IRISA
UMR

Rennes, Brest

Advanced Technologies for Operated Networks

ADOPNET

Rennes, Brest

Activity Report

2017

1   Team

Faculty Members
        Xavier Lagrange, Professor (HDR), IMT Atlantique (leader of the team)
        Isabel Amigo, Associate Professor, IMT Atlantique
        Alberto Blanc, Associate Professor, IMT Atlantique
        Bernard Cousin, Professor (HDR), UR1
        Annie Gravey, Professor, IMT Atlantique
        Cédric Gueguen, Associate Professor, UR1
        Romaric Ludinard, Associate Professor, IMT Atlantique
        Loutfi Nuaymi, Professor (HDR), IMT Atlantique
        Gwendal Simon, Professor (HDR), IMT Atlantique
        Bruno Stévant, Research Engineer, IMT Atlantique
        Géraldine Texier, Associate Professor, IMT Atlantique
        Sandrine Vaton, Professor (HDR), IMT Atlantique

Post-Doctoral Fellows
        Djamel Amar, IMT Atlantique
        Marwa Chami, IMT Atlantique
        Kun He, IMT Atlantique
        Hristina Hristova, IMT Atlantique, since December 2017
        Mauricio Iturralde, IMT Atlantique
        Santiago Ruano Rincon, IMT Atlantique
        Ahmed Triki, IMT Atlantique

Research Engineer
        Tanguy Kerdoncuff (part-time), IMT Atlantique

PhD students
        Anas El Ankouri, Orange Labs, CIFRE, since October 2017
        Iaad Ben Dhia, Orange Labs CIFRE, since November 2015
        Mariem Ben Yahia, Orange Labs CIFRE, since December 2015
        Ayman Chouayakh, Orange Labs, CIFRE, since March 2017)
        Romuald Corbel, Orange Labs CIFRE, since November 2016
        Xavier Corbillon, IMT Atlantique, since October 2015
        Jialong Duan, IMT Atlantique, since November 2014
        Souheir Eido, IMT Atlantique, since January 2013
        Ali El Amine, IMT Atlantique, since October 2016
        Mahdi Ezzaouia, joint PhD from IMT Atlantique and Université de Tunis El Manar,

since January 2016
Ahmad Fadel, Univ. Rennes 1, since January 2017
Rabah Guedrez, Orange Labs CIFRE since November 2014
Najmeddine Majed, Orange Labs CIFRE, since May 2015
Malo Manini, IRT B-COM, since September 2017
Maha Mdini, Astellia CIFRE, since December 2015
Cédric Morin, IRT B-Com CIFRE, since December 2016
Maxime Mouchet, IMT Atlantique, since October 2017
Serge Romaric Tembo, Orange Labs CIFRE, till January 2017
Alassane Samba, Orange Labs CIFRE, since February 2015
Antoine Saverimoutou, Orange Labs CIFRE, since October 2016
Farah Slim, Orange Labs CIFRE, since May 2015
Qipeng Song, IMT Atlantique, since October 2014
Cesar Vargas, Orange Labs CIFRE, since January 2017

Administrative assistant
Nadia Derouault (part-time), Inria
Sandrine Frouin (part-time), IMT Atlantique
Marie-Pierre Yvenat (part-time), IMT Atlantique
Armelle Lannuzel (part-time), IMT Atlantique

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 3G 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.

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.

2.2   Key Issues

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.

3   Scientific Foundations

3.1   Introduction

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 performance. However, when the analysis is focused on a particular mechanism, several scientific tools can be used like stochastic analysis or discrete optimization.

3.2   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 ressources 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.

As traffic is more and more heterogeneous in nature and as the applications have different needs in terms of Quality of Service it is important for operators to monitor and classify the traffic per category of applications. This can be based on port analysis or Deep Packet Inspection (DPI) but these methods have drawbacks, such as applications changing port numbers or using dynamic port numbers and the widespread deployment of encryption that prevents access to packet payload. Another approach to the traffic classification problem is to use pattern recognition methods such as Support Vector Machine (SVM) in order to classify flows on the basis of descriptors such as the length of packets.

It is important to detect anomalies in traffic and to be able to do so with a low false alarm rate and a low delay. Sequential decision theory provides a rigorous framework to deal with real-time traffic anomaly detection problems. These methods are useful in the context of anomaly based Intrusion Detection Systems (IDS). The anomalies that one can discover in the traffic if one works on coarse traffic aggregates such as aggregated volumes of traffic are not useful in the framework of IDS. On the contrary rich anomalies can be discovered if one observes the traffic at a finer time scale on a per flow basis. As the cardinality of the state space of IP adresses is very large it is necessary to design data stream mining methods to maintain in real time some traffic statistics at flow level.

The economical context that network operators have to face is considered to be very difficult. Indeed, the emergence of bandwidth demanding services are putting operators under pressure since they generate a lot of traffic that consumes capacities deployed by operators.

But on the other hand these services generate revenues for service providers mainly (i.e. OTT) rather than for network operators. Economical models must therefore be rethought in order to permit a fair share of the revenues between the different stakeholders. The interactions between the stakeholders in this ecosystem can be analyzed with a game theoretic approach.

3.3 Hardware and software traffic processing

Keywords: traffic analysis, commodity hardwaren, 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 ressources and to implement with a software approach various traffic management protocols.

3.4 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.

Within the vast field of operations research, discrete optimization is one of the most fascinating branch, which still encompasses many open fundamental problems. In particular, the impossibility to develop fast algorithms that computes optimal solutions for discrete problems have conducted network scientists to find trade-offs between performances and computability.

From a scientific standpoint, network scientists are interested in developing fast approximate algorithms, where the performances are bounded with respect to the optimal solution,

or exact algorithms that lever some relaxed version of problems. Meta-heuristics have also gained some interests since they allow significant progresses in problem solving at relatively low development costs.

3.5   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 informa- tion; 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. There- fore, 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.

The optical control plane has to be integrated with existing control planes.

This can be done either by designing a new Ethernet transport network (similarly to EPON in an FTTH access network). An alternative is to build a new multi-client optical transport layer that could be integrated in a global GMPLS framework (GMPLS is the current frame- work used in operators' networks to globally command their networks). This is facilitated by generalizing label switching in technologies used for transport networks. In both cases, SDN can be used to configure the network.

4 Application Domains

4.1 Content Delivery

Participants: Alberto Blanc, Bernard Cousin, Annie Gravey, Gwendal Simon, Bruno Stévant, Géraldine Texier, 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.

4.2 Network Control

Participants: Isabel Amigo, Alberto Blanc, Bernard Cousin, Annie Gravey, Cédric Gueguen, Xavier Lagrange, Romaric Ludinard, Loutfi Nuaymi, Géraldine Texier, Djamel Amar, Iaad Ben Dhia, Ayman Chouayakh, Jialong Duan, Souheir Eido, Ali El Amine, Mahdi Ezzaouia, Ahmad Fadel, Rabah Guedrez, Mauricio Iturralde, Tanguy Kerdoncuff,

Najmeddine Majed, Chami Marwa, Cédric Morin, Alassane Samba, Qipeng Song, Farah Slim, Ahmed Triki, 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 electromagnetic 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.

4.3   Network Monitoring

Participants: Isabel Amigo, Alberto Blanc, Gwendal Simon, Sandrine Vaton, Antoine Saverimoutou, Maha Mdini, Serge Romaric Tembo, 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 traffic 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 $0(n^2)$ 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 bandwith). 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.

5   Software

5.1   Wi2me and Wireless Measurements Sharing Platform (WMSP)

Participants: Alberto Blanc[1].

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

---

[1]Only participants in ADOPNET are listed.

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.

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

5.3   gGalop - Generates and Analyses Lots Of Packets

Participants: Santiago Ruano Rincon, Sandrine Vaton.

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.

6   New Results

6.1   New technologies to enhance multimedia delivery

Participants: Mariem Ben Yahia, Alberto Blanc, Xavier Corbillon, Bernard Cousin, Kun He, Hristina Hristova, Xavier Lagrange, Gwendal Simon, Géraldine Texier.

Virtual Reality and Omnidirectional Videos.

The rise of immersive media is expected to be a major digital disruption in the horizon of the next ten years. For a couple of years, the users have been experiencing VR services around three Degrees-of-Freedom (3-DoF): A user who watches a 360-degree video with a Head-Mounted Display (HMD) can choose the portion of the spherical content to display by rotating the head to a specific direction. However, the streaming of such videos through the Internet with state of the art streaming architectures requires, to provide high immersion feeling, much more bandwidth than the median access bandwidth. To decrease the need for bandwidth consumption while providing high immersion to users, scientists and specialists proposed to prepare and encode 360-degree videos into quality-variable video versions and to implement viewport-adaptive streaming. Quality-variable versions are different versions of the same video with non-uniformly spread quality: there exists some so-called Quality Emphasized Regions (QERs). With viewport-adaptive streaming the client, based on head movement prediction, downloads the video version with the high quality region closer to where the user will watch. We have been major actors of the scientific contribution related to viewport-adaptive streaming. In [36], we have proposed a protocol and made an analysis of the impact of this proposal with regards to four projections. In [34], we have released a dataset of 50 users watching 360-degree videos. This dataset is a key input of algorithms for the prediction of head movement. In [35], we have developed optimal models for the definition and the settings of the encoder for 360-degree videos.

In the meantime, we have keep on exploring the game engines, which offer another type of virtual reality services. Mobile gaming is an emerging concept wherein gamers are using mobile devices, like smartphones and tablets, to play best-seller games. Compared to dedicated gaming boxes or PCs, these devices still fall short of executing newly complex 3D video games with a rich immersion. Three novel solutions, relying on cloud computing infrastructure, namely, computation offloading, cloud gaming, and client-server architecture, represent the next generation of game engine architecture aiming at improving the gaming experience. The basis of these aforementioned solutions is the distribution of the game code over different devices (including set-top boxes, PCs, and servers). In order to know how the game code should be distributed, advanced knowledge of game engines is required. By consequence, dissecting and analyzing game engine performances help to better understand how to move in these new directions (i.e., distribute game code), which is so far missing in the literature. Aiming at filling this gap, we propose in [14] to analyze and evaluate one of the famous engines in the market, that is, *Unity 3D*. We begin by detailing the architecture and the game logic of game engines. Then, we propose a test-bed to evaluate the CPU and GPU consumption per frame and per module for nine representative games on three platforms, namely, a stand-

alone computer, embedded systems, and web players. Based on the obtained results and observations, we build a valued graph of each module, composing the Unity 3D architecture, which reflects the internal flow and CPU consumption. Finally, we made a comparison in terms of CPU consumption between these architectures.

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.

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 [31] 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.

DASH has not been extensively studied in relation with Content Centric Network (CCN) so far. Considering the video segment more important than its location, CCN has been proposed to enhance DASH streaming. This architecture with its in-network caching salient feature improves Quality of Experience (QoE) from consumer side. It reduces delays and increases throughput by providing the requested video segment from a near point to the end user. However, there are oscillations issues induced by caching with DASH. In [45], we proposed a new Network-Assisted Strategy (NAS) based on traffic shaping and request prediction with the aim of improving DASH flows investigating new internet architecture CCN.

To address the problem of illegal re-streaming of video streams, existing solutions are based on watermarking the legal video to track the leak users who re-stream the stream on illegal platform. However, these solutions do not aim at tracking leaks as fast as possible, nor are adaptive to the number of users. In [43], we presented a CDN-based adaptive delivery architecture for watermarked streaming. We proposed an algorithm to generate unique sequences of watermarks for the legal delivery. This algorithm is adaptive in the number of users and optimal for the time needed to detect the leak. It meets the demand of live video providers who do not know in advance the number of clients for a stream. Our algorithm copes with thousands of new clients per seconds and enables leak detection in less than five minutes with only five watermarks for live video streams watched by one billion of clients.

TCP Congestion Control and Shaping Methods for HTTP Adaptive Streaming.

HTTP Adaptive Streaming (HAS) is a streaming video technique commonly employed over best-effort networks (aka Internet). However, it is characterized by some issues that harm users'quality of experience (QoE) in cases of daily use. 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. We describe two traffic shaping methods, the Hierarchical Token Bucket shaping Method (HTBM) and the Receive Window Tuning Method (RWTM), as well as four popular congestion control variants: NewReno, Vegas, Illinois, and Cubic. In [28], 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.

Economic Considerations related to Multimedia Delivery.

We have also addressed the problem of content delivery from the perspective of network economics. We have in particular dealt with the question of network neutrality.

Network neutrality has been topic of discussion for the past 25 years, with current legislation/regulation in the United States and Europe targeting the ISPs or "common carriers." But the reality of the Internet in the 2010s is that various actors contribute to the delivery of data, with sometimes contradictory objectives. In [11], we highlight the fact that neutrality principles can be bypassed in many ways without violating the rules currently evoked in the debate; for example, via CDNs, which deliver content on behalf of content providers for a fee, or via search engines, which can hinder competition and innovation by affecting the visibility and accessibility of content. We therefore call for an extension of the net neutrality debate to all the actors involved in the Internet delivery chain. We particularly challenge the definition of net neutrality as it is generally discussed. Our goal is to initiate a relevant debate on net neutrality in an increasingly complex Internet ecosystem, and to provide examples of possible neutrality rules for different levels of the delivery chain, this level separation being inspired by the OSI layer model.

6.2   Function and Service Placement in Networks

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

Content placement in SDN.

Finally the management of CDN is a major concern for both network operators and content providers. Software Defined Networking (SDN) and Network Function Virtualization (NFV) have emerged as a promising solution for elastic, dynamic and scalable network management. However, employing these techniques in mobile network for live streaming has not received enough attention. By leveraging the development of SDN and virtualization techniques, mobile

live streaming service providers can efficiently manage their system to cope with network dynamics incurred by the variation of the environment. Specifically, we dynamically instantiate network entities at appropriate locations in response to the user live streaming demands. These network entities are in charge of transcoding and transmitting the live videos to the mobile end users, which we name as virtual Live streaming Agent (vLA). In [12], we investigate the dynamic virtualization and migration of vLAs for mobile live streaming services. Typically, rate adaptive streaming is adopted to improve spectrum efficiency and user Quality of Experience (QoE). We formulate an Integer Linear Program for the optimal vLA placement problem. Further, we design a practical SDN-based live vLA migration process. Then, by designing and integrating migration cost functions, we develop a dynamic vLA placement mechanism for dynamic environments with the consideration of migration cost. In [49], we investigate the joint optimization problem of content placement and user request redirection for mobile CDN system. Specifically, each Base Station (BS) maintains a transmission queue for replying user requests issued from other BSs. Due to the limited link capacity and the dynamic network environment, the optimization problem should be jointly considered with the transmission queue states. We employ the Stochastic optimization model to minimize the long-term time-average transmission cost under content availability and network stability constraints. By applying the Lyapunov optimization technique, we transform the long-term problem into a set of linear programming (LP) problems, which are solved in each short time duration. Further, we propose a semi-distributed online algorithm to jointly decide content placement and user request redirection. The evaluation confirms that our solution guarantees network stability comparing to the traditional user request redirection scheme.

Virtual Network Function Placement.

In the context of Farah Slim's thesis, 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 [63]. Within the Open Network Automation Platform (ONAP), we developped 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 avoir 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 datacen-

ter. 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 performances 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 an 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 problem statement has been presented in [65] and the heuristic described in a poster at COMPAS 2017. The validation of the results are under submission.

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

6.3   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 exponential traffic growth in optical networks has triggered the evolution from fixed-grid to flex-grid technology. This evolution allows better spectral efficiency and spectrum usage over current optical networks in order to facilitate huge dynamic traffic demands. The promise of flex-grid technology in terms of increasing the number of optical channels established over optical links, however, may not be sustainable because of the associated increase in optical amplification power.

In [46], we show that flex-grid technology is an effective mean to improve the spectral efficiency of optical communications. We detail a power control process that takes advantage of

---

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

link optical power and channel optical signal-to-noise ratio margins to allow network operators to support this optical power increase while maintaining the use of legacy optical amplifiers. For a given amplifier spectral bandwidth, it gives rise to the increase of the number of optical channels as it reduces the channel spacing. Therefore, in order to reap full benefits from flex-grid saved spectrum, further amplification power is required with respect to conventional fixed grid. This is a strong limitation when the legacy amplifiers cannot meet this new requirement due to their optical power limits. In this work, we demonstrate that exploiting the link margins allows supporting this increase while maintaining in use legacy amplifiers.

Protection of Optical Networks.

To ensure service continuity, for instance in optical networks, even after failures, primary paths should be protected by precomputed and generally configuring backup paths. Upon a failure occurrence, only backup paths protecting against that failure are activated to repair the affected primary paths. As a result, the backup paths protecting against different failures should share their resources to save them. Two strategies of resource sharing are proposed in literature to provide protection while saving resources: (1) restrained sharing which applies the resource sharing to the backup paths only and (2) global sharing which extends the resource sharing to the primary and backup paths. In this work ([18]), we study the strategies of resource sharing when the primary paths correspond to the shortest ones according to a strictly positive and static metric. Even when the amount of resources that can be shared between the primary and the backup paths is unbounded, we proved that the maximum number of backup paths is still bounded. Besides, our simulations showed that the resource sharing between the primary and backup paths has very slight impact on the backup path rejection, i.e. the two strategies of resource sharing have very close performances.

Management of 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 networks has become a primary concern in a society increasingly dependent on information technology. Novel solutions that contribute to achieving energy savings in wired networks have been proposed to mitigate ongoing and alarming climate change and global warming. A detailed survey of relevant power-saving approaches in wired networks is presented in [13]. 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 carrier-grade networks.

The reduction of operational expenditure has become a major concern for telecommunication operators and Internet service providers. In [50], we propose an energy aware routing

(EAR) in Carrier Ethernet networks operating with Shortest Path Bridging (SPB) protocol with equal cost multi-path (ECMP). Since traffic load has no influence on power consumption of Carrier Ethernet network elements, the conventional solution to reduce power consumption is to find the maximal set of network elements that can be turned off/on so that the network performance is not deteriorated. To tackle this optimization problem, we propose an exact method based on Mixed Integer Linear Programming (MILP) formulation, called SPB energy-aware routing (SPB-EAR). Since SPB-EAR is proved to be NP-hard, we present two heuristics algorithm suitable for large-sized networks, called Green SPB (G-SPB) and Fast Greedy SPB (FG-SPB). In this work, we consider that a connection between two nodes is represented by bundled link consisting of multiple cables. Experimentations on four realistic network topologies show that G-SPB and FG-SPB can save almost as much power consumption as SPB-EAR.

6.4 Advanced optical networks

Participants: Annie Gravey, Ahmed Triki, Djamel Amar.

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. Flexibility, facilitating a quick adaptation to varying traffic demands, in terms of supported protocols and traffic profiles, is mandatory. An efficient support of both fine granularity and large volumes of traffic demands, for uplink and downlink traffic, is necessary, as MANs have to interconnect both low activity nodes (e.g., small DSLAMs, eNodeBs) and high activity nodes (e.g., data centers, pools of RRH). MANs should provide methods for isolating different clients' flows, together with an excellent QoS, including high reliability and fast protection.

In the framework of the SASER project, together with Orange Labs, we furthered our investigations of the Time-domain Wavelength Interleaved Network (TWIN) technology, an optical burst switching technology for transport networks with active edge nodes, passive core nodes, and time slotted operation. In [67], we assessed the performance delivered in a metro network by two optical packet switching architectures, enabling sub-wavelength switching granularity. We compare POADM (Packet Optical Add/Drop Multiplexer) with TWIN (Time-domain Wavelength Interleaved Network). In order to perform a realistic performance assessment, the study was carried out over a large set of traffic demands, for which the candidate architectures were first dimensioned taking into account network reliability. Then, the delivered data plane performance was assessed by simulation in terms of electronic packet loss, jitter and insertion delay. Two routing scenarios (anyto- any and hub-and-spoke) were mapped on a physical topology inspired from a European operator network. Simulation results showed that both architectures easily achieve performance targets set by the Metro Ethernet Forum, as long as the network is properly dimensioned.

Our on-going collaboration with Nokia Bell Labs is currently focused on carrying out studies in the framework of the N-GREEN project. This project furthers our studies regarding the implementation of Optical Packet Switching (OPS) architectures. In [66], we considered the new technology, WDM Slotted Add/Drop Multiplexer (WSADM) which has been proposed in

N-GREEN as a new transport network technology based on subwavelength switching. This solution is promising as it is expected to reduce costs by exploiting low cost technologies. In order to assess the relative cost of WSADM, we compare it, on the one hand, with OTN over WDM as a dominant transport solution in the current metropolitan network, and, on the other hand, with POADM (Packet Optical Add/Drop Multiplexer) and TWIN (Time-domain Wavelength Interleaved Network) as two other subwavelength switching solutions. The cost assessment is carried out over a ten-year period of time, taking into account the predicted traffic evolution. We consider a hub-and-spoke virtual network mapped on a physical topology inspired from a European operator network. The comparative study showed that, considering the adopted cost model, WSADM presents a lower cost than other technologies, and a limited growth during the studied period.

6.5   Segment Routing

Participants: Géraldine Texier, Rabah Guedrez.

Segment Routing (SR) architecture has a great potential to replace the MPLS control plane. It simplifies considerably 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 encodes 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 underutilization 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 [38]. Furthermore, in [42], 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.

6.6   QoS management in fixed and mobile networks

Participants: Alberto Blanc, Bernard Cousin, Souheir Eido, Annie Gravey, Xavier Lagrange, Najmeddine Majed, Cedric Morin, Geraldine Texier.

QoS management in the SDN architecture.

Software Defined Networking (SDN) allows new approaches to provide Quality of Service (QoS). In legacy networks, strict QoS guarantees often result in bandwidth over-provisioning. Then, QoS enforcement either consumes too many resources, or is not flexible enough. We have proposed a solution to provide QoS, based on the creation of on-demand MPLS tunnels with guaranteed bandwidths across an SDN network. In the control layer, we have introduced an SDN Traffic Engineering Management (STEM) module that interacts with the northbound applications to satisfy their requests to forward QoS-guaranteed traffic flows [55].   STEM delegates the path selection to a Path Computation Element (PCE), and the path enforcement to an SDN controller. While existing works usually rely on statistic gathering to monitor the network, we rely on the stateful PCE to record the attributed resources and estimate the remaining network capacity, avoiding overloading the network with monitoring traffic. Upon STEM requests, the SDN controller enforces the QoS policy in the data plane. User flows are aggregated into an MPLS tunnel and packets are labeled with a priority depending on the flow effective bandwidth. The experimental results demonstrate that this solution efficiently enforces bandwidth sharing between priority and best effort flows in SDN networks.

Management of QoS for VoIP in LTE networks.

LTE/EPC is an all-IP mobile system which provides higher data rates and lower latency. However, in 2017, most phone calls between mobile terminals are made on 3G/2G networks because they include a circuit-switched network. Deploying Voice over LTE (VoLTE) and providing high quality is a real challenge for 4G networks. In [51], we evaluate metrics specified in 3GPP to characterize trade-offs between delay and quality of VoLTE phones in various network conditions. We report test results on clock accuracy, terminal delay in uplink and downlink under error-free conditions, as well as delay and quality in the presence of packet losses and network jitter. We discuss how the underlying methodology intended for delay testing can be extended to evaluate de-jitter buffer performance using a black-box approach, and how to model VoLTE packet delay/loss characteristics in a realistic way.

WebRTC (Real Time Communication) is another possible solution to provide a telephone service in LTE/EPC networks. In [52], we present experimental results on WebRTC voice quality as a function of LTE radio coverage. Different LTE radio conditions are tested by varying the radio path loss (with fast fading) in controlled test lab conditions. Voice quality is evaluated at different speech coding bit rates. Results show that, with acknowledged mode data transmission over LTE, degrading radio coverage translated mainly into increasing end-to-end delay and jitter, with virtually no packet loss up to the coverage limit. Voice quality is analyzed by studying the influence of the specific jitter buffer used in WebRTC endpoints.

Reliable user connectivity in 5G Networks.

Reliability was, and still is, a major concern for telecoms operators. Network outage can potentially produce high penalty in terms of revenue and user quality of experience. In [30], we advocate that the data plane reliability can be easily improved when the Software Defined Networking (SDN) concept is incorporated into LTE/EPC networks. As a way to ensure user connectivity be available even in case of network equipment failures, we propose two recovery modes: (i) automatic tunnel re-establishment and (ii) on-demand tunnel re-establishment. Through simulations, we show that those mechanisms outperform the recovery mechanism previously proposed in 3GPP standard

In the framework of Souheir Eido's thesis [2] defended in July 2017, we proposed a novel approach supporting seamless mobility for users relying on SIPTO-based mobile access. It combines the use of MPTCP together with the handover procedures specifed for LTE in order to provide Handover in those cases in which SIPTO currently does not support mobility. We described how to make MPTCP operate over the LTE architecture and how the procedures defined by 3GPP to support handover should be (slightly) modified in order to enable session continuity. The applicability of the above procedures on candidate Fixed Mobile Convergence architectures proposed by the european project FP-7 COMBO project (COnvergence of fixed and Mobile BrOadband access/aggregation networks) is assessed by mapping the 3GPP mobile functions, as well as the different proposed functional elements, on the functional blocks defined in COMBO for universal Data Path Management (uDPM). We also proposed several architectures for implementing these procedures on COMBO FMC functional entities.

Pricing strategies for OFDMA wireless networks.

In [16] we propose a suitable pricing policy bringing benefits to both the operators and the customers. It allows the operator to efficiently manage the cellular network radio resources, maintain user Quality of Service (QoS) for different types of services and optimize the revenue. We analyzes various possible LTE pricing schemes, including the one we have proposed, based on different criteria: network load and congestion, operator revenue, traffic differentiation and user categorization.

Introducing determinism in routing for industrial IoT networks.

Recent standardization activities bring high Quality of Service (QoS) and predictability to Internet of Things (IoT), which are "going industrial". Critical applications such as industrial process control, smart grid or vehicle automation require deterministic transmissions with properties such as on-time data deliveries and end-to-end reliability close to 100%. Traditional radio technologies based on collision detection and retransmission introduce unpredictable delays, and can not ensure reliable delivery within a narrowly bounded time. We have proposed to exploit spatial diversity and packet redundancy to compensate for the inherently lossy wireless medium. We have introduced "Leapfrog Collaboration", a communication mechanism which takes advantage of communication overhearing, and in which parallel transmissions over two

paths are scheduled [56]. Promiscuous listening between the paths enables nodes to possibly overhear transmissions on the other. We evaluate the delay and jitter of the communication by simulation using Contiki OS and show that Leapfrog Collaboration outperforms the default retransmission-based approach of IEEE802.15.4-TSCH by up to 28% and 54%, respectively, while providing high network reliability. In the context of a dependability competition, we have proposed a novel routing protocol which aims at providing deterministic networking over a lossy wireless medium. Our mechanism extends the Bit Index Explicit Replication with Traffic Engineering (BIER-TE) mechanism defined at the IETF to enable a network controller to dynamically controlling the replication and elimination of packets according to the QoS requirements [44]. This work is made jointly with OCIF team.

Managing the heterogeneity in wireless sensor networks.

With the IoT, various use cases emerge in several areas, such as transportation, health and energy management. Still, actually leveraging the IoT within applications is challenged by: (i) the software and hardware heterogeneity of sensors and actuators, as well as of their communication networks, and (ii) the high volume of data continuously produced over time by a large number of sensors. In [33], we revisit core Service-Oriented Architecture (SOA) concepts to integrate advanced continuous processing techniques. The resulting architecture allows overcoming the high heterogeneity and the very large data scale that arise in the Internet of Things. Further, we investigated how to leverage the Constrained Application Protocol (CoAP) protocol so as to enable the resource-efficient deployment of the proposed architecture over the large diversity of sensor networks.

6.7   Multiple Access Technology Selection

Participants: Iaad Ben Dhia, Bernard Cousin, Annie Gravey, Cédric Guéguen, Xavier Lagrange.

Along with the rapid growth of mobile broadband traffic, different Radio Access Technologies (RATs), including 3GPP families and IEEE ones, are being deployed. A key feature will be an increased integration of both the fixed access and the different radio access technologies (RAT). A typical mobile device today can support 3G, numerous releases of 4G LTE, possibly including LTE-Unlicensed, several types of WiFi (possibly with access points owned by home users), all this across several large spectral bands. Our objective is to consider two aspects: i) the optimization of the architecture, ii) the optimization of the selection algorithms.

WiFi/LTE coupling.

As a follow-up to the COMBO project in which the concept of Universal Access Gateway was defined, we focused on the convergence of the data pathes. We proposed new convergent architectures and analysed their performance. More specifically, we propose a convergence below the IP layer called very tight coupling: residential WiFi APs are connected to LTE base stations and all data packets are transported by the Packet Data Convergence Protocol

(PDCP) both for WiFi and for LTE. This represents an interesting solution to offload the LTE networks even for fast-moving terminals because a dual connection (WiFi and LTE) is kept. Unlike other coupling solutions (tight coupling at the SGW (Serving Gateway) level or loose coupling at the Internet level), very-tight coupling naturally guarantees session continuity of the application because the IP address is kept in all mobility scenarios. We also implemented the concept of very tight coupling on a testbed based on OpenAir Interface (see `http://www.openairinterface.org/`), proved its interest and measured the performance for different scenarios [48]. Using PDCP as the unifying protocol for all access technologies (which is one of the proposals of very tight coupling) is considered as a key aspect in 5G networks.

Radio Access Network Selection.

In [29], we consider the downlink of a heterogeneous network with several broadband RATs: 3G and 4G technologies with co-siting and WiFi access points. We start by formulating a centralized approach for the RAT selection as an optimization problem. We consider two types of services (Real Time and Non-Real Time services) and two types of subscribers (premium and normal ones). We define utility functions for the different types of users and services and maximise the global utility of the service. We show that our approach improves the user satisfaction while maintaining a reasonable blocking rate.

Radio Access Network Sharing.

In a shared radio access network, a user can be served through the network of his home operator or the network of another service operator in the sharing system. Consequently, when the home operator is unable to serve its user, and there is more than one available service operator, a selection decision must be made. The decision must consider the satisfaction of three main agents: the user, his home operator and the service operator.
In [9], we adopt a strategic algorithm for the access selection decision in a multi-operator wireless network. It is based on a cost function that combines the requirements of the user, its home operator profit and the offered QoS of the service operator. This cost function takes into account the operators strategies for cooperation. We focus on the service operator strategy and we propose two strategies: a pricing strategy that consists of increasing the service cost, and a sharing strategy that consists of limiting the amount of shared resources. Simulation results prove the efficiency of the proposed algorithm and show how sharing between operators brings benefits in terms of user acceptance and profits as well. In addition, results show that the service operator strategy affects the access selection decision and the cooperation benefits; a pricing strategy can guarantee high profits for the service operator and can improve its client acceptance.
In a multi-operator shared network, an appropriate decision is needed for how much to share resources in order to maintain user satisfaction, while maximizing cooperation benefits. In [40], we investigate resource sharing in a three operators sharing system. The study focuses on the value of the sharing factor, which is the percentage of the operator resources dedicated for guest users access. Simulation results showed that resource reservation improves client satisfaction in terms of blocking rates, and the value of the sharing factor affects the achieved profits of

the sharing operators. Besides, the best decision of the sharing factor and the pricing scenario depends on the capacity of the operator.

6.8   Radio Resource Management

Participants: Alberto Blanc, Bernard Cousin, Cédric Guéguen, Xavier Lagrange, Loutfi Nuaymi, Hussein Al Haj Hassan, Jialong Duan, Ali El Amine, Mahdi Ezzaouia, Qipeng Song.

Radio Resource Management (RRM) algorithms or heuristics are a key element for providing high system throughput 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 (RRM): Inter-Cell Interference Coordination, scheduling, energy-efficient power control and selection strategies.

Multi-Cell Interference Coordination and Power Allocation.

One major concern for operators of Long Term Evolution (LTE) networks is mitigating inter-cell interference problems. Inter-Cell Interference Coordination (ICIC) techniques are proposed to reduce performance degradation and to maximize system capacity. It is a joint resource allocation and power allocation problem that aims at controlling the trade-off between resource efficiency and user fairness [Yas15].

In [22], we provided a comprehensive survey of ICIC techniques, and study their performance while putting into consideration various design parameters. This study was implemented throughout intensive system level simulations under several parameters such as different network loads, radio conditions, and user distributions. Simulation results showed the advantages and the limitations of each technique compared to frequency reuse-1 model. Thus, we were able to identify the most suitable ICIC technique for each network scenario.

The exponential growth in the usage of mobile networks along with the increasing number of User Equipments (UEs) are exacerbating the scarcity of frequency resources. Dense frequency reuse on the downlink of multiuser Orthogonal Frequency Division Multiple Access networks leads to severe Inter-Cell Interference (ICI) problems. Resource and power allocation techniques are required to alleviate the harmful impact of ICI. Contrarily to the existing techniques that consider single-cell resource and power allocation problem without taking ICI into account, we formulate a centralized downlink multi-cell joint resource and power allocation problem. In [24], the objective is to maximize system throughput while guaranteeing throughput fairness between UEs. We demonstrate that the joint problem is separable into two independent problems: a resource allocation problem and a power allocation problem. Lagrange duality theory is used to solve the centralized power allocation problem. We also tackle the resource and power allocation problem differently by addressing it in a decentralized manner. We propose a non-cooperative downlink power allocation approach based on game

---

[Yas15]   M. Yassin, *Inter-Cell Interference Coordination in Wireless Networks*, Theses, Rennes 1, November 2015.

theory. The players are the base stations, and each base station seeks to maximize its own utility function. We investigate the convergence of our proposed centralized and decentralized approaches, and we compare their performance with that of state-of-the-art approaches.

Indeed, mobile network operators are facing the challenge to increase network capacity and satisfy the growth in data traffic demands. In this context, Long Term Evolution (LTE) networks, LTE-Advanced networks, and future mobile networks of the Fifth Generation seek to maximize spectrum profitability by choosing the frequency reuse-1 model. Due to this frequency usage model, advanced radio resource management and power allocation schemes are required to avoid the negative impact of interference on system performance. Some of these schemes modify resource allocation between network cells, while others adjust both resource and power allocation. In [23], we introduce a cooperative distributed interference management algorithm, where resource and power allocation decisions are jointly made by each cell in collaboration with its neighboring cells. Objectives sought are: increasing user satisfaction, improving system throughput, and increasing energy efficiency. The proposed technique is compared to the frequency reuse-1 model and to other state-of-the-art techniques under uniform and non-uniform user distributions and for different network loads. We address scenarios where throughput demands are homogeneous and non-homogeneous between network cells. System-level simulation results demonstrate that our technique succeeds in achieving the desired objectives under various user distributions and throughput demands

Resource Allocation in Centralized Radio Access Networks.

Centralized/Cloud Radio Access Network (C-RAN) is a promising mobile network architecture, which can potentially increase the capacity of mobile networks while reducing operators' cost and energy consumption. However, the feasibility of C-RAN is limited by the large bit rate requirement in the fronthaul. The objective of this thesis is to improve C-RAN performance while considering fronthaul throughput reduction, fronthaul capacity allocation and users scheduling.

In [1], we first investigate new functional split architectures between Remote Radio Heads (RRHs) and Baseband Units (BBU) on the uplink to reduce the transmission throughput in fronthaul: some low layer functions are moved from the BBU to RRHs. We provide a quantitative analysis.

We then focus on Coordinated Multi-point (CoMP) transmission on the downlink. CoMP can improve spectral efficiency but needs tight coordination between different cells, which is facilitated by C-RAN only if high fronthaul capacity is available. We compare different transmission strategies without and with multi-cell coordination. Simulation results show that CoMP should be preferred for users located in cell edge areas and when fronthaul capacity is high [37]. We propose a hybrid transmission strategy. Users are divided into two parts based on statistical Channel State Informations (CSIs): the users located in cell center areas are served by one transmission point with simple coordinated scheduling and those located in cell edge areas are served with CoMP joint transmission. This proposed hybrid transmission strategy makes a good trade-off between users' transmission rates and fronthaul capacity cost.

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 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 [6] but also to increase network connectivity [7] or provide energy efficient radio communication. 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 [39, 8] and energy allocation in smart grid [15].

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 [6], 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,

[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.

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 [39] we extend this approach with the introduction of the concept of minimal bandwidth, which corresponds to the minimal amount of radio resources that an under-loaded cell must keep in order to be protected from sudden and uneven high bit rates peaks. This minimal bandwidth guarantees a minimal service. The majority of the existing works on dynamic channel assignment neglects the use of this important parameter or consider it as a static one. In this context, we introduce a novel multicellular scheduler called Dynamic Inter-cellular Bandwidth Fair Sharing (DIBFS) that dynamically computes the minimal bandwidth of a cell according to its ratio of used bandwidth and available bandwidth.

For most ICIC technics, the available bandwidth is divided into inner and edge sub-bands and users are also classified into interior and edge users. The available resources in each zone are exclusively allocated to users belonging to this zone. Mobile users classification is usually based on a threshold that can be either a given mean SINR value or a given distance. However, ICIC approaches based on these static parameters cannot efficiently manage non-homogeneous distribution of users. In [8], we introduced a dynamic handoff algorithm that aims to adapt static ICIC schemes to uneven distribution of users. Our new solution dynamically computes the classification of active users into interior and edge users, based on a heuristic load balancing algorithm. In our proposal, each cell autonomously reconfigures its bandwidth allocation constraints without modifying bandwidth repartition across the cellular network. This makes the solution well adapted to the non-uniform repartition of users at the multi-cell scale. Simulation results show that the proposed scheme improves bandwidth usage, reduces packet delay, and increases user satisfaction compared to state-of-the-art ICIC techniques.

Dynamic Frame Aggregation Scheduler for Multimedia applications.

Providing Quality of Service (QoS) to real time applications over Wireless Local Area Networks (WLANs) is becoming a very challenging task due to the diversity of multimedia applications. Concurrently, there are numerous WLANs devices that are rising recently. In [6] we have focus on IEEE 802.11n since it was designed to support a high data transmission rate (toward 600 Mbps) based on frame aggregation schemes. The aggregation mechanism accumulates many frames before transmitting them into a single larger frame, thus reducing overhead and increasing efficiency and throughput. Yet, this scheme cannot provide QoS satisfaction for delay sensitive application even if it supports higher throughputs. Indeed, aggregation headers cause supplementary delays particularly when aggregating unfrequent packets with small sizes. To overcome this limitation, we propose in this paper a new Dynamic Frame Aggregation (DFA) scheduler to provide QoS satisfaction to real time services. To achieve this goal, we defined new scheduling parameters such as QoS delays to avoid accumulation of non-scheduled packets. Hence, the DFA scheduler serves packets and dynamically adjusts the aggregated frame size based on these QoS delays. Conducted simulations illustrate the performance of our proposed DFA scheduler in term of satisfying QoS, throughput, loss and delay requirements

of voice and video traffics.

Trade-off between spectrum efficiency and energy efficiency.

One of the used strategies to increase the spectral efficiency (SE) of cellular network is to reuse the frequency bandwidth over relatively small areas. The major issue in this case is higher interference, decreasing the energy efficiency (EE). In addition to the higher bandwidth, densification of the networks (e.g. small cells or multi-user multiple input single output, MU-MISO) potentially increases the area spectral efficiency (ASE). The total energy consumption of the wireless networks increases due to the large amount of circuit power consumed by the dense network structures, leading to the decrease of EE. There is thus a trade-off between spectrum efficiency and energy efficiency. In [5] we consider the Signal-to-leakage-and-noise ratio (SLNR) approach, which is a promising criterion for linear precoder design in multiuser multiple-input multiple-output systems. We derived an expression of a precoder maximizing the SLNR based on the generalized Rayleigh quotient theorem. Compared with the conventional SLNR precoders, we considered the non-homogeneous average received signal-to-noise ratio (SNR) condition due to the random network geometry and the leakage to other cells. Simulation results demonstrate the superiority of the SLNR precoder over zero-forcing (ZF) precoder in terms of EE-ASE tradeoff. Our contribution lies in the analysis of the performance of SLNR precoder in PPP networks in terms of tradeoff between EE and SE, and in the comparison between the well known ZF precoder and SLNR precoder, when static power consumption is considered.

Energy-efficient power control and selection strategies.

One of the most promising techniques to drastically reduce the energy consumption of cellular networks is the use of sleep-mode (SM) methods: when the traffic load is low, some components of the network, such as a base station (BS), can be switched off. In this case, the traffic load is managed by BSs that stay on. In [10], we investigate how user cooperation can further reduce the energy consumption of a cellular network that uses SM strategies. In particular, we study how sleeping periods can be extended when users tolerate a delay before the start of their service. We propose two delay-tolerant-user-aware SM strategies and provide mathematical grounds for the evaluation of their performance. We evaluate the strategies in the context of LTE networks with realistic daily traffic patterns. The results show considerable daily energy reductions (up to 21% compared to the always- on paradigm and up to 15% compared to the SM strategy without user cooperation).

Mobile networks and renewable energy.

Green Mobile Networks that are powered with renewable energy sources and Smart Grids are studied in [57]. The mobile network interacts with the smart grid, responding to its requests by adapting its load. Load adaptation is obtained by resource on-demand strategies that operate on Base Stations, and by taking decisions about the use of the renewable energy that is locally produced and that can be used for powering the green mobile network. The

results, derived through a Markovian model, show that the use of resource on-demand strategies in the green mobile network improves the interaction between the network and the smart grid: significant cost gain can be achieved, the responsiveness to the smart grid requests increases, low storage probability decreases. A synthesis of Celtic SooGREEN project latest results was proposed in [58].

Mobile relay and energy-efficiency.

We also consider mobile relays in public transport. We investigate the deployment of mobile relay in LTE network from the performance point of view. We study the data rate gain provided by a mobile relay by using stochastic geometry. We investigate the capacity gain brought by mobile relays with multiple users and multiple relays. The cell total average rate and the energy efficiency are evaluated. Furthermore, we propose a TDD/FDD hybrid mobile relay mode, motivated by the fact that a vehicular UE is static relative to its serving mobile relay and close to it, which leads to a relatively good channel condition on the access link. In [7] we show that deploying mobile relays in TDD/FDD hybrid mode is beneficial both from an energy efficiency and a capacity point of view when the penetration loss due to the vehicle is large (typically over 15 dB).

Energy Efficiency in WiMAX or in Wireless Ad Hoc Networks.

Power conservation mechanisms allow the operator to meet the QoS requirements of its customers while offering mobility service for longer duration. Therefore, it is essential to maximize the battery life of WiMAX equipments. In [27], we study the mechanisms of power conservation already proposed for the WiMAX network. We then propose an improved mechanism for energy conservation in the IEEE802.16e standard, taking into account the characteristics of the WiMAX network. Finally, we evaluate the various mechanisms of energy conservation in terms of energy consumption, mean delivery time and management throughput. We show through extensive simulations that our proposed mechanism retains more energy while providing a better mean delivery time and decreasing the management throughput.

Ad hoc networks are wireless networks that can operate without infrastructure and without centralized network management; they may contain nodes with limited battery power. Hence, energy conservation is a critical requirement in the design of routing protocols for ad hoc networks. Clustering has been proposed as a promising method for simplifying the routing process in mobile ad hoc networks when network size increases. In [19], we propose an energy-efficient multipath routing protocol, called ES-CMR (Energy aware and Stable Cluster-based Multipath Routing protocol), which preserves the residual energy of nodes and increases the network lifetime. To achieve this goal, we use an objective model to select energy-efficient paths with stable links. Simulation results demonstrate that ES-CMR has better performance in terms of energy consumption, network lifetime and end-to-end delay.

Energy-efficient M2M cellular coverage.

The S-ALOHA (i.e. slotted-ALOHA) protocol is recently regaining interest in Lower Power

Wide Area Networks (LPWAN) handling M2M traffic. The special features of M2M traffic and requirements highlight the importance of analytical models taking into account performance-affecting factors and giving a thorough performance evaluation for the M2M context. We propose this type of studies in [64]. We jointly consider the impact of capture effect, diversity of transmit power levels with imperfect power control. We propose a low-complexity but still accurate analytical model capable of evaluating S-ALOHA in terms of packet loss rate, throughput, energy-efficiency and average number of transmissions. The proposed model is able to facilitate dimensioning and design of S-ALOHA based LPWAN. The comparison between simulation and analytical results confirms the accuracy of our proposed model.

Macro reception diversity is studied in [20]. We propose a simple but accurate analytical model to estimate the macro diversity gain in pure and slotted ALOHA wireless networks. The proposed model takes into account Rayleigh fading, shadowing and capture effect. We obtain simple closed-form formulas for the network packet loss rate. We find that systems with macro reception diversity can benefit from shadowing. With path loss exponent 4, packet loss rate constraint 10 percent and 8 dB shadowing, the capacity of pure ALOHA with macro diversity is at least 2 times as much as that in systems in which a device transmits only to the best base station.

The thesis of Qipeng Song was defended in november 2017 [3]. In addition to the analysis of Aloha described before, the contributions of this thesis are the following:

- Survey about the energy efficiency related studies in the literature. We review, classify the existing research works into different categories, and compare the pros and cons between categories. We also review the advances of the LPWAN related study.

- In terms of adaptations of LTE RAN to the M2M context, we first analyze the conventional random access mechanism in LTE and identify the existing inefficiencies. We then propose a multiple period polling service for periodic M2M use cases. The proposed service is compared with conventional random access mechanism in LTE in a fluid model.

Energy allocation in smart grid.

In [15] we proposed a real-time neighborhood energy management (NEM) approach that aims to manage real-time residential energy. The introduced approach considers the neighborhood energy surpluses in order to reduce peak load demand and gas emissions. First, NEM allows decreases in energy cost by optimally choosing between locally generated energy, neighborhood energy surplus, or grid supplied. Second, NEM maximizes the producer's gains by selling the excess energy not only to the utility companies but also to neighbors at a more profitable price. Our proposed energy selling price is flexible and adequately adapted to the user's excess energy. Simulation results proved the effectiveness of our proposed approach. The results show that our energy sharing pricing model satisfies the requirements of each user (minimizing energy cost and maximizing gain). NEM can effectively motivate and encourage users to share energy which will effectively motivate and encourage users to invest in renewable energy.

6.9   Wireless network monitoring

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

WiFi network monitoring.

Today, WiFi networks are widely deployed all over the world, with high Access Point (AP) density in urban areas. Both end-users and network operators are trying to exploit this density by combining multiple APs into community networks, in order to share Internet connectivity, and possibly other services. WiFi networks suffer from decentralized management and a lack of coordination in frequency allocation and power control. In order to better use and configure these uncoordinated deployments, the first step is to characterize them. We have developed a collaborative platform [17] (see also section 5.1), where mobile stations collect simple network measurements (e.g., the presence of an AP) and send these measurements to a central system. By gathering and processing several network measurements from different mobile users, the platform characterizes the network deployment. We demonstrate the usefulness of this platform by considering two applications: 1) minimal AP set, to reduce the energy needed to provide WiFi coverage in a given area, and 2) optimal scanning parameters, to minimize the time a mobile station needs for the network discovery. These two applications show the system's viability to solve particular problems of community networks.

Every day large numbers of users connect to IEEE 802.11 networks in order to access the Internet and all sorts of services. However, due to their unplanned and unregulated nature, and the lack of admission control and Quality of Service Guarantees, these wireless networks can experience traffic demand that exceeds the network capacity. In this case, if a device tries to send more traffic, or if a new device joins the network, the aggregate throughput does not necessarily increase. We show [54] that it is possible for IEEE 802.11 stations to detect a saturated channel by passively monitoring the beacon frames. Access points (AP) send beacon frames periodically and encode them using the strongest modulation and coding scheme, so that even stations far away from the sending APs can decode them correctly. When sending beacons, APs sense the channel first and, if it is busy, delay sending the frame, resulting in unevenly spaced beacon frames, whenever other transmitters are active. We present several experiments, under varying traffic loads, and analyze the distribution of the beacon jitter, whose variance increases as the offered load increases. We show that it is possible to determine, with an acceptable error rate, whether a channel is saturated by comparing the distribution of the beacon jitter with a reference distribution corresponding to a saturated channel.

Simulations are an essential tool for studying wire-less networks, yet great care must be taken when choosing the simulation parameters, in order to have results reflecting what would happen in a real network. Thanks to extensive traces containing scan results collected by pedestrian users in an urban setting, we select the parameters of different NS-3 modules so that the results obtained match what we observed in a real setting, contrary to what happens if one uses the default values of these modules [47]. We extend the NS-3 simulator in order to faithfully simulate the scanning phase and in order to dynamically change the IP address assigned to Mobile Stations. Finally, we use the simulation parameters that have produced

realistic results to analyze what happens when the Access Point density changes.

Throughput Prediction in Mobile Networks.

In [61], we addressed statistical approaches for the prediction of throughput without history. Throughput has a strong impact on user experience in cellular networks. The ability to predict the throughput of a connection, before it starts, bring new possibilities, particularly to the Internet service providers. They could adapt contents to the quality of service really reachable by users, in order to enhance their experience. We have conducted several large measurement campaigns involving a panel of users connected to a production network in France, to determine whether it is possible to predict the achievable data rate using measurements collected, before establishing the connection to the content provider, on the operator network and on the mobile node. We establish evidence that it is indeed possible to exploit these measurements to predict, with an acceptable accuracy, the achievable data rate. We thus introduce cooperation strategies between the mobile user, the network operator and the content provider to implement such anticipatory solution.

Anomaly Detection.

For a successful and efficient network supervision, an Anomaly Detection System is essential. In [53], our goal is to develop a simple, practical, and application-domain specific approach to identify anomalies in the input/output data of network probes. Since data are periodic and continuously evolving, it is not possible to use threshold-based approaches. We propose an algorithm based on pattern recognition to help mobile operators detect anomalies in real time. The algorithm is unsupervised and easily configurable with a small number of tuning parameters. After weeks of deployment in a production network monitoring system, we obtain satisfactory results: we detect major anomalies with low error rate.

6.10   Network monitoring for high-speed fixed networks

Participants: Serge Romaric Tembo Mouafo, Santiago Ruano Rincon, Sandrine Vaton.

High performance traffic generation, capture and analysis on commodity hardware.

We have developed a testbed based on software and commodity hardware for research on flooding attacks against DNS infrastructure detection. We have developed a DNS query generator, that reproduces some flooding attacks against a DNS server and is able to saturate 10 GbE links with 11 millions requests/second. Then we have developed a detector that captures and processes DNS requests online and is able to detect anomalies such as overabundant queried domains at reception. Relying on DPDK and libmoon (a LuaJIT framework for DPDK), these two tools run on commodity hardware, while optimizing the number of packets that we can handle at transmission and reception. Both generation and reception tools run Lua scripts, achieving a high level of flexibility. Given the high number of possible elements to analyse from

the DNS messages (IP addresses, random qnames) we use data stream mining tools, mainly CountMin-Sketch (CMS), to restrict the use of memory space. This tool can trigger an alarm when a domain exceeds a threshold of queries per a small interval of time. These results have been presented in [59] and [60].

Fault localization in GPON FTTH networks: an artificial intelligence approach.

The PhD of Serge Romaric Tembo Mouafo has been defended in january 2017 [4]. The goal was to design an artificial intelligence method to locate anomalies in GPON-FTTH networks. Many metrics can be obtained from network equipments: alarms, error counters, temperature, power/intensity, etc... Signature based methods look for some characteristic patterns in order to recognize some particular faults (for example, a broken fiber). But signature based methods suffer from different problems. The signature are difficult to maintain, and there are many faults which are not identified since they do not correspond to any signature in the database.

We have followed a different direction, based on artificial intelligence. We have designed a Bayesian network to model the propagation of "faults" between the different equipments of the GPON-FTTH network. Some expert knowledge about fault propagation has been included in the topology of the Bayesian network. The Bayesian network characterizes the statistical dependence between the different metrics obtained from equipments. The parameters of the Bayesian network (conditional probabilities) have been tuned by processing a large scale dataset that corresponds to measurements performed on an operational network after some call to the operator's hot line. Some belief propagation algorithm has been used in order to infer root causes of faults and alarms from available metrics.

The results of this approach are very satisfactory. First of all, contrary to the diagnosis obtained with signature based method, there are no unidentified defaults any loner. And second, in the other cases, our method makes most of the time the same diagnosis as the signature based tool that is currently used by the operator for fault localization over operational networks. In the few cases when both tools do not agree, a careful analysis has been performed in order to understand why the decision was different and concluded that the decision of the artificial intelligence based method was the right one. Apart from the PhD of Serge Tembo two articles have been published on this research line in 2017 [21] [41].

6.11   Impact of new protocols on the quality and the security of web browsing

Participants: Antoine Saverimoutou, Sandrine Vaton.

Web browsing protocols are gaining the interest of the researchers. HTTP/2 has been standardized in 2015 and meanwhile, Google proposed another transport protocol, QUIC (Quick UDP Internet Connection). The main objective of the two protocols is to improve end-users quality of experience and communications security. HTTP/2 based web servers rely on TLS (Transport Layer Security) on top of TCP. Google has developed its own security system, natively integrated within QUIC, and runs on top of UDP. If performance issues, comparing HTTP/2 over TLS/TCP and QUIC/UDP, have been investigated by few researchers, no one

studied the security aspects of the two transport protocols. In [62] we have proposed a first security analysis of TLS/TCP and QUIC/UDP. Based on their characteristics, we have identified the vulnerabilities of the two protocols and evaluated their impact on HTTP/2 based web services.

6.12   Blockchain as a Software Connector for Distributed Services

Participants: Romaric Ludinard.

Since a couple of month, blockchain became 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 [26], we abstracted the behavior of the Bitcoin blockchain and studied its guarantees in term of consistency. Interestingly, we show that the Bitcoin blockchain satisfies the regularity register specification. It follows that the the strongest coherency implemented in Bitcoin is regularity under strong assumptions (e.g. partial synchronous system, sparse reads, . . .). This study contredicts the common belief that Bitcoin implements strong consistency criteria in asynchronous systems (and consensus).

Our future work is *i)* to derive a general framework to capture the behavior of different blockchains, *ii)* to derive scalable mechanisms to handle the ever increasing number of transactions, *iii)* to investigate the use of blockchains in networks (SDN, metrology, . . .).

7   Contracts and Grants with Industry

7.1   Contracts 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 (2014-2017) on the definition of programmable algorithm for connectivity in a segment routing network (Géraldine Texier).

    – 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 archictectures 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 qual-
ity 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.

7.2   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, Intitut Mines-
Telecom (IMT Atlantique, partner and coordinator for IMT, Télécom Sud Paris and
Télécom Ecole de Management), Lemasson, ATAWEY, Université de Caen Basse Nor-
mandie, Elisa, Polaran, Tele2, Energiforsk, Flexenclosure, BioSyncTechnology, INESC
TEC, Eurico Ferreira.

- Abstract: Mobile networks are witnessing an exponential growth of traffic volumes, as-
sociated 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.

7.3 ANR N-GREEN

Participants: Annie Gravey, Djamel AmarAhmed Triki.

- 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.

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

Participants: Annie Gravey, Djamel Amar.

- 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.

7.5 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.

7.6   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 Foudation 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 fondations for content delivery of novel interactive applications baesd on live video streaming.

7.7   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.

7.8   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.

7.9   Optimisation of mobile relays for LTE

Participants: Xavier Lagrange, Mauricio Iturralde, Tanguy Kerdoncuff.

- Title: Optimisation of mobile relays for LTE

- Framework: Industrial Contract

- Duration: Janv 2017- December 2017 (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 optimise it.

8   Other Grants and Activities

8.1   STIC AmSud PROVE

Participants: Sandrine Vaton, Isabel Amigo, Maxime Mouchet.

- Title: optimal Path discovery in Routing OVErlays

- Framework: STIC AmSud project

- Duration: 2016-2017 (2 years)

- Participants: IMT, LAAS/CNRS, Universidad de la Republica (Uruguay), Universidad de Concepcion (Chili)

- Abstract: The goal of the project is to build a routing overlay that can be widely deployed over a sizable population of routers. We want to design both active measurement methods providing an accurate estimation of the quality of overlay links without overloading the network, and online learning algorithms for discovering optimal routes with a scalable probing overhead.

8.2   HPTRAF (PEPS, CNRS INS2I)

Participants: Santiago Ruano Rincon, Sandrine Vaton.

- Title: High Performance TRAFfic analysis for DNS servers protection

- Framework: CNRS INS2I, Projet Exploratoire Premier Soutien (PEPS)

- Duration: july 2016 - december 2016, june 2017-may 2018 (18 months)

- Abstract: The goal is to design high performance traffic processing on commodity hardware with a software approach. Different problems are considered: traffic generation, traffic capture and analysis, anomaly detection and the considered throughput are Nx10 Gb/sec, which corresponds to dozens of millions of packets/second. We are in particular interested in the detection of flooding attacks against DNS servers, such as reflect and amplify or dafa888 attacks.

8.3   B<>COM 5M

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

- Title: 5G Massive-MIMO Mm Waves Multi-User plateform

- 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.

8.4   International Collaborations

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.

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, Antonine University), Ivory Coast (Houphouet-Boigny University and INPHB) 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.

Gwendal Simon is one of the 18 scientists who have developed a new program for the promotion of reproducibility in academic research, leaded by ACM Digital Library (DL). The task force has released a new approach to incentivize researchers to share datasets and more generally artifacts of their study. This approach is baesd on the concept of badges that are attached to papers. The task force has been invited in various conferences to disseminate the badging system, which has received much attention from leading conferences and journals.

Gwendal Simon is one of the core members of the Multimedia Cloud Computing Interest Group Interest Group (MCCIG) of the IEEE Technical Committee on Multimedia Communications (MMTC). This interest group promotes research and development in emerging area of cloud computing for multimedia communications, applications, and services. It aims to provide a platform for researchers and practitioners from academia and industry to discuss relevant topics and exchange views on the (potential) issues of utilizing cloud and its resources to further the quality, efficiency, effectiveness, and scope of multimedia communications. MCCIG will assist the IEEE MMTC by organizing and supporting academia events, such as conferences, workshops, and tutorials, special issues of relevant journals, and other efforts to promote this line of research.

Visiting researchers in 2017

- Souleymane OUMTANAGA (Professor) from Institut National Polytechnique Houphouet Boigny, Yamoussoukro, Ivoiry Coast.

- Assohoun ADJE (Dean) from University Felix Houphouet Boigny, Abidjan, Ivoiry Coast.

- Vincent MONSAN (Vice-Dean) from University Felix Houphouet Boigny, Abidjan, Ivoiry Coast.

- Omar SMAIL (Associate-Professor) from University Mustapha Stambouli, Mascara, Algeria.

- Melhem EL HELOU (Associate-Professor) from University Saint Joseph, Beirut, Lebanon.

- Pablo BELZARENA from Universidad de la República, Uruguay.

- Oluwafolake OJO from Federal University of Abeokuta, Nigeria.

- Mónica ESPINOSA BUITRAGO e is from Santo Tomás University, Bogotà, Colombia.

Sabbatical.

Géraldine Texier visited for 12 months INRIA@Silicon Valley in UC Berkeley, a joint program with INRIA, Californian universities and the CITRIS (Center for Information Technology Research in the Interest of Society).

8.5   National Collaborations

- Members of Adopnet team (Bernard Cousin, Cédric Guéguen, Xavier Lagrange, Géraldine Texier) have been detached (for a part of their time) to B<>Com, which is a national research and technology institute dedicated digital technologies. B<>Com provides unique technologies in the field of ultra-high-speed networks in order to accelerate the release of products designed to meet tomorrow's needs.

- Adopnet team members through their research projects collaborate with the worldwide research and innovation cluster, Images & Réseaux. With its network of partners specialized in ICT, Images & Réseaux brings innovators, industrialists and financiers together to support technology, usage and markets collectively.

- Since 2017 Sandrine Vaton is a member of the scientific council of AFNIC (*Association Française pour le Nommage Internet en Coopération*) which is in charge of administrating the .fr domain. The scientic council advises the board of directors and organizes JCSA (*Journées du Conseil Scientifique de l'AFNIC*), a yearly national scientific event around a specific theme.

9   Dissemination

9.1   Organization of conferences

Romaric Ludinard has been general chair of the 19th French days on algorithmic aspects of telecommunication problems and of the 2nd French days of network and communication protocols. Both events were colocalized in Quiberon, from Mai, 29th to June 02 and gathered around 80 French speaking people from Network and Distributed systems communities.

9.2   Awards

Xavier Corbillon and Gwendal Simon have received the best paper award from the IEEE International Conference on Communications (ICC) 2017 for their paper [36].

9.3   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 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

He is member of IEEE Communications Society (ComSoc) Technical Committee on Information Infrastructure and Networking (TCIIN).
He served, in 2017, in the Program Committee of the following conferences:

- DRCN 2017, 13th International Conference on the Design of Reliable Communication Networks

- FNC 2017, 12th International Conference on Future Networks and Communications

- ICSNC 2017, Twelfth International Conference on Systems and Networks Communications

- OPTICS 2017, International Conference on Optical Communication Systems

Annie Gravey is editor for the Journal of Communications and Networks, an international English-language journal published by the Korea Information and Communications Society. In 2017, she served in the Program Committee of the following conferences:

- APWiMob 2017, Asia Pacific Conference on Wireless and Mobile 2017

- CAMAD 2017, IEEE 22nd International Workshop on Computer Aided Modelling and Design of Communication Links and Networks

- Globecom 2017, IEEE Global Communications Conference, GC' 17 (Communication QoS, Reliability and Modeling and Selected Areas in Communications: E-Health)

- ICACCI 2017, IEEE Second International Conference on Advances in Computing, Communications and Informatics

- ICSigSys'2017 (The 2017 International Conference on Signal and Systems)

- PIMRC 2017, 2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC) - "Mobile and Wireless Networks": IEEE PIMRC 2017 Track 3

- WCNC 2018, IEEE Wireless Communications and Networking Conference

- Wimob 2017, 11th International Conference on Wireless and Mobile Computing, Networking and Communications

Xavier Lagrange is member of the scientific committee of Annals of Telecommunications published by Springer.
He also serves in the Program Committee of the following conference:

- IEEE ICC 2017, IEEE International Conference on Communications

- IEEE PIMRC 2017, 28th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications

- IEEE VTC 2017 Spring, Vehicular Technology Conference,

- WD'17 (Wireless Days 2017) - Wireless Networks track

He was also web co-chair for WiOpt 2017.

Loutfi Nuaymi is regular reviewer for Wiley Editions books proposals. He also served or serves in the Program Committee of the following conferences:

- IEEE Online GreenComm'17 (2017 IEEE Online Conference on Green Communications),

- VTC 2017 Spring, Vehicular Technology Conference Spring 2017

- ICC, International Conference on Communications, 2017 Green Communications Systems and Networks Symposium

He was also web co-chair for WiOpt 2017 and TPC Co-Chair for GreenNet Workshop in this same WiOpt Conference held in may 2017.

Gwendal Simon is in the editorial board of the IEEE MMTC R-letters related to Multimedia ACM SIG chapter. He was an area leader of IEEE ICME 2017 for the program committee of this conference. He also serves in the Program Committee of the following conferences:

- ACM Multimedia 2017, ACM flagship conference on Multimedia

- IEEE ICC 2017, IEEE International Conference on Communications

- IEEE Globecom 2017, IEEE Global Communications Conference

- IEEE ICME 2017, IEEE International Conference on Multimedia and Expo

- Packet Video 2017, 24th IEEE International Packet Video Workshop

- ACM Netgames 2017, 15th ACM Workshop on Network and Systems Support for Games

- ACM Nossdav 2017, 27th ACM workshop on Network and Operating System Support for Digital Audio and Video

- ACM MMSys 2017, the ACM Multimedia System Conference, which is the premier event for multimedia system and networking

- IEEE/IFIP CNSM 2017, IEEE International Conference on Network and Service Management, which is the flagship conference for the network management community

Géraldine Texier has served in the Program Committee of the Special Session on IoT connectivity and infrastructure of MMSys'17, the ACM Multimedia System Conference and in the Program Committee of the symposium on Blockchain Technology for Cybersecurity and Social Impact organized at the CITRIS and the Banatao Institute, University of California Berkeley.

Sandrine Vaton is associate editor of Transactions on Emerging Telecommunications Technologies (ETT). Sandrine is also a member of the steering committe of the Network Traffic Measurement and Analysis Conference (TMA). The first edition of the TMA Conference was held in Dublin in June 2017 as a unification of three successfull workshops (TRAC, TMA and WNM). 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

10   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]   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.

[5]   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.

[6]   C. Gueguen, M. Ezzaouia, M. Yassin, "Inter-cellular scheduler for 5G wireless networks", *Physical Communication*, 2016, https://hal.archives-ouvertes.fr/hal-01293199.

[7]   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.

[8]   X. Lagrange, "Very Tight Coupling between LTE and Wi-Fi for Advanced Offloading Procedures", *in: WCNC 2014 : IEEE Wireless Communications and Networking Conference*, 2014.

[9]   Z. Li, M. K. Sbai, 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.

[10] U. Mir, L. Nuaymi, "LTE Pricing Strategies", *in: VTC Spring 2013: Vehicular Technology Conference*, 2013.

[11] 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.

[12] I. Popescu, A. Triki, E. Le Rouzic, E. Bonetto, P. Gavignet, B. Arzur, P. Gravey, A. Gravey, "Optimal Cost and Performance Evaluation of Various Protection Schemes for Reliable All-Optical Sub-Wavelength Switching Network", *Journal of optical communications and networking 8*, 11, Nov 2016, p. 902–918.

[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.

[16] M. Yassin, M. A. AboulHassan, S. Lahoud, M. Ibrahim, D. Mezher, B. Cousin, E. A. Sourour, "Survey of ICIC Techniques in LTE Networks under Various Mobile Environment Parameters", *Wireless Networks*, 2015, p. 1, https://hal.archives-ouvertes.fr/hal-01198389.

Doctoral dissertations and "Habilitation" theses

[1] J. Duan, *Coordination inside Centralized Radio Access Networks with Limited Fronthaul Capacity*, PhD Thesis, IMT Atlantique, IRISA, Nov 2017.

[2] S. Eido, *Contrôle de la mobilité dans un réseau d'opérateur convergé fixe-mobile*, PhD Thesis, IMT Atlantique, IRISA, July 2017.

[3] Q. Song, *Radio Access Mechanisms for Massive Machine TypeCommunication in Long-Range Wireless Networks*, PhD Thesis, IMT Atlantique, IRISA, Nov 2017.

[4] S. R. Tembo Mouafo, *Applications de l'intelligence répartie à la recherche, l'identification et la résolution de pannes dans un réseau de télécommunication*, PhD Thesis, IMT Atlantique, IRISA, Jan 2017.

Articles in referred journals and book chapters

[5] A. M. Alam, P. Mary, J.-Y. Baudais, X. Lagrange, " Asymptotic Analysis of Area Spectral Efficiency and Energy Efficiency in PPP Networks with SLNR Precoder", *IEEE Transactions on Communications 65*, 7, April 2017, p. 3172 – 3185, https://hal.archives-ouvertes.fr/hal-01551410.

[6] E. CHARFI, C. GUEGUEN, L. CHAARI, B. COUSIN, L. KAMOUN, "Dynamic Frame Aggregation Scheduler for Multimedia applications in IEEE 802.11n Networks", *Transactions on Emerging Telecommunications Technologies*, 2016, p. 1 – 17, https://hal.archives-ouvertes.fr/hal-01427247.

[7] Y. CHEN, F. YAN, X. LAGRANGE, "Performance analysis of cellular networks with mobile relays under different modes", *Telecommunication Systems 66*, 2, October 2017, p. 217 – 231, https://hal.archives-ouvertes.fr/hal-01582555.

[8] M. EZZAOUIA, C. GUEGUEN, M. AMMAR, S. BAEY, X. LAGRANGE, A. BOUALLEGUE, "A Dynamic Inter-cellular Bandwidth Fair Sharing scheduler for future wireless networks", *Physical Communication 25*, December 2017, p. 85 – 99, https://hal.archives-ouvertes.fr/hal-01611283.

[9] S. FARHAT, A. E. SAMHAT, S. LAHOUD, B. COUSIN, "Radio Access Network Sharing in 5G: Strategies and Benefits", *Wireless Personal Communications*, 2017, p. 1–26, https://hal.archives-ouvertes.fr/hal-01546827.

[10] S. GAMBOA, A. PELOV, P. MAILLÉ, X. LAGRANGE, N. MONTAVONT, "Reducing the energy footprint of cellular networks with delay-tolerant users", *IEEE Systems Journal 11*, 2, June 2017, p. 729 – 739, https://hal.archives-ouvertes.fr/hal-01611343.

[11] E. GOURDIN, P. MAILLÉ, G. SIMON, B. TUFFIN, "The Economics of CDNs and Their Impact on on Service Fairness", *IEEE Transactions on Network and Service Management 14*, 1, 2017, p. 22–33, https://hal.inria.fr/hal-01398923.

[12] J. LIU, Q. YANG, G. SIMON, "Migration-Based Dynamic and Practical Virtual Streaming Agent Placement for Mobile Adaptive Live Streaming", *IEEE Transactions on Network and Service Management*, 2017.

[13] R. MAALOUL, L. CHAARI, B. COUSIN, "Energy Saving in Carrier-Grade Networks: A Survey", *Computer Standards & Interfaces*, 2017, p. 1–25, https://hal.archives-ouvertes.fr/hal-01539826.

[14] F. MESSAOUDI, A. KSENTINI, G. SIMON, P. BERTIN, "Performance Analysis of Game Engines on Mobile and Fixed Devices", *ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM) 13*, 4, 2017, p. 57:1–57:28.

[15] Z. MHADHBI, S. ZAIRI, C. GUEGUEN, B. ZOUARI, "Real-Time Distributed Management for Control of Smart Grids", *IEEE Journal of Emerging and Selected Topics in Power Electronics 5*, 1, March 2017, p. 490–503.

[16] U. MIR, L. NUAYMI, M. H. REHMANI, U. ABBASI, "Pricing strategies and categories for LTE networks", *Telecommunication systems*, 2017, p. 1–10.

[17] L. MOLINA, T. KERDONCUFF, D. SHEHADEH, N. MONTAVONT, A. BLANC, "WMSP: Bringing the Wisdom of the Crowd to WiFi Networks", *IEEE Transactions on Mobile Computing 16*, 12, December 2017, p. 3580 – 3591, https://hal.archives-ouvertes.fr/hal-01635369.

[18] M. Y. SAIDI, B. COUSIN, "Resource Sharing Strategies: Which Sharing to Better Protect Primary Shortest Paths?", *Journal of High Speed Networks*, 2017, p. 1–18, https://hal.archives-ouvertes.fr/hal-01555342.

[19] O. SMAIL, B. COUSIN, I. SNOUSSAOUI, "Energy-Aware and Stable Cluster-Based Multipath Routing Protocol for Wireless Ad Hoc Networks", *International Journal of Networking and Virtual Organisations*, 2017, https://hal.archives-ouvertes.fr/hal-01427003.

[20] Q. SONG, X. LAGRANGE, L. NUAYMI, "Evaluation of Macro Diversity Gain in Long Range ALOHA Networks", *IEEE Communications Letters 21*, 11, November 2017, p. 2472 − 2475, https://hal.archives-ouvertes.fr/hal-01656227.

[21] S. R. TEMBO MOUAFO, S. VATON, J.-L. COURANT, S. GOSSELIN, M. BEUVELOT, "Model-based probabilistic reasoning for self-diagnosis of telecommunication networks: application to a GPON-FTTH access network", *Journal of Network and Systems Management 25*, 3, July 2017, p. 558 − 590, https://hal.archives-ouvertes.fr/hal-01533710.

[22] M. YASSIN, M. A. ABOULHASSAN, S. LAHOUD, M. IBRAHIM, D. MEZHER, B. COUSIN, E. A. SOUROUR, "Survey of ICIC Techniques in LTE Networks under Various Mobile Environment Parameters", *Wireless Networks 23*, 2, February 2017, p. 403–418, https://hal.archives-ouvertes.fr/hal-01198389.

[23] M. YASSIN, S. LAHOUD, M. IBRAHIM, K. KHAWAM, D. MEZHER, B. COUSIN, "Cooperative Resource Management and Power Allocation for Multiuser OFDMA Networks", *IET Communications 11*, 16, September 2017, p. 2552 − 2559, https://hal.archives-ouvertes.fr/hal-01593122.

[24] M. YASSIN, S. LAHOUD, K. KHAWAM, M. IBRAHIM, D. MEZHER, B. COUSIN, "Centralized versus Decentralized Multi-Cell Resource and Power Allocation for Multiuser OFDMA Networks", *Computer Communications 107*, 2017, p. 112 − 124, https://hal.archives-ouvertes.fr/hal-01539926.

[25] A. ZRIBI, R. PYNDIAH, S. SAOUDI, X. LAGRANGE, "Erasure coding for reliable adaptive retransmission in wireless broadcast/multicast systems", *Telecommunication Systems 65*, 4, August 2017, p. 591 − 604, https://hal.archives-ouvertes.fr/hal-01573596.

Publications in Conferences and Workshops

[26] E. ANCEAUME, R. LUDINARD, M. POTOP-BUTUCARU, F. TRONEL, "Bitcoin a Distributed Shared Register", *in: Stabilization, Safety, and Security of Distributed Systems - 19th International Symposium, SSS*, 2017, https://doi.org/10.1007/978-3-319-69084-1_34.

[27] A. BELGHITH, A. WALHA, B. COUSIN, M. S. OBAIDAT, "Synchronized Power Saving Mechanism for WiMAX Networks", *Proceedings of 2017 IEEE International Conference on Communications (ICC)*, Paris, France, May 2017, https://hal.archives-ouvertes.fr/hal-01660888.

[28] C. BEN AMEUR, E. MORY, B. COUSIN, E. DEDU, "TcpHas: TCP for HTTP Adaptive Streaming", *in: Communications (ICC), 2017 IEEE International Conference on*, IEEE (editor), *Proceeding of 2017 IEEE International Conference on Communications (ICC)*, Paris, France, May 2017, https://hal.archives-ouvertes.fr/hal-01660914.

[29] I. BEN DHIA, M. BOUHTOU, T. EN NAJJARY, X. LAGRANGE, S. LAHOUD, "Optimization of Access Points Selection and Resource Allocation in Heterogeneous Wireless Network", *in: IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, 2017.

[30] S. Ben Hadj Said, B. Cousin, S. Lahoud, "Software defined networking (SDN) for reliable user connectivity in 5G networks", *in: Network Softwarization (NetSoft), 2017 IEEE Conference on*, IEEE (editor), *Proceedings of 2017 IEEE Conference on Network Softwarization (NetSoft)*, Bologna, Italy, July 2017, `https://hal.archives-ouvertes.fr/hal-01660873`.

[31] 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`.

[32] B. Billet, V. Issarny, G. Texier, "Composing Continuous Services in a CoAP-based IoT", *in: AIMS - 6th IEEE International Conference on AI & Mobile Services*, Honolulu, United States, June 2017, `https://hal.inria.fr/hal-01519132`.

[33] B. Billet, V. Issarny, G. Texier, "Composing Continuous Services in a CoAP-based IoT", *in: AIMS-6th IEEE International Conference on AI & Mobile Services*, 2017.

[34] X. Corbillon, F. De Simone, G. Simon, "360-Degree Video Head Movement Dataset", *in: MMSys 2017 : 8th ACM on Multimedia Systems Conference*, ACM, p. 199 – 204, Taipei, Taiwan, June 2017, `https://hal.archives-ouvertes.fr/hal-01597830`.

[35] X. Corbillon, A. Devlic, G. Simon, J. Chakareski, "Optimal Set of 360-Degree Videos for Viewport-Adaptive Streaming", *in: Proceedings of the 2017 ACM Conference on Multimedia (MM)*, p. 943–951, 2017.

[36] X. Corbillon, G. Simon, A. Devlic, J. Chakareski, "Viewport-Adaptive Navigable 360-Degree Video Delivery", *in: ICC 2017 : IEEE International Conference on Communications*, p. 1 – 7, Paris, France, May 2017, `https://hal.archives-ouvertes.fr/hal-01574040`.

[37] J. Duan, X. Lagrange, F. Guilloud, "Analysis of Different User Grouping Algorithms in a C-RAN Downlink System", *in: ICC 2017 : IEEE International Conference on Communications*, p. 1 – 6, Paris, France, May 2017, `https://hal.archives-ouvertes.fr/hal-01574029`.

[38] O. Dugeon, R. Guedrez, S. Lahoud, G. Texier, "Demonstration of Segment Routing with SDN based label stack optimization", *in: ICIN 2017 : 20th Conference on Innovations in Clouds, Internet and Networks*, p. 143 – 145, Paris, France, March 2017, `https://hal.archives-ouvertes.fr/hal-01574782`.

[39] M. Ezzaouia, C. Gueguen, M. Yassin, M. Ammar, X. Lagrange, A. Bouallegue, "Autonomous and Dynamic Inter-Cell Interference Coordination Techniques for Future Wireless Networks", *in: WiMob 2017 - 13th IEEE International Conference on Wireless and Mobile Computing, Networking and Communications*, Rome, Italy, October 2017, `https://hal.archives-ouvertes.fr/hal-01593117`.

[40] S. Farhat, A. E. Samhat, S. Lahoud, B. Cousin, "Resource Sharing in 5G Multi-Operator Wireless Network", *in: 4th International Conference on Computer Science, Computer Engineering, and Education Technologies (CSCEET 2017)*, Beyrouth, Lebanon, April 2017, `https://hal.archives-ouvertes.fr/hal-01712854`.

[41] S. Gosselin, J.-L. Courant, S. R. Tembo Mouafo, S. Vaton, "Application of probabilistic modeling and machine learning to the diagnosis of FTTH GPON networks", *in: ONDM 2017 : 21st Conference on Optical Network Design and Modeling*, p. 1 – 3, Budapest, Hungary, May 2017, `https://hal.archives-ouvertes.fr/hal-01573963`.

[42] R. Guedrez, O. Dugeon, S. Lahoud, G. Texier, "A New Method For Encoding MPLS Segment Routing TE Paths", *in: the Network of the Future (NOF), 2017 8th International Conference on*, IEEE, 2017.

[43] K. He, P. Maillé, G. Simon, "Delivery of Live Watermarked Video in CDN: Fast and Scalable Algorithms", *in: Proceedings of the 27th ACM Workshop on Network and Operating Systems Support for Digital Audio and Video (NOSSDAV)*, p. 79–84, 2017.

[44] H. Jiang, Z. Brodard, T. Chang, A. Bouabdallah, N. Montavont, G. Texier, P. Thubert, T. Watteyne, G. Papadopoulos, "Dependability Competition: Controlled Replication for Higher Reliability and Predictability in Industrial IoT Networks", *in: EWSN 2017 : International Conference on Embedded Wireless Systems and Networks*, ACM, p. 282 − 283, Uppsala, Sweden, February 2017, `https://hal.archives-ouvertes.fr/hal-01638297`.

[45] R. Jmal, G. Simon, L. Chaari, "Network-assisted strategy for dash over CCN", *in: Proceedings of the IEEE International Conference on Multimedia and Expo (ICME)*, p. 13–18, 2017.

[46] M. Kanj, E. Le Rouzic, B. Cousin, "Power-Aware Regeneration Algorithm in Flex-grid Networks", *in: 43rd European Conference on Optical Communication (ECOC 2017)*, Gothenburg, Sweden, September 2017, `https://hal.archives-ouvertes.fr/hal-01543930`.

[47] T. Kerdoncuff, A. Blanc, N. Montavont, "Using Empirically Validated Simulations to Control 802.11 Access Point Density", *in: WCNC 2017 : IEEE Wireless Communications and Networking Conference*, p. 1 − 6, San Francisco, United States, March 2017, `https://hal.archives-ouvertes.fr/hal-01534795`.

[48] Y. Khadraoui, X. Lagrange, A. Gravey, "Implementation of LTE/WiFi Link Aggregation with Very Tight Coupling", *in: IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, 2017.

[49] J. Liu, Q. Yang, G. Simon, "Delay Oriented Content Placement and Request Redirection for Mobile-CDN", *in: Proc. of 42nd IEEE Conference on Local Computer Networks (LCN)*, p. 498–501, 2017.

[50] R. Maaloul, R. Taktak, L. Chaari, B. Cousin, "Equal Cost Multiple Path Energy-Aware Routing in Carrier-Ethernet Networks with Bundled Links", *in: 14th ACS/IEEE International Conference on Computer Systems and Applications (AICCSA 2017), Proceedings of 14th ACS/IEEE International Conference on Computer Systems and Applications*, Hammamet, Tunisia, October 2017, `https://hal.archives-ouvertes.fr/hal-01660934`.

[51] N. Majed, S. Ragot, X. Lagrange, A. Blanc, "Delay and quality metrics in Voice over LTE (VoLTE) networks: An end-terminal perspective", *in: ICNC 2017 : International Conference on Computing, Networking and Communications : Communications QoS and System Modeling*, p. 643 − 648, Santa Clara, Ca, United States, January 2017, `https://hal.archives-ouvertes.fr/hal-01574769`.

[52] N. Majed, S. Ragot, X. Lagrange, A. Blanc, "Experimental evaluation of WebRTC voice quality in LTE coverage tests", *in: QoMEX 2017 : 9th International Conference on Quality of Multimedia Experience* , p. 1 − 6, Erfurt, Germany, May 2017, `https://hal.archives-ouvertes.fr/hal-01574796`.

[53] M. MDINI, A. BLANC, G. SIMON, J. BAROTIN, J. LECOEUVRE, "Monitoring the network monitoring system: Anomaly Detection using pattern recognition", *in: 2017 IFIP/IEEE Symposium on Integrated Network and Service Management (IM)*, p. 983–986, May 2017.

[54] L. MOLINA, A. BLANC, N. MONTAVONT, L. SIMIĆ, "Identifying Channel Saturation in Wi-Fi Networks via Passive Monitoring of IEEE 802.11 Beacon Jitter", *in: MobiWac 2017 - 15th ACM International Symposium on Mobility Management and Wireless Access*, ACM, p. 63 − 70, Miami Beach, United States, November 2017, `https://hal.archives-ouvertes.fr/hal-01656170`.

[55] C. MORIN, G. TEXIER, C.-T. PHAN, "On demand QoS with a SDN traffic engineering management (STEM) module", *in: 2017 13th International Conference on Network and Service Management (CNSM)*, IEEE, p. 1–6, 2017.

[56] G. PAPADOPOULOS, T. MATSUI, P. THUBERT, G. TEXIER, T. WATTEYNE, N. MONTAVONT, "Leapfrog Collaboration: Toward Deterministic and Predictable in Industrial-IoT Applications", *in: IEEE International Conference on Communications (ICC)*, 2017.

[57] D. RENGA, H. AL HAJ HASSAN, M. MEO, L. NUAYMI, "Improving the interaction of a green mobile network with the smart grid", *in: ICC 2017 : IEEE International Conference on Communications*, p. 1 − 7, Paris, France, May 2017, `https://hal.archives-ouvertes.fr/hal-01656115`.

[58] H. ROCHA, M. EL TABACH, C. GRANGEAT, J. GASCON, S. IMADALI, G. AKOPOLI-JOHNSON, X. CAMPDERROS, A. BOUSSELMI, D. MARQUET, E. ALEXANDRI, G. DELSART, A. HOSSAIN, C. CAVDAR, T. CHAHED, L. SALAHALDIN, A. CONTE, A. ANDERSSON, V. JOHNSON, L. NUAYMI, H.-O. SCHECK, A. M. MASUCCI, A. GATI, S. E. ELAYOUBI, W. YORO, "SooGREEN: Service-oriented optimization of Green mobile networks", *in: GREENNET 2017 : International workshop on Service-oriented optimization of Green Mobile Networks - WiOpt conference*, p. 8, Paris, France, May 2017, `https://hal.archives-ouvertes.fr/hal-01548231`.

[59] S. RUANO RINCON, S. VATON, S. BORTZMEYER, "A Software-based Approach to Generate and Detect Flooding Attacks against DNS Infrastructure", *in: DNS-OARC 26 : 26th workshop of Domain Name System Operations Analysis and Research Center*, Madrid, Spain, May 2017, `https://hal.archives-ouvertes.fr/hal-01581496`.

[60] S. RUANO RINCON, S. VATON, S. BORTZMEYER, "A software-based approach to reproduce and detect flooding attacks against DNS", *in: RIPE 74 2017 : RIPE NCC meeting - Réseaux IP Européens*, Budapest, Hungary, May 2017, `https://hal.archives-ouvertes.fr/hal-01581498`.

[61] A. SAMBA, Y. BUSNEL, A. BLANC, P. DOOZE, G. SIMON, "Instantaneous Throughput Prediction in Cellular Networks: Which Information Is Needed?", *in: 2017 IFIP/IEEE International Symposium on Integrated Network Management (IM)*, 2017 IFIP/IEEE International Symposium on Integrated Network Management (IM), IEEE, Lisbonne, Portugal, May 2017, `https://hal.archives-ouvertes.fr/hal-01535696`.

[62] A. SAVERIMOUTOU, B. MATHIEU, S. VATON, "Which Secure Transport Protocol for a Reliable HTTP/2-based Web Service : TLS or QUIC ?", *in: ISCC 2017 : 22nd IEEE symposium on International Symposium on Computers and Communications*, Heraklion, Greece, July 2017, `https://hal.archives-ouvertes.fr/hal-01565795`.

[63] F. SLIM, F. GUILLEMIN, A. GRAVEY, Y. HADJADJ-AOUL, "Towards a Dynamic Adaptive Placement of Virtual Network Functions under ONAP", *in: Proceedings of the third IEEE Conference on Network Function Virtualization and Software Defined Networks*, 2017.

[64] Q. Song, X. Lagrange, L. Nuaymi, "An Analytical Model for S-ALOHA Performance Evaluation in M2M Networks", *in: ICC 2017 : IEEE International Conference on Communications*, p. 1 − 7, Paris, France, May 2017, https://hal.archives-ouvertes.fr/hal-01656085.

[65] B. Stévant, J.-L. Pazat, A. Blanc, "Vers une plate-forme communautaire d'hébergement à base de micro-services collaboratifs", *in: COMPAS 2017*, Nice, France, June 2017, https://hal.inria.fr/hal-01701626.

[66] A. Triki, A. Gravey, P. Gravey, M. Morvan, "Long-Term CAPEX Evolution for Slotted Optical Packet Switching in a Metropolitan Network", *in: ONDM 2017 : 21th International Conference on Optical Network Design and Modeling*, p. 1 − 6, Budapest, Hungary, May 2017, https://hal.archives-ouvertes.fr/hal-01532047.

[67] A. Triki, I. Popescu, A. Gravey, P. Gravey, T. Tsuritani, "Carrier-Grade Performance Evaluation in Reliable Metro Networks Based on Optical Packet Switching", *in: ICNC 2017 : International Conference on Computing, Networking and Communications* , p. 70 − 75, San Diego, United States, January 2017, https://hal.archives-ouvertes.fr/hal-01574147.