations of a given video, and it is up to the end-users to choose the representation that best matches their characteristics. The CDNs have to take into account the characteristics of every end-user to prepare the content, distribute it to the edge servers, and deliver it to the end-users.

The objective of ADOPNET is twofold:

- to contribute to the development of new technologies to enhance multimedia delivery. For example Adaptive Streaming for Multimedia Broadcast Multicast Services (eMBMS) and video-friendly Multi-Path End-to-End Protocols (MPTCP).
- to work on architectures for content delivery. For example content placement, network dimensioning and server management in the fog.

2.3.2 Network Control

Participants: Isabel Amigo, Alberto Blanc, Bernard Cousin, Annie Gravey, Cédric Gueguen, Xavier Lagrange, Romaric Ludinard, Loutfi Nuaymi, Géraldine Texier, Iaad Ben Dhia, Marwa Chami, Ayman Chouayakh, Ali El Amine, Mahdi Ezzaouia, Ahmad Fadel, Rabah Guedrez, Mauricio Iturralde, Tanguy Kerdoncuff, Najmeddine Majed, Cédric Morin, Alassane Samba, Farah Slim, Cesar Vargas.

Today, customers can access services via fixed line networks or via radio access networks (RAN). Controlling these access networks consists in both performing control of each access network, and allowing concurrent access to several such networks. Up to now, fixed and mobile access networks have been optimized and have evolved independently, with partly contradicting trends (e.g., centralization of fixed networks, decentralization of mobile networks). Currently, there is a complete functional and physical separation of fixed line access/aggregation networks and mobile networks.

Fixed Mobile Convergence (FMC) at network level focuses on the design of procedures enabling the users to dynamically select one access network (or possibly several) for a given service, and enabling network operators to effectively share deployed resources (links and equipment) between fixed and mobile accesses. The advent of Digital-Radio-over-the-Fiber technologies (and the companion Cloud-RAN concept) and the generalization of heterogeneous cellular networks increases both the dynamicity and the heterogeneity of the traffic flows that the access/aggregation networks should accommodate. It raises new issues for optical networks, which can be addressed by developing virtualization techniques in order to have easily manageable networks and optical switching in order to combine energy efficiency and high quality of service. From a pure radio point of view, it also extends the possibility of developing multi-radio-access-technology (RAT) selection algorithms and opportunistic energy efficient radio resource management procedures.

- *Virtualization of optical networks.* Transmissions on optical fibers have unique features: large bandwidth, low loss, low cost, light weight, immunity to elec-

tromagnetic interference and corrosion resistance. However, the management of optical network is a very challenging task. Network virtualization can provide a very efficient management and thus, a very efficient use of available network resources. By using network virtualization solutions, network resources can be managed as logical services, rather than physical resources. Due to the high degree of manageability provided by network virtualization, network operators can improve network efficiency and maintain high standards of flexibility, scalability, security, and availability. As a result, it reduces capital and operational costs for network operators.

- *Advanced optical networks.* Several forecasts have emphasized that distribution/aggregation networks, also called Metro Area Networks (MAN), are particularly impacted by traffic evolution. Future MANs should fulfill several requirements: quick adaptation to varying traffic demands, efficient support of both fine granularity and large volumes of traffic demands, possible isolation of different clients' flows, together with an excellent QoS, energy efficiency and low Operational Expenditures (OPEX). Optical packet/burst switching (OPS/OBS) combines sub-wavelength granularity, optical transparency and is thus energy efficient. The challenge is to achieve a high multiplexing gain together with a QoS similar to the one provided by electronic switching and to develop efficient MAC (Medium Access Control mechanisms) with contention avoidance. In the context of Fixed-Mobile Convergence, fiber-based access technologies can be used for fronthauling and backhauling traffic generated by mobile users. Our objective is to propose a dynamical and adaptive control of interfaces and routes to allow an efficient use of available resources in access and aggregation networks.
- *Multiple Access Technology Selection.* Different RATs, including 3GPP families and IEEE ones, are now widely deployed. A key feature will be an increased integration of both the fixed access and the different RATs. Our objective is to consider two aspects: i) the optimization of the architecture to allow a better integration of the different access technologies in a convergence perspective, ii) the optimization of the selection algorithms.
- *Radio Resource Management.* Radio Resource Management (RRM) algorithms or heuristics are a key element for providing high system throughput and high mobile user satisfaction. We focus on two aspects of RRM: power allocation and scheduling. We work on RRM issues in cellular networks where part of the energy comes from renewable sources such as wind and solar. We also consider RRM proposals for cellular M2M with different QoS requirements and according to different criteria, starting with energy efficiency. We propose opportunistic scheduling techniques, which take advantage of multi-path fading and multi-user diversity to provide high throughput. Our specific approach is to take into account the variability of the traffic and the queuing aspects. We propose scheduling algorithms for hybrid networks where a terminal can relay the traffic of some others and propose to combine it with opportunistic routing.
- *Traffic Engineering and Quality of Service.* Traffic engineering techniques allow to control networks for better resource utilization, resiliency, robustness and quality of service. However, the ossification of the Internet, among others, puts limits to

end-to-end QoS. New paradigms such as SDN allows to rethink control of networks in the WAN-scale and at the inter-domain level, through the introduction of a centralized brain which allows for more complex solutions, which are at the same time more easily implemented thanks to standardization and abstractions.

2.3.3 Network Monitoring

Participants: Isabel Amigo, Alberto Blanc, Gwendal Simon, Sandrine Vaton, Antoine Saverimoutou, Maha Mдини, Santiago Ruano Rincon, Maxime Mouchet.

Network monitoring refers to the observation of network and traffic by means of probes of different types and by the analysis of measurements. The goal is to gain information about the traffic or the state of the network and its devices.

The dramatic increase of traffic due to the popularity of video contents and increased data rates in access networks puts high pressure on the design of probes: they should be fast enough to capture traffic without sampling and easily configurable. Advanced data analysis methods should be used in order to process measurements, build traffic models or rise alarms in case of anomalies. It is also necessary to orchestrate the measurements at different probes, to semantically analyse the different sources of information and to communicate from the measurement layer to other layers to trigger counter-measures.

Network monitoring finds applications in various areas. A first application is the characterization of network usage (e.g. bandwidth consumption and variability). A second application is to characterize the network infrastructure in order to assist the network operator in the task of operating and maintaining the network. A third application of network monitoring addresses security issues, for example the early detection of attacks distributed through botnets. A fourth application concerns monitoring users' quality of experience, for example the quality of web navigation.

- *Traffic monitoring acceleration for flexible and very high capacity traffic monitoring probes.* We develop the concept of traffic monitoring acceleration in order to reach bit rates of dozens to hundreds of Gb/sec. We develop different approaches, some are based on hardware acceleration on FPGA and others are based on specific capture engines and optimization mechanisms in software.
- *Detection/localization of failures in access networks.* Failures in access networks trigger hundreds of alarms and it is very difficult to find the root causes of these alarms with rule based methods. Indeed the number of rules to maintain in order to take into account any possible case is very large. It is interesting to complement rule based approaches with probabilistic approaches that model the dependencies between failures, alarms and signal levels on the network equipments. In particular we develop an approach based on Bayesian network modelling in order to locate failures in GPON-FTTH networks.
- *Traffic anomaly detection for network security.* Anomalies in traffic can reveal ongoing attacks such as flooding attacks. Traffic anomaly detection involves building traffic models, continuously monitoring traffic in order to extract appropriate traf-

fic descriptors and triggering an alarm when the observed behavior significantly diverges from the model.

- *New metrics and methods to measure the quality of web navigation.* It is important to understand which are the different factors that contribute to the quality of experience of web navigation, to monitor this QoE and to identify the reasons of a degradation. Network performance but also the performance of web browsers and the way web sites are designed have an impact the quality of navigation. New metrics have been defined by the W3C but differences in their implementation lead to unreliable results. New protocols such as QUIC must also be taken into account since many monitoring methods are made obsolete by ciphering. Our objective is to design new metrics and methods to measure the quality of web navigation in this changing landscape.
- *Big Data technologies for network management.* One of our objectives is to conceive a mechanism that allows the gathering of fine-tuned data about the QoS actually perceived by the end-users in (almost) real time. Moreover, a related objective is to identify whether the cause of a QoS degradation is internal to the network operator or due to an actor out of the scope of the network operator. A consequence of such approach is that the network operator would be able to manage their network based on the client-perceived QoS (or QoE) rather than on the traditional network equipment QoS. This objective requires to analyze data from a huge number of sources, and thus to develop statistical tools that group data flows and find correlations in subset of data
- *Parcimonious monitoring.* Continuous monitoring of network resources enables to make more-informed resource allocation decisions but incurs overheads. There is a trade-off between monitoring costs and the benefits of accurate state information. Let us consider for example a routing overlay. Routing overlays are a possible alternative solution to the ossification of the Internet and the problems of quality of some Internet routes. The nodes of a routing overlay measure with active probes the quality of the IP routes between them, and they collaborate to route the traffic to destination (each node acting as a routing proxy). An *all-pair probing* approach would assume that all the links of the overlay are continuously monitored. This approach is definitely not scalable as it would require $O(n^2)$ measures at each time step where n is the number of nodes of the overlay. An objective is to design efficient monitoring and routing strategies to discover optimal routes with a scalable probing effort, in order to build a routing overlay that can be widely deployed over a sizable population of routers.
- *Statistical characterization of performance metrics.* Traffic and performance metrics are an object of study by themselves. We are interested in developing new statistical models to characterize the traffic and network performance (for example, delay or bandwidth). The goal is to design accurate models, to develop some algorithms to calibrate the parameters of these models from real measurements, and to demonstrate their accuracy. These models will be an input for diverse network management tasks, such as the parcimonious monitoring problem in a routing overlay context that we have just mentioned above.

3 Scientific achievements

3.1 New technologies to enhance multimedia delivery

Participants: Mariem Ben Yahia, Xavier Corbillon, Bernard Cousin, Kun He, Hristina Hristova, Gwendal Simon.

Virtual Reality and Omnidirectional Videos.

The rise of immersive media is expected to be a major digital disruption in the next decade. The growing popularity of these applications calls for the development of new delivery approaches. Our team is one of the most visible research labs in the area.

We have kept on working on the delivery of 360-degree videos where the quality of the frames that are displayed to the users depends on the head orientation. In [25], we have proposed a new model for the optimal settings of the video tiles, this approach being considered as the most efficient for content delivery. In [38], we have challenged this idea about video tiling and we have studied other approaches for the preparation of content with heterogeneous quality.

One of the main problems related to 360-degree video delivery is that the client has to download video segments in advance, based on the prediction of the head orientation in the next seconds. We have made two studies in the area. The first one is a novel approach for more accurate predictions. The main idea is to identify regular trajectories in the traces of previous clients and to predict that a new user is likely to follow one of the trajectories [46]. The second study is related to the behavior of the downloading algorithm when the prediction changes before the deadline. Sometimes, the client has enough time to download other content; we have developed optimal solution in this area [53].

Finally, another idea that is now rising in the area is that watching 360-degree video is not enough and users call for even more autonomy: he/she wishes not only rotational but also translational movements within the virtual space, which leads to *6 degrees of freedom* (6-DoF). We have studied 6-DoF, where a scene is captured from multiple viewpoints and people can switch from one viewpoint to another. This application raises new challenging problems. We have been the first to develop new delivery algorithms in this regard [29].

The work on immersive media has resulted in the successful defense of a PhD by Xavier Corbillon [1].

Improving Live Rate-Adaptive Video Streaming.

The delivery of live video on the Internet is still a major research problem given the increasing popularity of the services (for example Netflix) and the growth of the video quality. We have made some contributions to improve the performance of the now widely adopted rate-adaptive streaming such as DASH (Dynamic Adaptive Streaming over HTTP).

HTTP Adaptive Streaming is successful but poor bandwidth prediction, notably in mobile networks, may cause bit-rate oscillations, increased segment delivery delays, video freezes, and may thus negatively impact the end user quality of experience. To address this issue, we propose in [23] to exploit the stream prioritization and termination features of the HTTP/2 protocol to achieve video frame filtering and scheduling, so as to maximize the amount of video data received on time by the client. We evaluated with optimal scheduling and filtering algorithms the maximum gain we may expect from such delivery schemes where video frames are carried in dedicated HTTP/2 streams. Evaluation showed that our HTTP/2-based video frame scheduling scheme brings benefits for video quality.

We have worked on the management of CDN in the context of live delivery. Our first work has focused on load balancing the load over the different relay of CDN in the context of live streaming [14]. Our second work has been on the placement of network services, especially in the context of mobility [13]. The expertise that has been developed over the years in the area of interactive live streaming management has also been consolidated in a survey paper in a journal [7].

Finally, we have addressed the protection of stakeholders and the right of the video owner by the implementation of watermarking strategies for video streams. In [37], we have worked on the optimisation of the delivery, aiming at reducing the cost of delivery in the content Delivery Networks.

TCP Congestion Control and Shaping Methods for HTTP Adaptive Streaming.

HTTP Adaptive Streaming (HAS) is a streaming video technique widely used over the Internet. However, it is characterized by some issues that may harm user quality of experience (QoE). The main use case of the present investigation involves HAS clients competing for bandwidth inside the same home network. Based on related works, we found that one of the most convenient solutions for this use case is to define a bandwidth manager. Studies have shown that managing the bandwidth between HAS clients using traffic shaping methods improves the QoE. Additionally, the TCP congestion control algorithm in the HAS server may also impact the QoE because every congestion control variant has its own method to control the congestion window size.

Based on previous work, we describe, in [9], two traffic shaping methods, the Hierarchical Token Bucket shaping Method (HTBM) and the Receive Window Tuning Method (RWTM), as well as four popular TCP congestion control variants: NewReno, Vegas, Illinois, and Cubic. In this paper, our objective is to provide a detailed comparative evaluation of combining these four congestion control variants with these two shaping methods. The main result indicates that Illinois with RWTM offers the best QoE without causing congestion. Results were validated through experimentation and objective QoE analytical criteria.

In [8], our objective is to improve the user Quality of Experience (QoE) and network Quality of Service (QoS) when many HAS players are sharing the same bottleneck link and competing for bandwidth. The two major factors of this degradation are the large OFF period of HAS, which causes false bandwidth estimations, and the TCP congestion

control, which is not suitable for HAS given that it does not consider the different video encoding bitrates of HAS. This work proposes a HAS-based TCP congestion control, TcpHas, that minimizes the impact of the two aforementioned issues. It does this by using traffic shaping on the server. Simulations indicate that TcpHas improves both QoE, mainly by reducing instability and convergence speed, and QoS, mainly by reducing queuing delay and packet drop rate.

3.2 Function and Service Placement in Networks

Participants: Alberto Blanc, Annie Gravey, Gwendal Simon, Bruno Stévant, Farah Slim.

Virtual Network Function Placement.

In the context of Farah Slim's thesis[6], conducted in collaboration with Orange Labs, Lannion, we addressed the placement of Virtual Network Functions (VNFs) within potential geographical locations controlled by the network operator. Within the Open Network Automation Platform (ONAP), we developed a resource allocation strategy for deploying VNFs on distributed data centers organized as a three-level data center hierarchy exploiting co-location facilities available within Main and Core Central Offices. We precisely proposed an active VNFs placement strategy, which dynamically offload requests on the basis of the load observed within a data center. We compare via simulations the performance of the proposed solution against mechanisms so far proposed in the literature, notably the centralized approach of the multi-site project within OpenStack, currently adopted by ONAP. It turns out that the proposed algorithm yields better performance in terms of both data center occupancy and overhead. Furthermore, it allows extending the applicability of ONAP in the context of distributed cloud, without requiring any modification.

Placement of Micro-Services on Edge Infrastructure.

In order to avoid using third-party infrastructures, some users might be interested in using their own devices to host their services. These voluntary-provided devices can be considered together as an edge infrastructure where services can be deployed the same way as in a datacenter. Micro-services oriented applications are interesting in this context as they can be placed independently on the different devices of the infrastructure, offering different solutions for the deployment. But each deployment will result in variable performance of the application as the micro-services will be hosted on devices with different CPU or network capabilities.

Finding the optimal placement for the micro-services over such edge infrastructure giving the optimal performance is a NP-hard problem. To solve it we defined a model of the application performance depending of the placement and proposed a heuristic based on Particle-Swarm Optimization. The solutions found by this heuristic have been tested and validated on a platform emulating an edge infrastructure interconnecting

micro-services with variable QoS.

The implementation of the optimization heuristics and the results observed on an emulated infrastructure have been presented in [48].

This work is done as part of Bruno Stévant thesis under supervision of Jean-Louis Pazat, from MYRIADS team, advised by Alberto Blanc.

3.3 Advanced management of optical and carrier networks

Participants: Bernard Cousin.

Transmissions on optical fibers have unique features: large bandwidth, low loss, low cost, light weight, immunity to electromagnetic interference and corrosion resistance. However, the management of optical network is a very challenging task [Muk00]. First, due to the physical constraints in all-optical WDM networks (e.g., same wavelength throughout a path), the management of such networks may require specific algorithms and specific adaptations of the protocols. Second, the management of any heterogeneous and large network requires powerful methods for its coherent and complete management. For instance, one may want to establish a light path over several networks operated by different network operators, each network having various optical devices managed by its own policy. Third, advanced capabilities which can be provided by optical networks require appropriate management tools. For instance, advanced optical packet switching, on-demand optical resource management, automatic protection of optical connections, multipoint optical connections, etc. are some of these advanced capabilities. Thus we propose an advanced management of optical networks.

Management of Flex-grid Optical Networks.

The continuously increasing traffic of Internet services (cloud services, video streaming, social networks and recently Internet of things services) is leading to a huge traffic growth in the core optical networks. This traffic evolution is pushing network operators to exploit efficiently their infrastructures in order to postpone, as much as possible, the expensive deployment of new infrastructures. In this respect, the migration from fixed to flex-grid optical networks was triggered in order to efficiently use optical network capacity taking benefits from the improved spectral efficiency of flexible transponders. In a previous work, we demonstrated that migrating towards flexible networks while keeping in use existing optical amplifiers will cause power saturation problem over highly loaded links due to the increase in the number of optical channels. To overcome this problem, we proposed pour previous work a power adaptation process that consists on converting transmission performance margins into optical power attenuation over optical links. However, the realized work considered only transparent optical network controlled by GMPLS protocol suite. In [12], we consider the case of translucent optical network where optical regeneration is required and thus the power adaptation process is adapted to such kind of network. New routing algorithm and protocol extensions

[Muk00] B. MUKHERJEE, "WDM optical communication networks: progress and challenges", *IEEE Journal on Selected Areas in Communications* 18, 10, 2000, p. 1810 – 1824.

are proposed to take into account power and regeneration information in the GMPLS control plane of translucent network

Management of (Optical) Carrier Ethernet Technology.

Carrier Ethernet is an extension to Ethernet to enable telecommunication network providers to provide Ethernet services to customers and to utilize optical Ethernet technology in their networks. It is mainly provided using optical fibers interconnected by Ethernet switches.

Energy consumption of large-scale optical networks has become a primary concern in a society increasingly dependent on information technology. Novel solutions that contribute to achieving energy savings in wired (optical) networks have been proposed to mitigate ongoing and alarming climate change and global warming. A detailed survey of relevant power-saving approaches in wired (optical) networks is presented in [15]. We give a special focus on carrier-grade networks. At first we perform a comprehensive study of communication infrastructures regarding energy saving. Then, we highlight key issues to enable green networks, ranging from network design to network operation. After that, we present the major contributors to power consumption in wired networks. Afterwards, we survey, classify, and compare the main energy-aware methods and mechanisms that are the most appropriate for improving the energy efficiency of (optical) carrier-grade networks.

Soft-Defined Networking (SDN) is a new approach that enables operators to easily manage all the network elements. In [16], we address the problem of energy-aware routing in SDN-based optical carrier-grade Ethernet networks. Our approach is based on turning off network nodes and links to reduce energy consumption, while respecting the rule space capacity for each Openflow switch, and maintaining an allowable maximum link utilization. The problem of identifying the optimal set of network elements to be turned off is NP-hard. We first present an exact model based on an Integer Linear Programming formulation for the problem. Then, we describe a set of first-fit heuristic algorithms suitable for large-sized networks. The exact and heuristic approaches are tested on SNDlib-based instances. Experimentations show the efficiency of both exact and heuristic methods for different network topologies. In particular, our heuristic algorithms are able to achieve a good balance between energy consumption, resource utilization, and network performance.

Carrier grade networks are in general over-dimensioned in order to protect against network resource failures and to handle probable traffic peaks. Such network design exhibits non-negligible energy waste. As well known, during network operation, the traffic load varies remarkably over day hours. Typically, a significant amount of energy saving can be achieved by turning off redundant and underutilized resources. Ensuring a sufficient level of reliability while taking into account energy saving objective is a very challenging task. In [43], we study the multi-commodity reliable network design for carrier Ethernet networks. Each traffic demand is routed along one working path, and a corresponding backup path computed considering dedicated protection scheme. The primary and backup path must be node-disjoint. We also assume that the (optical) links of the carrier grade networks are made of multiple physical cables, called bundles. We

propose an exact method based on an Integer Linear Programming (ILP) formulation for the two node-disjoint paths with energy-aware routing (TNDP-EAR) problem. The studied problem is known to be NP-hard. In order to solve it efficiently, we propose a heuristic-based algorithm called GreenTNDP. Preliminary experimental results show the effectiveness of our algorithms to solve the problem.

3.4 Segment Routing

Participants: Géraldine Texier, Rabah Guedrez.

Segment Routing (SR) architecture has a great potential to replace the MPLS control plane. It considerably simplifies the operation and management of the MPLS networks. A Segment Routing path does not require signaling because it relays on the source routing paradigm. The instantiation of segment routing over the MPLS control plane requires to encode a path as a stack of labels that will be inserted in the packet header by the ingress node. This has a direct consequence on the size of the label stack which increases linearly with the length of the path. Unfortunately, such approach runs into the routers physical limitation known as the Maximum Stack Depth (MSD), that bounds the maximum number of labels a router can push onto packets. Consequently, it prevents traffic to flow on some of the network paths, leading to under-utilization of network resources. Therefore, the MSD restrains the adoption of Segment Routing as it impacts the service provider ability to perform traffic engineering. Several algorithms have been proposed to mitigate the impact of the MSD. They usually rely on an optimization of the SR paths encoding. However, none of them eliminates the impact of the MSD limitation. In a demonstration, we couple the capabilities of an SDN controller and a path encoding engine to reduce that size of the label stack to express segment routing paths. Furthermore, we propose a path segmentation approach to definitively eliminate the impact of the MSD. Accordingly, all the possible paths in the network may be considered to forward traffic. This approach is based on the introduction of a new type of Segment Identifiers (SID)s called Targeted SID (TSIDs). We detail the architectural requirements and propose an optimization algorithm to reduce the introduced overhead. Rabah Guedrez presented these results during his thesis defense on the 12th of December 2018 [3].

3.5 QoS management in fixed and mobile networks

Participants: Alberto Blanc, Bernard Cousin, Annie Gravey, Mauricio Iturralde, Tanguy Kerdoncuff, Xavier Lagrange, Najmeddine Majed, Cédric Morin, Géraldine Texier.

Management of QoS for VoIP in LTE networks.

Fourth-generation mobile networks, based on the Long Term Evolution (LTE) standard, are all- IP networks. Thus, mobile telephony providers are facing new types of quality degradations related to the voice packet transport over IP network such as delay,

jitter and packet loss. These factors can heavily degrade voice communications quality. The real-time constraint of such services makes them highly sensitive to delay and loss. Network providers have implemented several network optimizations for voice transport to enhance perceived quality. However, the proprietary quality management algorithms implemented in terminals are left unspecified in the standards. In this context, we are interested in media adaptation mechanisms integrated in terminals to enhance the overall Quality of Experience (QoE). In a thesis with Orange Labs [4], we experimentally evaluate Voice over LTE (VoLTE) QoE metrics such as delay and Mean Opinion Score (MOS) using a standardized test method. We propose some enhancements to the actual test method and discuss how this method can be extended to evaluate de-jitter buffer performance. We also experimentally evaluate WebRTC voice quality in different radio conditions using a real LTE test network. We evaluate the impact of jitter buffer and bit rate variations on the measured quality. To enhance voice codec robustness against packet loss, we propose a simple application-layer redundancy in [44]. We implemented it for the Enhanced Voice Service (EVS) codec and evaluate it. Finally, we propose a signaling protocol that allows sending redundancy requests during a call to dynamically activate or deactivate the redundancy mechanism.

Mobile relay and Quality of Service.

Even with dense base station deployments, public transport users often have a low quality for mobile services. Due to the insulation of the vehicle, passengers experience little to no connectivity on their end devices and low data bit rate. In this context, we propose a mobile relay architecture based on two imbricated levels of LTE networks and adapted to public transport systems. This architecture is evaluated on an actual LTE test-bed, consisting in standard radio interfaces, off-the-shelf terminals and the Amarisoft software suite as described. One of the specifics of a mobile relay is the use of a radio link between the core network and the base stations, with all the limitations of this medium. In [41] we evaluate the impact on data rate of signaling mechanisms and of tunnelling in that context when a few terminals are connected through the relay.

In [40] we consider a system with a lot of terminals and use a simulation-based approach. We evaluate the QoS of an LTE mobile relay architecture for public railway transport systems for two representative services: client-server requests and voice communications. We compare the performance of a direct transmission against a mobile relay architecture for different types of requests and different load conditions. This work, therefore, evaluates the mobile relay performance in terms of load time, throughput, packet loss ratio and end-to-end latency. Our findings show that a mobile relay architecture highly improves the QoS performance for train passengers. Furthermore, the gain is greater as the load increases.

Load Balancing in SDN Network.

Software Defined Network (SDN) is a concept based on a decoupling between the control plane and the data plane of a network. Thus, the network becomes programmable and can be adapted to the application requirements. The study that is discussed in this work ([11]) looks at load planning and load balancing in a SDN architecture where controllers are distributed. To do this, a model and theoretical methods

for performance evaluation -with appropriate software tools to predict and control the quality of service offered to users- are exposed. This work described also a distributed network architecture with SDN controllers and a module based on an adaptive load balancing algorithm that is fault tolerant and follows controller load. The experiments show a significant gain in efficiency of our solution.

Urban wireless sensor network infrastructures and crowdsensing.

The widespread deployment of connected Things in our cities allows for the enhanced management of the urban space. However, due to environmental constraints, the connected Things are often battery-powered, which affects the lifetime of the IoT Networks. We believe that the urban IoT networks must leverage the power of the crowd, leading to combine the fixed urban IoT networks with the crowdsensing capabilities of the citizens' smartphones. That is, we integrate the offloading of a portion of the traffic generated by the fixed network to mobile crowdsensing devices that also contribute with relevant urban observations (e.g., for noise pollution monitoring). [49] highlights the key technical features of the resulting solution, whose evaluation shows that we are able to extend the lifetime of the battery-operated IoT network by a up to 7 factor.

In urban participatory mobile distributed systems, people get involved in producing new knowledge about the urban environment. Service-oriented and cloud computing are evident baseline technologies for the target mobile distributed systems. Service orientation provides the abstraction to deal with the assembly of the relevant heterogeneous component systems. The cloud provides the infrastructure to deal with the gathering and analyses of the observations coming from the sensing infrastructure, including from people. However, cloud-based centralized solutions come at a price, regarding both resource consumption and privacy risk. Further, the high heterogeneity of the participating nodes results in diverse levels of sensing accuracy. [39] provides an overview of the past and ongoing research of the INRIA Mimove team to overcome the challenges facing urban participatory mobile distributed systems, which leverages mobile collaborative sensing, networking and computing. This includes the collaboration with the Adopnet Team on the management of the traffic routing to extend the urban wireless sensor network infrastructure's lifetime. The resulting architecture allows overcoming the high heterogeneity and the very large data scale that arise in the Internet of Things.

3.6 Radio Resource Management

Participants: Bernard Cousin, Cédric Guéguen, Xavier Lagrange, Loutfi Nuaymi, Ali El Amine, Mahdi Ezzaouia.

Radio Resource Management (RRM) algorithms or heuristics are a key element for providing high system throughput, low energy consumption and high mobile user satisfaction. The past decades have witnessed intense research efforts on RRM. Though the energy constraint has received a lot of attentions for a couple of years, developing energy-efficient RRM is still a research issue. In our team, we focus on several aspects of radio resource management: interference coordination, scheduling, energy-efficient

power control, radio carrier aggregation or user selection strategies.

Radio Resource Management in 5G networks.

Heterogeneous Networks (HetNETs) are considered as an effective solution to improve the coverage and system throughput for 5G cellular mobile networks. The extremely growing mobile market, together with the arising demand for high data rates, motivate us to open a new spectrum related to millimeter waves (mmwaves) while using beamforming that can serve simultaneously a group of users. In [34], we formulate an optimization problem for HetNETs multi-user selection in a multi-input-multi-output and orthogonal frequency-division multiple access (MIMO-OFDMA) system, aiming to maximize the total system throughput. We solve the problem by applying a modified version of well-known metaheuristic algorithms. The optimal solution is obtained using an exhaustive search algorithm that provides an ideal solution which is however complex to be computed. Greedy zero-forcing dirty-paper gZF-DP and zero-forcing selection ZFS algorithms were selected from literature for the sub-optimal solution. In parallel, a water-filling algorithm has been optimized after adding new power constraint and it has been used for power distribution. Hence, we analyze the throughput performance of our systems using throughput metric. The results show that ZFS outperforms gZF-DP algorithm as it achieves higher total throughput, While gZF-DP outperforms ZFS algorithm in execution time.

In order to ensure high transmission rate to a wide range of voice, video and data services, radio carrier aggregation (CA) has been introduced in the Long Term Evolution Advanced (LTE-A) network. Moreover, CA is one of the principal enabling technologies for the 5G. Indeed, 4G and 5G can aggregate up to five component carriers (CC), simultaneously, to support a higher bandwidth. In this context, CC selection method is necessary. In [42], we propose a new CC selection method in order to maximize the global system throughput. Neural network approach is introduced to select the best couple user-CC via a utility function. Simulation results prove that the proposed method outperforms in terms of system throughput, fairness and packet loss rate.

Scheduling.

One key phenomenon of wireless transmissions is multi-path propagation. It generates fast fading or in other words quick variations of the channel state (few milliseconds timescale), which are thus specific to each terminal in a cellular network. Contrary to conventional access methods like Round Robin (RR), opportunistic scheduling techniques originally proposed by ^[KH95,WC99] take advantage of multi-path fading and multi-user diversity to provide high throughput: they wait for the most favorable transmission

[KH95] R. KNOPP, P. HUMBLET, "Information capacity and power control in single-cell multiuser communications", in: *Proc. IEEE Int. Conf. on Communications (ICC)*, 1, p. 331 – 335, June 1995.

[WC99] C. Y. WONG, R. S. CHENG, "Multiuser OFDM with Adaptive Subcarrier, Bit, and Power Allocation", *IEEE J. Sel. Areas Commun.* 17, 10, Oct. 1999, p. 1747 – 1757.

conditions for a given terminal to serve it. An implicit assumption is that the terminal has always data packets to transmit or to receive at any time. In our work, we take into account the variability of the traffic and the queuing aspects. We have proposed new efficient heuristics avoiding the supposed necessary trade-off between system capacity and QoS. The queuing aspect is taken into consideration as well as higher layer requirements. Frequency diversity in addition to time and multi-user diversity are also exploited in a cross layer design and allow to significantly improve opportunistic scheduling approach. This concept can be used in order to increase system throughput, fairness, QoS and QoE but also to increase network connectivity [8] or provide energy efficient radio communication [36, 10]. Currently we work in order to increase the efficiency of these solutions. These activities can lead to many other subjects, such as dynamic inter-cellular bandwidth fair sharing [2, 32], energy allocation in smart grid [17] and routing [33].

Inter-cellular Bandwidth Sharing.

Enhancing the Quality of Experience (QoE) in wireless networks is a crucial issue. Many acknowledged works focus on intra-cellular scheduling. They have shown that when the channel impairment is taken into consideration by the opportunistic scheduling approaches, it allows to reach higher throughputs and, for the most efficient ones, a higher fairness. However, if some of these works provide results near to optimum considering a single cell, high QoE cannot be guaranteed for scenarios where the cells are overloaded.

In [7], we have proposed a new intercellular scheduler called Inter-cellular Bandwidth Fair Sharing Scheduler (IBFS) able to help the overloaded cells thanks to a dynamic cell bandwidth allocation. Our resource allocation technique is based on an adequate emergency parameter called Mean Cell Packet Delay Outage Ratio (MCPDOR). This metric is used to select the best candidate cell to receive additional bandwidth from its neighbors. The logical metric could be to base our approach on the global cell traffic load, but we have shown that it is not the optimal metric. Indeed, cell's mobiles have no reason to use the same data rate profiles (less or more elastic) or the same applications with the same delay constraints. Intra-cellular schedulers of the cells with more elastic traffic profile or more restrictive QoS constraints have a more difficult task to ensure QoS. They could require more bandwidth than the schedulers of other cells with higher global throughput but less restrictive QoS constraints or lower peak data rate demands. Consequently, the IBFS scheduler should be based on a reliable metric, which is a crucial issue for its performance. Thanks to the new introduced metric MCPDOR that measures the cell emergency to access to more radio resources, IBFS is able to always select the appropriate cell to help. Performance evaluation shows that the proposed scheduler widely outperforms existing solutions in various scenarios. A variant of our solution that does not consider MCPDOR is also proposed and evaluated.

In [2, 32], we have investigated different BBU-RRH mapping strategies for C-RAN architectures. We introduced a novel hybrid frame configuration model, combined with a dynamic algorithm, in order to determine and apply the appropriate transmission strategy. Results show that the proposed solution adapts to network load conditions, reaching the performances of the one-to-many mapping at low load conditions and of

the one-to-one mapping at high load conditions.

LSA spectrum auctions for 5G networks.

Licensed Shared Access (LSA) is a new complementary regulatory framework which aims to optimize wireless spectrum utilization. Under LSA, an incumbent operator can share his owned spectrum with an "LSA licensee". This sharing is supervised by the regulator, but the allocation and pricing mechanism to be used is not specified yet. To fill that gap, in [28], we propose PAM: Proportional Allocation Mechanism, which is a truthful auction mechanism offering a good compromise between fairness and efficiency and can generate the highest revenue to the regulator compared to other truthful mechanisms proposed in the literature.

In [26], the allocation is made among groups such that two base stations in the same group can use the same spectrum simultaneously. In this context, different auction schemes were proposed, however they consider the scenario in which the regulator has one and only one block to allocate. We remove this hypothesis and then suppose that the regulator has K identical blocks of spectrum to allocate, and we propose a truthful auction mechanism based on the well-known Vickrey-Clarke-Groves mechanism (VCG). Simulations show that the efficiency of the proposed mechanism is at least 60% of VCG which is known to be efficient. Since those mechanisms could generate an extremely low revenue, we extend them by introducing a reserve price per bidder which represents the minimum amount that each winning bidder should pay in [27]. Since this may be at the expense of the allocation fairness, for each mechanism we find by simulation the reserve price that optimizes a trade-off between expected fairness and expected revenue. Also, for each mechanism, we analytically express the expected revenue when valuations of operators for the spectrum are independent and identically distributed from a uniform distribution.

Energy management and base station switching in green mobile networks.

Considering the exponential increase in mobile data traffic, requiring denser cellular access networks, the use of renewable energy (RE) to power base stations (BSs) may contribute to reduction of the huge operational cost faced by mobile network operators (MNOs) due to power supply. Furthermore, the smart grid (SG) paradigm is deeply changing the energy market, envisioning an active interaction between grid and customers. Hence, MNOs can combine renewable-powered BSs with properly designed energy management strategies to improve the interaction with the SG, with the twofold objective of reducing the energy bill and providing ancillary services. In [18], we propose a stochastic model to investigate a renewable-powered mobile network dynamically adapting its energy consumption to accomplish SG requests, and receiving rewards in return, by exploiting two techniques. First, resource on demand (RoD) can dynamically switch off unneeded BSs. Second, an energy management policy takes efficient decisions about using/harvesting locally produced RE, depending on SG requests. The proposed techniques highly increase the probability of responding to ancillary service demands, up to 90%, also depending on the RE system size, with RoD raising, by up to 20%, the

probability of accomplishing SG requests. Consequently, cost saving can become equal to the total cost or even greater, providing revenues to the MNO.

To the best of our knowledge, research efforts did not take into consideration partially RE-equipped systems. Yet, this is of great importance considering the high cost of these systems and the feasibility of implementing RE system at all base station sites. Thus, it is of high interest to study the percentage of sites to be equipped with RE systems. In [31], we analyze the energy and cost savings for a defined energy management strategy of a RE hybrid system. Our study of the relationship between cost savings and percentage of sites equipped with RE, show important results. For example, our simulation shows that a cost gain of 60% is realized when 30% of the base stations are equipped with solar panels that harvest only 35% of the total network energy demand at full load. Results also show an upper limit for the battery capacity at which the cost gain is maximized.

Energy efficient radio communication.

Increasing the spectral efficiency and guaranteeing high Quality of Service (QoS) and high Quality of Experience (QoE) is a crucial issue of wireless communications. The best opportunistic resource allocation schedulers allow to reach these objectives because they take into consideration the radio conditions and users requirement in the allocation process. However, this is often processed at the expense of energy efficiency, which is now essential regarding the alarming greenhouse gas emission and the need to improve the device battery lifetime. Reaching both low system energy consumption, high spectral efficiency and high QoS is a very difficult task. Specialized solutions as MaxSNR, Proportional Fairness, or T-MAC have been well designed to meet one of these criteria but not the other ones. Other solutions propose static tradeoffs that provide good average results on these two metrics without success outperforming specialized scheduler in their focused domain.

In [36], we propose an optimized trade-off between energy, throughput and fairness thanks to a new opportunistic approach that combines the advantages without the drawbacks of specialized schedulers. Performance evaluations show that the proposed solution allows to have the same system capacity that MaxSNR scheduler while solving its lack of fairness concerning mobiles at different distances from the access point. In addition we also show that this can be made while lowering energy consumption. In [10], we underline that the network objectives must be dependent of the context and particularly to the traffic load. In underloaded context, guaranteeing high Quality of Service (QoS) is easily achievable due to large surplus of available radio resources and the focus must be put on energy rather than system throughput. On the contrary, in a highly traffic loaded context, the lack of available radio resources required that resources allocation algorithms focus on system capacity in order to preserve QoS and satisfy users; thus energy consumption must become lesser important. The main contribution of this papers is to propose a Dynamic Tradeoff (DT) scheduler able to tune its priorities and the multiuser usage benefit according to the network traffic load context. It provides a better energy efficiency than specialized energy aware scheduler when it is feasible while providing the same spectral efficiency and delays as throughput oriented scheduler when it is required. This is achieved with a fairness special attention that is

also guarantee. Future works could focus on other metrics like mean packet delay in order to adapt the multiuser usage to different contexts.

Device-To-Device transmission for Machine-Type Communications.

Reducing energy consumption is a key requirement for Massive Machine-Type Communication (mMTC) devices operating on battery power. Device-to-Device (D2D) communication is a promising technology that can be used in 5G networks for this purpose. In [52], we identify the interest of using a D2D relay mechanism compared with a direct link with an unfavorable link budget. We first look for an optimal Relay-MTC device configuration that minimizes the energy consumption. We then compare the energy consumption in direct and relaying mode expressing it in terms of the distance between the base station and the MTC device and between the base station and the relay. We show that when the MTC device is close to the base station, D2D relay mechanism can reduce the energy consumed by the MTC device at the expense of an increase in the global energy consumption (i.e. the energy consumed by the MTC device plus the energy consumed by the relay). On the other hand, when the MTC device is far from the base station, D2D relay mechanism allows reducing both the energy consumption by the MTC device and the global energy consumption.

In [51], we analyze the energy consumption of the MTDs when Automatic Repeat reQuest (ARQ) and Hybrid ARQ with Chase Combining (CC-HARQ) mechanisms are used to improve the reliability of D2D communications. By using the tools of stochastic geometry, we derive analytical expressions for the global success probability, the average number of transmissions, and the average MTD energy consumption. Numerical results show that CC-HARQ outperforms ARQ in terms of energy consumption, especially for low relay density when the distance between an MTD and its relay increases or when the density of MTDs sharing the same sub-channel increases.

Energy Efficiency in Wireless Ad Hoc Networks.

The amount of data represented by the Internet of Things (IoT) is continually growing and is expected to reach more than one third of the total amount of Internet traffic by 2020. Wireless sensors pose a great challenge because of the varying radio conditions and the limited energy and computational capabilities they have. In [33], we have developed an Objective Function (OF) that uses fuzzy logic to dynamically adapt to variable environments in wireless networks. Simulation results will show that the proposed algorithm increases performance compared to other solutions by up to 15% in terms of throughput and by up to 14% in terms of Packet Delivery Ratio (PDR) without compromising energy consumption. In addition, mobile ad hoc wireless networks are characterized by the absence of central administration and any network element may be very mobile. It may exist no fixed element within an ad hoc network. In fact, within these networks, all elements must cooperate so as to create a temporary network topology which enables communication. To create this topology and carry data, ad hoc networks must use efficient routing protocols. In [24], we propose a multipath routing protocol with low energy consumption in order to improve the performance of mobile ad hoc wireless networks. Our protocol ESMR (Energy aware and Stable Multipath Routing Protocol) uses a path selection strategy which is based on energy constraint

and link stability. It is designed on a realistic mobility model, contrary to most existing protocols which are based on random mobility models with some unrealistic behaviors such as sudden stop, abrupt acceleration. Simulation results demonstrate that ESMR has better performance in terms of energy consumption and network reliability.

Energy allocation in smart grid.

In [17], we propose a distributed energy management approach that aims to manage residential energy. The proposed approach considers the neighborhood energy surpluses in order to decrease energy costs. This management is improved based on a set of trust factors that a buyer defines on his neighbors to avoid non-optimal energy purchases. To evaluate the performance of this approach and to study its impact on the neighborhood, we elaborated a formal model representing the overall behavior of the system using colored Petri nets (CP-nets). The choice of CP-nets is justified by the fact that, in our approach, we have to deal with a variety of protocols and several operations that are executing simultaneously, and potentially interacting with each other. This formalism allowed us to formally verify the proposed approach as well as to generate a set of performance indicators. The obtained indicators prove the effectiveness of our solution compared to other approaches.

3.7 Wireless network monitoring

Participants: Alberto Blanc, Maha Mdini, Alassane Samba, Gwendal Simon.

Throughput Prediction in Mobile Networks.

We have worked on the prediction of the throughput in cellular network. The originality of our work is that we focus on the case where we cannot rely on previous measures and thus we only consider that we have the information that are provided by the base station and at the devices. This use case is especially useful when the application requests the selection of a given quality at the very beginning of the connection. We have developed models based on Machine Learning to get an accurate prediction [19]. Alassane Samba has successfully defended his thesis on the topic [5].

Root Cause Diagnosis in Large-Scale Networks.

One of the problem in network monitoring is that, when an anomaly is detected, it is not trivial to identify the cause of the anomaly. It is even getting harder due to the number of interplaying devices, equipments, services, and software that are simultaneously in the flows. We have proposed a solution based on Machine Learning approaches to improve the identification of the root cause of anomaly [45]. Our work has shown that we obtain a significant improvement in comparison to previous approaches.

3.8 Blockchain as a Software Connector for Distributed Services

Participants: Romaric Ludinard.

For two years, blockchain has become omnipresent in the media. Blockchain refers to the technology behind Bitcoin cryptocurrency, allowing participants to perform currency transfers without a trusted third party. This goal is achieved by enforcing nodes to collectively maintain a replicated tamper proof history of ever executed transactions, the so called blockchain. Every participant can thus check this history to validate new transactions. However, this data structure, as well as protocols to share, update and leverage this structure are currently understudied and the set of guaranteed properties vary with these protocols.

In [54], we model the behavior of different blockchains in an abstraction called Blockchain Abstract Data Type. The goal of this abstraction is allow reasoning about consistency guarantees provided by such blockchains and the associated requirements in term of communication abstractions as well as consensus number.

Current blockchain designs can be tessellated in two groups. In one hand, open systems rely on sybil proof mechanisms like proof-of-work to validate an update on the blockchain, but provide weak consistency guarantees. On the other hand private or consortium blockchain rely on preidentified groups of participants that are allowed to update the system state. These participants usually execute byzantine consensus or state machine replication algorithm to agree on the system state and modifications. However, these approaches fail to scale and are devoted to small groups of participants. In [22], we investigate an alternative approach that relay on Bitcoin transactions to identify and authenticate subgroups of the system to execute these algorithms, resulting in strong consistency guarantees at large scale.

Transactions scalability is an other impediment of current blockchain designs. These approaches linearize the whole set of transactions requiring participants to agree to both set and order. As a consequence, the current throughput is limited to 3 to 7 transactions per second in the Bitcoin system. In [21], we provide an alternative approach to store the history of transactions. Instead of relying on a fully ordered chain of blocks of transactions, these transactions are stored in a directed acyclic graph. The resulting partial order on transactions still satisfies causality of transactions and thus allow to validate these transactions while allowing concurrent update of the history with an extremely low level of inconsistencies.

4 Software development

4.1 Web application development in R langage

Participants: Alassane Samba.

A package developed for the R language in order to deploy web applications in operational network [47]. It analyzes and visualizes the process of an efficient deployment in a fully virtualized environment based on Machine Learning strategies.

4.2 Wi2me and Wireless Measurements Sharing Platform (WMSP)

Participants: Alberto Blanc¹.

The WiFi technology becomes more and more popular and the the density of access points is very high in urban areas. Several community networks, which are based on sharing WiFi residential access points, are now available. They can provide locally a wireless access at a high speed rate but show uncontrolled performance. In this scenario, the goal for a user is to have multiple interfaces, and exploit them the best he/she can, by always selecting the best matching between flows and interfaces. In order to have real traces and to evaluate the performance, the availability and the potentiality of these networks, OCIF team have developed a new mobile sensing tool, called Wi2Me Traces Explorer. It is an Android-based application that performs network discovery, automatic authentication and TCP traffic generation through WiFi and 3G.

Wireless Measurements Sharing Platform (WMSP) is a Wi2Me-based collaborative information service to gather, aggregate, and exploit data collected by mobile users. WMSP solves the challenges related to the collection, data pre-processing and aggregation of partial and/or inaccurate WiFi measurements. To ensure the scalability of the system, we have used Big Data and cloud-based technologies. WMSP preprocesses raw measurements provided by the users. These data are further analyzed by plugable "applications" which are an integral part of the system, to solve particular problems, for instance to facilitate cellular traffic offloading, and network planning.

ADOPNET team is involved in Wi2me and WMSP. It studies in cooperation with OCIF how to analyse the gross results given by the platform in order to characterize the performance and the quality of service of the community networks.

4.3 360-Transformations

Participants: Xavier Corbillon, Hristina Hristova, Gwendal Simon.

Omnidirectional videos, or 360-degree videos, are captured from all directions so that the frames can apply on a sphere. However, the encoding of videos and most of the video management techniques take a video that is on a flat 2-dimensional rectangular area. The spherical video must thus be projected into a map before being encoded and manipulated. The mapping of a spherical surface onto a rectangular area has been studied for centuries. Various mappings have been proposed, including equirectangular, cube map, and pyramidal.

360-Transformation is a software that enables the mapping from one projection to another for any omnidirectional video. The software, which is released under an MIT free software license, manipulates the different frames of a video to re-project them on another mapping. It also enables to encode the projected video with different encoding parameter settings, in particular to have a region of interest encoded at high quality and other parts of the video encoded at a lower quality.

360-Transformation follows the main concepts that have been adopted by the MPEG

¹Only participants in ADOPNET are listed.

experts for the Omnidirectional Media Application Format (OMAF). It is available at <https://github.com/xmar/360Transformations>.

4.4 gGalop - Generates and Analyses Lots Of Packets

Participants: Santiago Ruano Rincon, Sandrine Vatou.

gGalop is a suit of tools, built on top of commodity hardware and high-performance networking software frameworks, that makes it possible to generate and process Domain Name System (DNS) packets at 10GbE wire-rate.

We have developed gGalop as the main component of a flexible testbed for research on methods to countermeasure flooding attacks against DNS infrastructure. From one side, gGalop can reproduce different kinds of flooding attacks against or using the DNS, and it is able to scale, saturating several 10GbE ports depending on the hardware it runs on. At the reception side, we have developed different script prototypes to analyse network streams on-the-fly, and to identify elements common to anomalies or abuse sources.

5 Contracts and collaborations

5.1 International Initiatives

5.1.1 CELTIC SooGreen

Participants: Loutfi Nuaymi.

- Title: Service Oriented Optimization of Green Mobile Networks
- Framework: CELTIC project
- Duration: July 2015- June 2018 (3 years)
- Partners : Alcatel-Lucent, Nokia, Orange Labs, Arelis Broadcast, KTH, Institut Mines-Telecom (IMT Atlantique, partner and coordinator for IMT, Télécom Sud Paris and Télécom Ecole de Management), Lemasson, ATAWAY, Université de Caen Basse Normandie, Elisa, Polaran, Tele2, Energiforsk, Flexenclosure, BioSyncTechnology, INESC TEC, Eurico Ferreira.
- Abstract: Mobile networks are witnessing an exponential growth of traffic volumes, associated with the emergence of new services. In particular, video services constitute a major part of the traffic and their share is expected to increase. In the same time, Internet of Things (IoT) related traffic will gain in importance with the explosion of the number of connected objects. This situation pushes towards an evolution of network architectures (e.g. LTE-A features on centralized/virtual RAN) and of content delivery solutions (e.g. in network caching). SooGREEN is built around the need of reducing the energy consumption of services in light of

the traffic evolutions and exploiting the new network architectures, while keeping in mind the development of smart grids. This includes: Modeling the energy consumption of services in different mobile network architectures and taking into account the end-to-end path, A joint dynamic optimization of the mobile access network and the content delivery solutions, Proposal of solutions for enabling the bi-directional interaction of the mobile network and the smart grid by exploiting the flexibility of some services and the energy storage capabilities in the network.

5.1.2 Dynamic Distribution of On-demand and Live Videos in Mobile Network

Participants: Gwendal Simon.

- Title: Dynamic Distribution of On-demand and Live Videos in Mobile Network
- Framework: National Natural Science Foundation of China
- Duration: 01/10/2016 to 31/09/2019 (36 months)
- Partners: Xidian University
- Abstract: The objective of the project is to provide the theoretical foundations for content delivery of novel interactive applications based on live video streaming.

5.1.3 Inclusive Radio Communications

Participants: Bernard Cousin, Ahmad Fadel.

- Title: Inclusive Radio Communications (IRACON)
- Framework: European Cooperation in Science and Technology (COST)
- Duration: 2016 to 2019
- Partners: numerous European research institutions
- Abstract: The European Cooperation in Science and Technology (COST) provides funding for the creation of research networks, called COST Actions. These networks offer an open space for collaboration among scientists across Europe and thereby give impetus to research advancements and innovation. The Inclusive Radio Communications (IRACON) concept defines those technologies aimed to support wireless connectivity at any rates, for any communicating units, and in any type of scenarios. Indeed the Wireless Internet of Things beyond 2020 will require revolutionary approaches in Radio Access technologies, networks and systems. Some theoretical foundations have to be revisited and breaking technologies are to be discovered during the coming decade. IRACON Action aims at scientific breakthroughs by introducing novel design and analysis methods for the 5th-generation (5G) and beyond-5G radio communication networks. Challenges

include i) modelling the variety of radio channels that can be envisioned for future inclusive radio, ii) capacity, energy, mobility, latency, scalability at the physical layer and iii) network automation, moving nodes, cloud and virtualization architectures at the network layer, as well as iv) experimental research addressing Over-the-Air testing, Internet of Things, localization and tracking and new radio access technologies.

5.2 National Initiatives

5.2.1 ANR N-GREEN

Participants: Annie Gravey.

- Title: New-Generation of Routers for Energy Efficient Networks
- Framework: ANR 2015
- Duration: October 2015- September 2018 (3 years)
- Partners : Nokia Bell Labs, Intitut Mines-Telecom (IMT Atlantique, , Télécom Sud Paris and Télécom ParisTech), UVSQ, III/V Lab.
- Abstract: The objective of the N-GREEN project is to propose systems and protocols, and network concepts that can support the predicted traffic increases while significantly reducing energy consumption. The main focus of this project is on identifying building blocks and operational rules for network elements that allow reducing both CAPEX and OPEX. First of all, N-GREEN aims at proving the concept of a new core switch/router architecture offering a higher capacity and reduced power consumption by adopting new optical technologies for the interconnection backplane and optical bypasses. Furthermore N-GREEN will investigate the impact of the introduction of such switch/routers on network architectures, taking into account, on the one hand, the opportunities offered by the WDM packet structure and optical bypass and, on the other hand, major trends on new service architectures and traffic patterns. Energy consumption metrics will be used for the network design. Finally, new routing protocols will be proposed as well as new controllers matching SDN requirements, in order to efficiently manage the N-GREEN network and enable future virtualisation through NFV.

5.2.2 Optimal Routing and Spectrum Assignment in Realistic FlexGrid Elastic Optical Networks

Participants: Annie Gravey.

- Title: Optimal Routing and Spectrum Assignment in Realistic FlexGrid Elastic Optical Networks
- Framework: ANR 2016

- Duration: 36 months, starting in January 2018
- Partners: LIMOS at University Clermont-Auvergne, IMT Atlantique
- Abstract: This projects aims to develop efficient Routing and Spectrum Assignment (RSA) algorithms able to optimize in a tractable way the WDM optical spectrum use in Spectrally Flexible Optical Networks (SFONs), with arbitrary topologies and large sizes; e.g. several tens of nodes, and several hundreds of connections. Algorithms have to be compatible with SDN paradigm. Hence, FLEXOPTIM will regularly interact with Orange Labs teams involved in SDN forums and standardization bodies. The key challenge is algorithm scalability. The RSA problem is NP-Hard, much harder than the Routing and Wavelength Assignment problem for fixed, grid WDM networks. FLEXOPTIM shall explore new mathematical approaches reducing the number of variables to overcome the drawbacks of current methods.

5.2.3 Live Watermarking in CDN

Participants: Kun He, Gwendal Simon.

- Title: Enhancing Watermarking Solutions for Live Video Streaming
- Framework: SME and Region Bretagne funding
- Duration: September 2016- February 2018 (18 months)
- Partners: Broadpeak, Kupelseki Group
- Abstract: The objective of this project is to improve the performance of watermarking solutions for live streaming, in particular to reduce the impact of the solution on the overall traffic of the CDN.

5.2.4 5M project at IRT B<>COM

Participants: Bernard Cousin, Cédric Gueguen, Xavier Lagrange, Malo Manini.

- Title: 5G Massive-MIMO Mm Waves Multi-User plateforme
- Framework: IRT
- Duration: January 2017- December 2019 (36 months)
- Partners : Mitsubishi Electric R&D Centre Europe, Orange Labs, B<>com, University of Rennes 1, IMT Atlantique, INSA Rennes
- Abstract: The 5M project deals with the increase of the number of antennas in wireless communication systems, called Massive MIMO system, according to its network dimension. He is particularly interested in: the optimization of their capacity by increasing the number of transmitting antennas and the use of millimeter

frequency bands, the combination and pooling of radio interfaces (multi-RAT) optimizing the overall network, the reduction of the energy consumption of network, the physical implementation to prove the technological feasibility and validate the expected contributions.

5.3 Bilateral industry grants

5.3.1 CIFRE Thesis with Orange

Members of ADOPNET have numerous research projects in cooperation with Orange.

- CIFRE thesis (2015-2018) on Traffic Monitoring and Forecasting based on Big Data (Alberto Blanc and Gwendal Simon)
 - The idea here is to leverage big data technologies to implement traffic forecasting strategies and to detect in advance traffic troubles.
- CIFRE thesis (2014-2018) on the definition of programmable algorithm for connectivity in a segment routing network (Géraldine Texier), defended on the 12th of December 2018.
 - Segment routing is a new but promising mechanism to optimize the forwarding of packets in networks that implement predefined segments. The objective of the work is to study and to propose algorithms to enable traffic engineering and quality of service by reservation or traffic prioritization with segment routing.
- Thesis (2015-2018) on QoS management for mobile voice over IP services (Alberto Blanc and Xavier Lagrange)
 - After decades of voice communications with circuit-switch technology, voice over IP is the only way to provide a telephone service in 4G cellular networks. Furthermore, new codecs like EVS (Enhanced Voice Service) are available. Offering an excellent quality of service (QoS) is a key point for operators. The aim of this PhD is to design new algorithms to improve audio quality control in mobile voice over IP services. The work includes the identification of key areas for improvement, the design and development of new algorithms for QoS control and the experimental evaluation of the proposed algorithms.
- CIFRE thesis (2015-2018) on content delivery for 5G networks (Loutfi Nuaymi and Gwendal Simon)
 - The design of 5G networks considers not only the development of new wireless technologies but also the conception of new architectures and protocols to support the novel generation of applications, mainly multimedia and interactive to enable immersion. The thesis aims at addressing these questions alltogether.
- CIFRE thesis (2015-2018) on the study and implementation of algorithms for managing resource in a cloudified network (Annie Gravey).

- Resource management in a cloudified network is not yet well known. This is typically true in the well-known OpenStack framework. The objective of the present thesis is to design resource management algorithms (e.g. task scheduling and resource allocation in a virtualized network), to mathematically analyse them and to test them within Orange Labs.
- CIFRE thesis (2015-2018) on the joint optimisation of resource allocation and access network selection (Xavier Lagrange and Samer Lahoud).
 - The objective of the work is to consider the available access technologies (3G, 4G, WiFi) and to propose access network selection methods that can work on large networks with an acceptable computation time in order to optimize both the quality of service and minimize the cost
- CIFRE thesis (2016-2019) on the new protocol stack of the Internet for content delivery (Gwendal Simon)
 - Some novel proposals have been studied, implemented and deployed in the Internet although the understanding of their impact on the network performance are still largely unknown. It is especially the case of HTTP/2 and also QUIC. We want to analyze the impact of these protocols on the content delivery with respect to the other competing traffic flows.
- CIFRE thesis (2016-2019) on the measurement of the quality of Web navigation (Sandrine Vaton)
 - Some new protocols such as HTTP/2, Quic or TLS1.3 have an impact on the quality of experience that users of the web will receive, and also on the metrics that monitoring tools can rely on. We want to analyze new methods and metrics for assessing the quality of web navigation taking into account these new protocols.
- CIFRE thesis (2017-2020) on game theoretic studies for new dynamic spectrum access mechanisms in the 5G context (Patrick Maillé, Loutfi Nuaymi, Isabel Amigo)
 - Different dynamic spectrum access mechanisms are considered in the context of 5G networks. These mechanisms will dramatically change how spectrum is managed and their associated business models. This thesis studies the different dynamic spectrum access mechanism from a mathematical and economic point of view. The objective is to evaluate opportunities and risks for operators in these new contexts.
- CIFRE thesis (2017-2020) on optical access architectures compatible with the new 5G Radio Access Network interfaces (Annie Gravey, Isabel Amigo)
 - The objective of the thesis is to evaluate the impact of different optical access architectures on the interfaces that are announced for the 5G access network. In particular, the thesis will study transport solutions considering different splits of the mobile-protocol stack. The adaptation according to network conditions will be done thanks to virtualization techniques such as SDN and NFV.

- CIFRE thesis (2017-2020) on the use of D2D communication for optimized IoT-connectivity (Xavier Lagrange)
 - The objective is of the thesis is to provide an energy-efficient connectivity to a very large number of devices by using terminals connected to cellular networks as relays.

5.3.2 Control distribution in an SDN architecture

Participants: Géraldine Texier.

- Title: Control distribution in an SDN architecture
- Framework: CIFRE Thesis
- Duration: December 2016- December 2019 (36 months)
- Partners: TDF
- Abstract: The SDN architecture specifies a "logically" distributed control but most of the solution are currently defined for a centralized control. We want to propose an architecture and algorithms for the distribution of the control with a focus on the management of Quality of Service in the SDN architecture.

5.3.3 Immersive Video Delivery

Participants: Hristina HristovaXavier CorbillonGwendal Simon.

- Title: Immersive Video Delivery in 5G Networks
- Framework: direct contract
- Duration: February 2018- April 2019 (1 year)
- Partners: Huawei
- Abstract: The objective of this project is to develop new approaches for the delivery of immersive media in 5G networks.

5.3.4 Live Network Anomaly

Participants: Alberto Blanc, Maha Mdini, Gwendal Simon.

- Title: Live Network Anomaly by Massive Collection of Data in Mobile Networks
- Framework: CIFRE framework
- Duration: February 2016- February 2019 (3 years)

- Partners: Astellia
- Abstract: The objective of this project is to enhance the capacity of Astellia to analyze the cause of anomaly in the network they constantly monitor. Big data technologies and algorithms based on statistics can provide the essential components of new approaches, for live implementation of anomaly detection systems.

5.3.5 Optimisation of mobile relays for LTE

Participants: Xavier Lagrange, Mauricio Iturralde, Tanguy Kerdoncuff.

- Title: Optimization of mobile relays for LTE
- Framework: Industrial Contract
- Duration: January 2018- December 2018 (12 months)
- Partners: SGP (Société du Grand Paris)
- Abstract: Even with dense base station deployments, public transport users often have a low quality for mobile services. Due to the insulation of the vehicle, passengers experience little to no connectivity on their end devices and low data bit rate. The objective of the project is to propose a mobile relay architecture for LTE, to test it on a testbed with off-the-shelf terminals and to optimize it.

5.4 Collaborations

5.4.1 International forum

Bernard Cousin is IRISA's representative to the Traffic Management forum (TM Forum) while Annie Gravey is IMT Atlantique's representative for the same forum. TM Forum is an international association for digital business, connecting talented individuals, leading companies, and diverse ecosystems to accelerate digital business transformation.

The dataset that has been developed by Xavier Corbillon and Gwendal Simon for users watching 360-degree videos has become a resource for MPEG committee of Omnidirectional Media Application Format (OMAF) standard.

5.4.2 Cooperation with universities

We have very good and long-lasting ties with some international universities, namely Tunisia (Tunis university, Sfax University and Manouba University), Lebanon (Lebanese University, Saint Joseph University, Ivory Coast (Houphouet-Boigny University and IN-PHB) and Algeria (Oran university and Mascara university). Two of these international cooperations are supported by formal agreements where Adopnet members are the collaboration leaders :

- between University of Rennes 1 and Institut National Polytechnique Félix Houphouet-Boigny (Ivory Coast), signed in 2012, and renewed in 2017.
- between University of Rennes 1 and University Saint Joseph (Lebanon), signed in 2011.

We have a long-lasting collaboration with EPFL and the research team of Pascal Frossard. In 2018, Xavier Corbillon (phD student) has spent 9 weeks in EPFL lab for a study related to multi-viewpoint immersive media.

5.4.3 Visiting researchers

- Assohoun ADJE (Dean) from University Felix Houphouet Boigny, Abidjan, Ivory Coast.
- Omar SMAIL (Associate-Professor) from University Mustapha Stambouli, Mascara, Algeria.

6 Dissemination

6.1 Awards

We received:

- The *Best Paper Award* at the 9th edition of the ACM MMSys conference, which is the premier conference in the area of multimedia streaming [29].
- The *Best Paper Award* at the 20th edition of the IEEE Multimedia Signal Processing (MMSP) workshop [38]
- The “*top-3 paper award*” at the 20th IEEE International Symposium on Multimedia (ISM) [53].

6.2 Promoting scientific activities

6.2.1 Scientific Events Organisation

Géraldine Texier was co-organizing the conference AlgoTel 2018, a French conference, bringing together every year the entire university and industrial community wishing to share its skills and recent results in algorithmics and optimization applied to telecommunications problems.

Gwendal Simon was the general chair of the 16th edition of the ACM Netgames workshop, which was held at Amsterdam in June 2018.

6.2.2 Scientific Events Selection

Chair of Conference Program Committees Gwendal Simon was the *general chair* of the 16th edition of the ACM Netgames workshop. He was also the program chair of the workshop, both roles having been merged. He was *reproducibility chair* of the 9th edition of ACM MMSys conference, which consisted in ensuring that a committee of a dozen researchers review the artifacts of the accepted papers at the conference.

Member of Conference Program Committees Isabel Amigo has served in the Program Committee of ITC29, TMA 2017, Big-DAMA 2017 SIGCOMM workshop, SSN 2017 (Spring School on Networks).

Bernard Cousin is member of IEEE Communications Society (ComSoc) Technical Committee on Information Infrastructure and Networking (TCIIN). He served, in 2018, in the Program Committee of the following conferences:

- FNC 2018, International Conference on Future Networks and Communications
- ICSNC 2018, International Conference on Systems and Networks Communications
- NECO 2018, 7th International Conference of Networks and Communications
- OPAL 2018, International Conference on Optics, Photonics and Lasers
- OPTICS 2018, International Conference on Optical Communication Systems
- SCS 2018, Smart Cities Symposium

In 2018, Annie Gravey served in the Program Committee of the following conferences:

- APWiMob 2018, Asia Pacific Conference on Wireless and Mobile 2018
- CAMAD 2018, IEEE 23rd International Workshop on Computer Aided Modelling and Design of Communication Links and Networks
- Globecom 2018, IEEE Global Communications Conference, GC' 18 (Communication QoS, Reliability and Modeling and Selected Areas in Communications: E-Health)
- ICACCI 2018, IEEE Second International Conference on Advances in Computing, Communications and Informatics
- ICSigSys'2017 (The 2017 International Conference on Signal and Systems)
- PIMRC 2018, 2018 IEEE 29th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC) - Track 3: Mobile and Wireless Networks
- WCNC 2018, IEEE Wireless Communications and Networking Conference

- Wimob 2018, 12th International Conference on Wireless and Mobile Computing, Networking and Communications

Xavier Lagrange serves in the Program Committee of the following conferences:

- IEEE ICC 2018, IEEE International Conference on Communications
- PIMRC 2018, 2018 IEEE 29th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC) - Track 2: MAC and Cross-Layer Design
- IEEE VTC 2018 Spring, Vehicular Technology Conference,
- WD'18 (Wireless Days 2018) - Wireless Networks track

Loutfi Nuaymi served in the Program Committee of the following conferences:

- IEEE Online GreenComm'18 (2018 IEEE Online Conference on Green Communications),
- VTC 2018 Spring, Vehicular Technology Conference Spring 2018
- ICC, International Conference on Communications, 2018 Green Communications Systems and Networks Symposium

Romaric Ludinard serves in the Program Committee of the following conferences:

- Algotel 2018, a french conference gathering the network and distributed system community
- BSCT 2018 : 1st Workshop on Blockchain and Smart Contract Technologies
- SERIAL 2018 : 2nd Workshop on Scalable and Resilient Infrastructures for Distributed Ledgers
- NCA 2018 : 17th IEEE International Symposium on Network Computing and Applications (NCA 2018)

Gwendal Simon was the *general chair* of the 16th edition of the ACM Netgames workshop. He was *reproducibility chair* of the 9th edition of ACM MMSys conference. He also serves in the Program Committee of the following conferences:

- ACM Multimedia 2018, ACM flagship conference on Multimedia
- IEEE ICC 2018, IEEE International Conference on Communications
- IEEE Globecom 2018, IEEE Global Communications Conference
- ACM Nossdav 2018, 27th ACM workshop on Network and Operating System Support for Digital Audio and Video

- ACM MMSys 2018, the ACM Multimedia System Conference, which is the premier event for multimedia system and networking

G eraldine Texier has served in the Program Committee of the following conferences:

- Special session on IoT and Smart cities at the 9th ACM Multimedia Systems Conference (MMSys 2018)
- Algotel 2018, a french conference gathering the network and distributed system community
- INTERNET 2018, the Tenth International Conference on Evolving Internet
- AdHoc-Now 2018, the 17th International Conference on Ad Hoc Networks and Wireless

Sandrine Vaton is also a member of the steering committee of the Network Traffic Measurement and Analysis Conference (TMA). She also serves in the Program Committees of the following conferences:

- IEEE/IFIP Network Operations and Management Symposium (NOMS)
- IFIP/IEEE International Workshop on Analytics for Network and Service Management (AnNet)
- IEEE/IFIP Network Traffic Measurement and Analysis Conference (TMA)
- DCNET, International Conference on Data Communication Networking

6.2.3 Journals

Bernard Cousin is member of the Editorial Boards for:

- Wireless Communication & Mobile Computing journal (Wiley)
- International Journal of Communication Networks and Information Security
- Smart Control and Management of Networks (ISTE)
- International Journal of Computer Network and Information Security (IJCNIS) : Associate-Editor

Loutfi Nuaymi is regular reviewer for Wiley Editions books proposals.

Annie Gravey is editor for the Journal of Communications and Networks, an international English-language journal published by the Korea Information and Communications Society.

Gwendal Simon is in the editorial board of the IEEE MMTC R-letters related to Multimedia ACM SIG chapter.

Sandrine Vaton is associate editor of Transactions on Emerging Telecommunications Technologies (ETT).

6.2.4 Scientific Expertise

Xavier Lagrange was member of the expert committee for the evaluation of the LIP6 laboratory by HCERES (Haut Conseil de l'évaluation et de la recherche et de l'enseignement supérieur) in 2018

7 Bibliography

Major publications by the team in recent years

- [1] I. AMIGO, P. BELZARENA, S. VATON, "Revenue sharing in network utility maximization problems", *NETNOMICS: Economic Research and Electronic Networking* 17, 3, Nov 2016, p. 255–284.
- [2] R. APARICIO PARDO, K. PIRES, A. BLANC, G. SIMON, "Transcoding Live Adaptive Video Streams at a Massive Scale in the Cloud", in: *MMSys 2015 : 6th ACM Multimedia Systems Conference*, p. 49–60, 2015.
- [3] X. CORBILLON, R. APARICIO, N. KUHN, G. TEXIER, G. SIMON, "Cross-Layer Scheduler for Video Streaming over MPTCP", in: *ACM MMSys*, 2016.
- [4] X. CORBILLON, G. SIMON, A. DEVLIC, J. CHAKARESKI, "Viewport-adaptive navigable 360-degree video delivery", in: *2017 IEEE international conference on communications (ICC)*, IEEE, p. 1–7, 2017.
- [5] M. EL HELOU, M. IBRAHIM, S. LAHOUD, K. KHAWAM, D. MEZHER, B. COUSIN, "A network-assisted approach for RAT selection in heterogeneous cellular networks", *IEEE Journal on Selected Areas in Communications* 33, 6, 2015, p. 1055–1067.
- [6] S. GOSSELIN, D. B. JOSEPH, F. MOUFIDA, T. MAMOUNI, J. A. TORRIJOS, L. CUCALA, D. BREUER, E. WEIS, F. GEILHARDT, D. V. HUGO, E. BOGENFELD, A. HAMIDIAN, N. FONSECA, Y. LIU, S. KUEHRER, A. GRAVEY, A. MITCSENKOV, J. V. GALAN, E. M. RITE, L. S. GOMEZ, L. ALONSO, S. HOEST, A. MAGEE, "Fixed and Mobile Convergence: Needs and Solutions", in: *European Wireless 2014; 20th European Wireless Conference*, p. 1–6, May 2014.
- [7] C. GUEGUEN, M. EZZAOUIA, M. YASSIN, "Inter-cellular scheduler for 5G wireless networks", *Physical Communication*, 2016, <https://hal.archives-ouvertes.fr/hal-01293199>.
- [8] C. GUEGUEN, A. RACHEDI, M. GUIZANI, "Incentive scheduler algorithm for cooperation and coverage extension in wireless Networks", *IEEE Transactions on Vehicular Technology* 62, 2, January 2013, p. 797–808, <https://hal-upec-upem.archives-ouvertes.fr/hal-00740058>.
- [9] X. LAGRANGE, "Very Tight Coupling between LTE and Wi-Fi for Advanced Offloading Procedures", in: *WCNC 2014 : IEEE Wireless Communications and Networking Conference*, 2014.
- [10] Z. LI, M. K. SBAL, Y. HADJADJ-AOUL, D. ALLIEZ, G. SIMON, K. D. SINGH, G. MADEC, J. GARNIER, A. GRAVEY, "Network Friendly Video Distribution", in: *NoF 2012 : 3rd International Conference on the Network of the Future*, 2012.

- [11] U. MIR, L. NUAYMI, “LTE Pricing Strategies”, *in: VTC Spring 2013: Vehicular Technology Conference*, 2013.
- [12] V. M. MORALES, P.-H. HORREIN, A. BAGHDADI, E. HOCHAPFEL, S. VATON, “Energy-efficient fpga implementation for binomial option pricing using opencl”, *in: Proceedings of the conference on Design, Automation & Test in Europe*, European Design and Automation Association, p. 208, 2014.
- [13] L. SADEGHIOON, A. GRAVEY, B. USCUMLIC, M. MORVAN, P. GRAVEY, “Full Featured and Lightweight Control for Optical Packet Metro Networks”, *Journal of optical communications and networking* 7, 2, Feb 2015, p. A235–A248.
- [14] L. SUAREZ, L. NUAYMI, J.-M. BONNIN, “Energy-efficient BS switching-off and cell topology management for macro/femto environments”, *Computer Networks* 78, 2015, p. 182 – 201, Special Issue: Green Communications, <https://doi.org/10.1016/j.comnet.2014.10.028>.
- [15] L. YANG, L. GONG, F. ZHOU, B. COUSIN, M. MOLNÁR, Z. ZHU, “Leveraging light forest with rateless network coding to design efficient all-optical multicast schemes for elastic optical networks”, *Journal of Lightwave Technology* 33, 18, 2015, p. 3945–3955.

Doctoral dissertations and “Habilitation” theses

- [1] X. CORBILLON, *Enable the next generation of interactive video streaming*, PhD Thesis, IMT Atlantique, IRISA, Oct 2018.
- [2] M. EZZAOUIA, *Allocation de ressource opportuniste dans les réseaux sans fil multicellulaires*, PhD Thesis, IMT Atlantique, IRISA, ENIT, Université Tunis El Manar, Nov 2018.
- [3] R. GUEDREZ, *Enabling Traffic Engineering Over Segment Routing*, PhD Thesis, IMT Atlantique, IRISA, dec 2018.
- [4] N. MAJED, *Measuring and Improving the Quality of Experience of Mobile Voice over IP*, PhD Thesis, IMT Atlantique, IRISA, Oct 2018.
- [5] A. SAMBA, *Science des données au service des réseaux d’opérateur*, PhD Thesis, IMT Atlantique, IRISA, oct 2018.
- [6] F. SLIM, *Etude et implémentation d’algorithmes de gestion de ressources pour un système d’exploitation de réseau*, PhD Thesis, IMT Atlantique, IRISA, Mar 2018.

Articles in referred journals and book chapters

- [7] M. ABDALLAH, C. GRIWODZ, K. CHEN, G. SIMON, P. WANG, C. HSU, “Delay-Sensitive Video Computing in the Cloud: A Survey”, *ACM Transactions on Multimedia Computing, Communications, and Applications* 14, 3s, 2018, p. 54:1–54:29, <https://doi.org/10.1145/3212804>.
- [8] C. BEN AMEUR, E. MORY, B. COUSIN, E. DEDU, “Performance Evaluation of TcpHas: TCP for HTTP Adaptive Streaming”, *Multimedia Systems* 24, 5, October 2018, p. 491–508, <https://hal.archives-ouvertes.fr/hal-01756934>.

- [9] C. BEN AMEUR, E. MORY, B. COUSIN, “Combining Traffic Shaping Methods with Congestion Control Variants for HTTP Adaptive Streaming”, *Multimedia Systems* 24, 1, February 2018, p. 1 – 18, <https://hal.archives-ouvertes.fr/hal-01249646>.
- [10] C. GUEGUEN, M. MANINI, “Dynamic Tradeoff between Energy and Throughput in Wireless 5G Networks”, *Wireless Communications and Mobile Computing*, 2018, <https://doi.org/10.1155/2018/7484786>.
- [11] T. ISSA, Z. RAOUL, A. KONATÉ, J. C. ADÉPO, B. COUSIN, A. OLIVIER, “Analytical Load Balancing Model in Distributed Open Flow Controller System”, *Engineering* 10, 12, 2018, p. 863–875, <https://hal.archives-ouvertes.fr/hal-02008134>.
- [12] M. KANJ, E. LE ROUZIC, J. MEURIC, B. COUSIN, “Optical Power Control in Translucent Flexible Optical Networks With GMPLS Control Plane”, *Journal of optical communications and networking* 10, 9, 2018, p. 760–772, <https://hal.archives-ouvertes.fr/hal-01858708>.
- [13] J. LIU, Q. YANG, G. SIMON, W. CUI, “Migration-Based Dynamic and Practical Virtual Streaming Agent Placement for Mobile Adaptive Live Streaming”, *IEEE Trans. Network and Service Management* 15, 2, 2018, p. 503–515.
- [14] J. LIU, Q. YANG, G. SIMON, “Congestion Avoidance and Load Balancing in Content Placement and Request Redirection for Mobile CDN”, *IEEE/ACM Transactions on Networking*. 26, 2, 2018, p. 851–863.
- [15] R. MAALOUL, L. CHAARI, B. COUSIN, “Energy Saving in Carrier-Grade Networks: A Survey”, *Computer Standards & Interfaces* 55, January 2018, p. 8–26, <https://hal.archives-ouvertes.fr/hal-01539826>.
- [16] R. A. MAALOUL, R. TAKTAK, L. CHAARI, B. COUSIN, “Energy-Aware Routing in Carrier-Grade Ethernet using SDN Approach”, *IEEE Transactions on Green Communications and Networking*, September 2018, <https://hal.archives-ouvertes.fr/hal-01858703>.
- [17] Z. MHADBI, S. ZAIRI, C. GUEGUEN, B. ZOURI, “Validation of a Distributed Energy Management Approach for Smart Grid Based on a Generic Colored Petri Nets Model”, *Journal of Clean Energy Technologies* , 2018.
- [18] D. RENGA, H. AL HAJ HASSAN, M. MEO, L. NUAYMI, “Energy Management and Base Station On/Off Switching in Green Mobile Networks for Offering Ancillary Services”, *IEEE Transactions on Green Communications and Networking*, September 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01924278>.
- [19] A. SAMBA, Y. BUSNEL, A. BLANC, P. DOOZE, G. SIMON, “Predicting file downloading time in cellular network: Large-Scale analysis of machine learning approaches”, *Computer Networks* 145, November 2018, p. 243–254, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01951758>.

Publications in Conferences and Workshops

- [20] I. AMIGO, G. GOMEZ SENA, M. CHAMI, P. BELZARENA, “An SDN-based approach for QoS and Reliability in Overlay Networks”, in: *TMA 2018 : Network Traffic Measurement and Analysis Conference*, p. ., June 2018. Poster, <https://hal.archives-ouvertes.fr/hal-01881258>.

- [21] E. ANCEAUME, A. GUELLIER, R. LUDINARD, B. SERICOLA, “Sycomore : a Permissionless Distributed Ledger that self-adapts to Transactions Demand”, *in: NCA 2018 - 17th IEEE International Symposium on Network Computing and Applications*, IEEE, p. 1–8, Boston, United States, November 2018, <https://hal.archives-ouvertes.fr/hal-01888265>.
- [22] E. ANCEAUME, A. GUELLIER, R. LUDINARD, “UTXOs as a proof of membership for Byzantine Agreement based Cryptocurrencies”, *in: IEEE Symposium on Recent Advances on Blockchain and Its Applications*, IEEE, p. 1–8, Halifax, Canada, July 2018, <https://hal.archives-ouvertes.fr/hal-01768190>.
- [23] M. BEN YAHIA, Y. LE LOUEDEC, L. NUAYMI, G. SIMON, “When HTTP/2 Rescues DASH: Video Frame Multiplexing”, *in: INFOCOM 2017 : IEEE International Conference on Computer Communications*, p. 677 – 682, Atlanta, United States, May 2017, <https://hal.archives-ouvertes.fr/hal-01656188>.
- [24] S. E. BENATIA, O. SMAÏL, M. BOUDJELAL, B. COUSIN, “ESMRsc: Energy Aware and Stable Multipath Routing Protocol for Ad Hoc Networks in Smart City”, *in: 2nd International Conference on Artificial Intelligence in Renewable Energetic Systems (ICAIREs'2018)*, Springer (editor), *Lectures Notes in Networks and Systems: Renewable Energy for Smart and Sustainable Cities*, 62, p. 31–42, Tipasa, Algeria, November 2018, <https://hal.archives-ouvertes.fr/hal-01950397>.
- [25] J. CHAKARESKI, R. AKSU, X. CORBILLON, G. SIMON, V. SWAMINATHAN, “Viewpoint-Driven Rate-Distortion Optimized 360° Video Streaming”, *in: International Conference on Communication (ICC)*, IEEE (editor), IEEE, Kansas City, United States, May 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01896281>.
- [26] A. CHOUAYAKH, A. BECHLER, I. AMIGO, L. NUAYMI, P. MAILLÉ, “A truthful auction mechanism for dynamic allocation of LSA spectrum blocks for 5G”, *in: NetGCoop 2018 - 9th International Conference on NETWORK Games, CONTROL and OPTIMISATION*, New York, United States, November 2018, <https://hal.archives-ouvertes.fr/hal-01923463>.
- [27] A. CHOUAYAKH, A. BECHLER, I. AMIGO, L. NUAYMI, P. MAILLÉ, “Auction mechanisms for Licensed Shared Access: reserve prices and revenue-fairness tradeoffs”, *in: IFIP PERFORMANCE*, Toulouse, France, December 2018, <https://hal.archives-ouvertes.fr/hal-01883697>.
- [28] A. CHOUAYAKH, A. BECHLER, I. AMIGO, L. NUAYMI, P. MAILLÉ, “PAM: A Fair and Truthful Mechanism for 5G Dynamic Spectrum Allocation”, *in: PIMRC 2018 - 29th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, Bologna, Italy, September 2018, <https://hal.archives-ouvertes.fr/hal-01881249>.
- [29] X. CORBILLON, F. DE SIMONE, G. SIMON, P. FROSSARD, F. SIMON, “Dynamic adaptive streaming for multi-viewpoint omnidirectional videos”, *in: ACM Multimedia Systems (MMSys)*, 18, Amsterdam, Netherlands, June 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01896282>.
- [30] J. CORDOVA, G. ESPINOZA, L. NUAYMI, “Simple capacity estimations in the complex 5G/New Radio system”, *in: PIMRC 2018*, Bologna, Italy, September 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01924302>.
- [31] A. EL AMINE, H. AL HAJ HASSAN, L. NUAYMI, “Analysis of Energy and Cost Savings in Hybrid Base Stations Power Configurations”, *in: VTC 2018 - IEEE 87th Vehicular Technology Conference*, IEEE, Porto, Portugal, June 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01923392>.

- [32] M. EZZAOUIA, C. GUEGUEN, M. EL HELOU, M. AMMAR, X. LAGRANGE, A. BOUALLEGUE, “A Dynamic Transmission Strategy Based on Network Slicing for Cloud Radio Access Networks”, *in: 10th Wireless Days Conference*, Dubai, United Arab Emirates, April 2018, <https://hal.archives-ouvertes.fr/hal-01972777>.
- [33] P. FABIAN, A. RACHEDI, C. GUEGUEN, S. LOHIER, “Fuzzy-based Objective Function for Routing Protocol in the Internet of Things”, *in: IEEE Global Communications Conference (Globecom)*, Abu-Dhabi, United Arab Emirates, December 2018, <https://hal.archives-ouvertes.fr/hal-01956385>.
- [34] A. FADEL, B. COUSIN, A. KHALIL, “User Selection in 5G Heterogeneous Networks Based on Millimeter-Wave and Beamforming”, *in: IEEE HPCC Conference*, Exeter, United Kingdom, June 2018, <https://hal.archives-ouvertes.fr/hal-01798960>.
- [35] A. GRAVEY, D. AMAR, P. GRAVEY, M. MORVAN, B. USCUMLIC, D. CHIARONI, “Modelling packet insertion on a WSADM ring”, *in: 22nd International Conference on Optical Network Design and Modeling (ONDM 2018)*, IEEE, Dublin, Ireland, May 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01847654>.
- [36] C. GUEGUEN, M. MANINI, “Fairness-Energy-Throughput Optimized Trade-off in Wireless Networks”, *in: ICNC 2018 - International Conference on Computing, Networking and Communications, International Conference on Computing, Networking and Communications*, IEEE, p. 1–8, Maui, United States, March 2018, <https://hal.archives-ouvertes.fr/hal-01688870>.
- [37] K. HE, P. MAILLÉ, G. SIMON, “Watermarked video delivery: traffic reduction and CDN management”, *in: Proceedings of the 9th ACM Multimedia Systems Conference, MMSys 2018, Amsterdam, The Netherlands, June 12-15, 2018*, p. 76–88, 2018.
- [38] H. HRISTOVA, X. CORBILLON, G. SIMON, V. SWAMINATHAN, A. DEVLIC, “Heterogeneous Spatial Quality for Omnidirectional Video”, *in: 2018 IEEE 20th International Workshop on Multimedia Signal Processing*, IEEE (editor), *2018 IEEE 20th International Workshop on Multimedia Signal Processing*, IEEE, Vancouver, Canada, August 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01896283>.
- [39] V. ISSARNY, G. BOULOUKAKIS, N. GEORGANTAS, F. SAILHAN, G. TEXIER, “When Service-oriented Computing Meets the IoT: A Use Case in the Context of Urban Mobile Crowdsensing”, *in: ESOC 2018 - 7th European Conference on Service-oriented and Cloud Computing*, Como, Italy, September 2018, <https://hal.inria.fr/hal-01871515>.
- [40] M. ITURRALDE, T. GALEZOWSKI, X. LAGRANGE, “Performance of Mobile Relays in Loaded Conditions for Railway Transportation”, *in: 16th International Conference on Intelligent Transport Systems Telecommunications*, Lisbon, Portugal, October 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01897568>.
- [41] T. KERDONCUFF, T. GALEZOWSKI, X. LAGRANGE, “Mobile relay for LTE: proof of concept and performance measurements”, *in: 2018 IEEE 87th Vehicular Technology Conference: VTC2018-Spring*, IEEE, Porto, Portugal, June 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01846055>.
- [42] R. KHDHIR, B. COUSIN, K. MNIF, K. BEN ALI, “Neural network approach for component carrier selection in 4G/5G networks”, *in: 2018 Fifth International Conference on Software Defined Systems (SDS)*, IEEE, Barcelona, Spain, April 2018, <https://hal.archives-ouvertes.fr/hal-01877384>.

- [43] R. A. MAALOUL, R. TAKTAK, L. CHAARI, B. COUSIN, “Two Node-Disjoint Paths Routing for Energy-Efficiency and Network Reliability”, *in: 25th International Conference on Telecommunication (ICT 2018)*, p. 554 – 560, Saint-Malo, France, July 2018, <https://hal.archives-ouvertes.fr/hal-01875381>.
- [44] N. MAJED, S. RAGOT, L. GROS, X. LAGRANGE, A. BLANC, “Application-Layer Redundancy for the EVS Codec”, *in: 26th European Signal Processing Conference (Eusipco)*, Rome, Italy, September 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01971759>.
- [45] M. MDINI, G. SIMON, A. BLANC, J. LECOEUVE, “ARCD: a Solution for Root Cause Diagnosis in Mobile Networks”, *in: 14th International Conference on Network and Service Management, CNSM 2018, Rome, Italy, November 5-9, 2018*, p. 280–284, 2018.
- [46] S. PETRANGELI, G. SIMON, V. SWAMINATHAN, “Trajectory-Based Viewport Prediction for 360-Degree Virtual Reality Videos”, *in: 2018 IEEE International Conference on Artificial Intelligence and Virtual Reality, AIVR 2018, Taichung, Taiwan, December 10-12, 2018*, p. 157–160, 2018.
- [47] A. SAMBA, “Construction et déploiement d’applications web basées sur R”, *in: Septièmes Rencontres R*, Rennes, France, July 2018, <https://hal.archives-ouvertes.fr/hal-01836400>.
- [48] B. STÉVANT, J.-L. PAZAT, A. BLANC, “Optimizing the Performance of a Microservice-Based Application Deployed on User-Provided Devices”, *in: ISPDC 2018 - 17th International Symposium on Parallel and Distributed Computing*, IEEE, p. 133–140, Genève, Switzerland, June 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01894535>.
- [49] G. TEXIER, V. ISSARNY, “Leveraging the Power of the Crowd and Offloading Urban IoT Networks to Extend their Lifetime”, *in: LANMAN 2018 - IEEE International Symposium on Local and Metropolitan Area Networks*, p. 1–6, Washington, DC, United States, June 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01813313>.
- [50] B. USCUMLIC, D. CHIARONI, B. LECLERC, T. ZAMI, A. GRAVEY, P. GRAVEY, M. MORVAN, D. BARTH, D. AMAR, “Scalable Deterministic Scheduling for WDM Slot Switching Xhaul with Zero-Jitter”, *in: 2018 International Conference on Optical Network Design and Modeling (ONDM)*, IEEE, Dublin, France, May 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01847657>.
- [51] C. VARGAS ANAMURO, N. VARSIER, J. SCHWOERER, X. LAGRANGE, “Modeling of MTC Energy Consumption for D2D communications with Chase Combining HARQ Scheme”, *in: Globecom Workshop 5G Advanced: The Next Evolution Step of 5G NR*, 2018, <https://hal.archives-ouvertes.fr/hal-01842196>.
- [52] C. VARGAS ANAMURO, N. VARSIER, J. SCHWOERER, X. LAGRANGE, “Simple modeling of energy consumption for D2D relay mechanism”, *in: Wireless Communications and Networking Conference Workshops*, Barcelone, Spain, April 2018, <https://hal-imt-atlantique.archives-ouvertes.fr/hal-01836546>.
- [53] M. B. YAHIA, Y. L. LOUÉDEC, G. SIMON, L. NUAYMI, “HTTP/2-Based Streaming Solutions for Tiled Omnidirectional Videos”, *in: 2018 IEEE International Symposium on Multimedia, ISM 2018, Taichung, Taiwan, December 10-12, 2018*, p. 89–96, 2018.

Internal Reports

- [54] E. ANCEAUME, A. D. POZZO, R. LUDINARD, M. POTOP-BUTUCARU, S. TUCCI-PIERGIOVANNI, “Blockchain Abstract Data Type”, *Research report*, Sorbonne Université, CNRS, Laboratoire d’Informatique de Paris 6, LIP6, Paris, France, February 2018, <https://hal.sorbonne-universite.fr/hal-01718480>.