



ADvanced technologies for OPerated NETworks

Advanced Technologies for Operated Networks

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2 Overall Objectives

2.1 Overview

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

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

Very different transmission technologies are required on the access to cope with this heterogeneity. Even though the IP protocol has been widely adopted, leading to a widespread *connectivity*, by itself it is not enough to offer *seamless communications*. For instance, somebody using a smart phone connected to a WiFi network will have to restart most of his communications (e.g., downloading a file, a VoIP call) when switching to a 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 have also 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. Thus, network monitoring is a key function for operators in order to enable the network to react 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 of implementations on test beds are required to analyze performances. However, when the analysis is focused on a particular mechanism, several scientific tools can be used like stochastic analysis, discrete optimization.

3.2 Mathematical methods and models

Keywords: decision theory, estimation theory, classification, data stream mining, queuing systems analysis, 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, heavy tailed distributions, etc... It is necessary to produce accurate traffic models in order to predict, for example, the utilization of resources or the quality of service. Very often traffic models are of stochastic nature. They can be very simple such as a Poisson process or more sophisticated such as Markov modulated models or, for example, fractional Brownian motions. These models are often parametric and their parameters must be estimated by the analysis of traffic captures.

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

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 the problem of applications that change or use dynamic port numbers and the problem of ciphered traffic. 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, for example, 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 very rich anomalies can be discovered if one observes the traffic at a finer time scale, such as the volumes of traffic per IP address for example. As the cardinality of the state space of IP addresses is very large it is necessary to use specific methods from data stream mining to maintain counts of packets per IP address on high bit rate links in real time.

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 the revenues these services generate revenues for service providers (i.e. OTT) but not 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 some tools of game theory.

3.3 Hardware and software traffic processing

Keywords: GPU, multi-core, parallelization, 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. A software approach is not always sufficient when one has to process traffic at bit rates higher than Gb/sec. Another solution is to use hardware acceleration in order to speed up some treatments. For example FPGA boards such as NetFPGA or COMBO cards are two platforms available for hardware accelerated treatments of network traffic. Software defined networking (SDN) with OpenFlow is also promising 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.

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

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

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

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 framework 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, Géraldine Texier, Sandrine Vaton, Ramon Aparicio-Pardo, Chiheb Ben Ameer, Mariem Ben Yahia, Xavier Corbillon, Mahdi Ezzaouia, Karine Pires.

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: Alberto Blanc, Bernard Cousin, Annie Gravey, Cédric Gueguen, Xavier Lagrange, Samer Lahoud, Loutfi Nuaymi, Hussein Al Haj Hassan, Hassan Ali Ahmad, William David Diego Maza, Chiheb Ben Ameer, YangYang Chen, Souheir Eido, Mahdi Ezzaouia, Moufida Feknous, Mohamad Kanj, Soha Farhat, Romain Jacquet, Pratibha Mitharwal, Ion Popescu, Alassane Samba, Qipeng Song, Farah Slim, Luis Suarez, Mohamad Yassin.

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.

4.3 Network Monitoring

Participants: Alberto Blanc, Gwendal Simon, Sandrine Vaton, Franck Cornevaux Juignet, Tristan Groléat, André Lalevée, Maha Mдини, Serge Romaric Tembo, Santiago Ruano Rincon.

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

The dramatic increase of the user data 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 to cope with the dynamicity of the network and the needs of monitoring applications. Advanced data analysis methods should be used in order to process measurement data and extract traffic descriptors, 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 measurements and to communicate from the measurement layer to other layers to trigger counter-measures.

Network monitoring finds application in various area. 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 is an application of traffic analysis at the level of different probes in the network.

- *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.
- *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.

5 Software

5.1 Wi2me

Participants: Alberto Blanc, Xavier Lagrange¹.

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.

ADOPNET team is involved in Wi2me project. 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 Blockmon

Participants: Tristan Groléat, Sandrine Vaton.

¹Only participants in ADOPNET are listed.

Blockmon is a software allowing construction of flexible and high performance (rates in the 10Gbps range) monitoring and data analysis nodes, where a node can be for example a hardware probe or a PC. Blockmon is based around the notion of blocks, which are small units of processing (e.g., packet counting). Blocks are connected and communicate via gates, and the set of inter-connected blocks represents a composition, where compositions are expressed in terms of an XML file.

Blockmon was developed in the framework of FP7 European project DEMONS (see See also : <http://fp7-demons.eu/>). Several partners are co-authors of the software: Andrea di Pietro (University of Pisa), Felipe Huici (NEC Europe), Nicola Bonelli (University of Pisa), Brian Trammell (ETH Zurich), Peter Kastovsky (INVEA-TECH), Tristan Groléat (Télécom Bretagne), Sandrine Vaton (Télécom Bretagne), Maurizio Dusi (NEC Europe). The Blockmon distribution is available under a BSD-style license at <http://blockmon.github.com/blockmon>.

5.3 High performance open source traffic generator

Participants: Tristan Groléat, Sandrine Vaton.

Traffic generators that support tens of Gb/sec are necessary in order to test hardware accelerated traffic monitoring probes. But commercial traffic generators that support such bit rate are very expensive. For that reason we have developed our own easily configurable, extendable, affordable and open source traffic generator. The open-source traffic generator is available at <https://github.com/tristan-TB/hardware-traffic-generator>.

The architecture of the traffic generator is very flexible. Parameters of the traffic such as data rate, packet size, inter-packet delay, packet header and payload can be easily configured through a GUI. The architecture of the traffic generator is modular and each module can be configured without FPGA reconfiguration. The creation of new modules modifying the generated traffic is also possible.

The traffic generator is able to generate traffic accurately at any rate up to 20 Gb/sec, even when sending small packets, which are the most challenging to handle. The generator respects the configured data rate with a very good accuracy.

6 New Results

6.1 New technologies to enhance multimedia delivery

Participants: Alberto Blanc, Bernard Cousin, Xavier Lagrange, Gwendal Simon, Chiheb Ben Ameer, Ramon Aparicio-Pardo.

Adaptive Multimedia Multicast Services in Networks.

Video broadcast technologies are essentially not designed to address a heterogeneous population of end-users. The same content is delivered, without regard to the characteristics of the receiving devices (e.g., display size and hardware capabilities) and to the quality of the support network. Yet, the heterogeneity of the devices that are used to consume video has increased, ranging from HDTV to smartphones. The specification of video broadcast technologies for

the latest generation (Long Term Evolution, LTE) and the next generation (5G) of cellular networks opens new opportunities to address the limitations of video broadcasting. We studied a solution that combines broadcast delivery from the server to the end-users and unicast feedback from each end-user to the server as we proposed in the case of cooperation between Digital Video Broadcasting and LTE [10]. The objective is to keep the benefits of broadcast for massive distribution of the same content (one transmission for several recipients) and to combine them with dynamic adaptation thanks to a feedback channel.

Rate-adaptive streaming technologies, such as the Dynamic Adaptive Streaming over HTTP (DASH) standard, provides an efficient and easy solution to stream multimedia in a heterogeneous context. However, it reinforces the streaming capacity problem in the core Content Delivery Network (CDN) infrastructure since delivering one video means delivering an aggregation of multiple representations. In particular, for live rate-adaptive streaming, a large set of non-divisible data streams need to be either delivered in whole, or not delivered at all. Previous theoretical models that deal with streaming capacity problems are based on elastic bit rates, and do not capture these emerging features faced by today's CDNs. In [20], we identified a new, discretized streaming model, for live rate-adaptive video delivery in CDNs. For this model we formulated a general optimization problem. We presented a fast, easy to implement, and near-optimal algorithm with performance approximation ratios that are negligible for large networks. These are the first sets of results for the discretized streaming model, and have both practical and theoretical importance in a topic that has become critical.

Large scale delivery of live video streams.

The delivery of multimedia applications have become a major concern for network operators because these applications have stringent requirements, which are sometimes difficult to accommodate with the underlying protocols and infrastructure of Internet.

Adaptive streaming addresses the increasing and heterogeneous demand of multimedia content over the Internet by offering several encoded versions for each video sequence. Each version (or representation) is characterized by a resolution and a bit rate, and it is aimed at a specific set of users, like TV or mobile phone clients. While most existing works on adaptive streaming deal with effective playout-buffer control strategies on the client side, we took a providers' perspective and propose solutions to improve user satisfaction by optimizing the set of available representations. We formulated an integer linear program that maximizes users' average satisfaction, taking into account network dynamics, type of video content, and user population characteristics. The solution of the optimization is a set of encoding parameters corresponding to the representations set that maximizes user satisfaction. We evaluated this solution by simulating multiple adaptive streaming sessions characterized by realistic network statistics, showing that the proposed solution outperforms commonly used vendor recommendations, in terms of user satisfaction but also in terms of fairness and outage probability. The simulation results showed that video content information as well as network constraints and users' statistics play a crucial role in selecting proper encoding parameters to provide fairness among users and to reduce network resource usage. We also proposed a few guidelines that can be used, in realistic settings, to choose the encoding parameters based on the user characteristics, the network capacity and the type of video content [28].

Nowadays, more and more users are watching online videos produced by non-professional sources (e.g., gamers, teachers of online courses, witnesses of public events) by using an increasingly diverse set of devices to access the videos (e.g., smartphones, tablets, HDTV). Live streaming service providers can combine adaptive streaming technologies and cloud computing to satisfy this demand. We analyzed the problem of preparing live video streams for delivery using cloud computing infrastructure, e.g., how many representations to use and the corresponding parameters (resolution and bit-rate). We used an integer linear program (ILP) to maximize the average user quality of experience (QoE) and a heuristic algorithm that can scale to large number of videos and users. We also introduced two new datasets: one characterizing a popular live streaming provider (Twitch) and another characterizing the computing resources needed to transcode a video. They were used to set up realistic test scenarios. We compared the performance of the optimal ILP solution with current industry standards, showing that the latter are sub-optimal. The solution of the ILP also shows the importance of the type of video on the optimal streaming preparation. By taking advantage of this, the proposed heuristic can efficiently satisfy a time varying demand with an almost constant amount of computing resources [39].

The delivery of live video channels for services such as twitch.tv leverages the so-called Telco-CDN-Content Delivery Network (CDN) deployed within the Internet Service Provider (ISP) domain. A Telco-CDN can be regarded as an intra-domain overlay network with tight resources and critical deployment constraints. In [33] we addressed two problems in this context: (1) the construction of the overlays used to deliver the video channels from the entrypoints of the Telco-CDN to the appropriate edge servers; and (2) the allocation of the required resources to these overlays. Since bandwidth is critical for entrypoints and edge servers, our ultimate goal is to deliver as many video channels as possible while minimizing the total bandwidth consumption. To achieve this goal, we proposed two approaches: a two-step optimization where the optimal overlays are firstly computed, then an optimal resource allocation based on these pre-computed overlays is performed; and a joint optimization where both optimization problems are simultaneously solved. We also devised fast heuristic algorithms for each of these approaches. The conducted evaluations of these two approaches and algorithms provide useful insights into the management of critical Telco-CDN infrastructures.

Gateway-based 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 its 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 work, we found that one of the most convenient solutions for this use case is to define a bandwidth manager, on the gateway side, that divides the available home bandwidth between HAS clients. Two main methods have previously been proposed to shape the HAS streams in accordance with the bandwidth manager direction and are referred as gateway-based shaping methods: a highly renowned method, Hierarchical Token Bucket Method (HTBM), that uses the hierarchical token bucket queuing discipline, and another method, Receive Window Tuning Method (RWTM), that employs TCP flow control by handling only acknowledgment TCP packets. In this work, [40, 2] we compare these two shaping methods. Results indicate that

RWTM improves the QoE better than HTBM and does not add queuing delay. Results were validated through experimentation and objective QoE analytical criteria.

6.2 Flexible management of optical networks

Participants: Bernard Cousin, Mohamad Kanj.

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 [9, 8]. 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 a flexible management of optical networks.

Indeed, 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 networks, in order to facilitate dynamic and huge traffic demands. The integration of Flex-Grid technology increases the number of optical channels established over optical links, leading however to an increase in amplification power and thus possibly saturating optical amplifiers. In [37], we propose a power adaptation process that takes advantage of link Optical Signal to Noise Ratio (OSNR) margins to allow network operators to support this power increase while keeping in use legacy amplifiers. Results show that controlling channel optical power permits to benefit from the Flex-Grid promises in terms of spectrum and capacity gain using in-place amplifiers infrastructure.

In [31], we study the multicast-capable routing, modulation and spectrum assignment (MC-RMSA) schemes that consider the physical impairments from both the transmission and light-splitting in elastic optical networks (EONs). Specifically, we propose to provision each multicast request with a light-forest which consists of one or more light-trees to avoid the dilemma that because of the accumulated physical impairments, a relatively large light-tree may have to use the lowest modulation-level and hence consume too many frequency slots. In order to further improve the spectral efficiency and compensate for the differential delays among the light-trees, we incorporate the rateless network coding (R-NC) in the multicast system. We first formulate an integer linear programming (ILP) model to solve the problem for static network planning. Then, we propose three time-efficient heuristics that leverage the set-cover problem and utilize layered auxiliary graphs. The simulation results indicate that in both the ILP and heuristics, the MC-RMSA with R-NC can achieve better performance

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

on the maximum index of used frequency slots than that without. After that, we evaluate the heuristics in dynamic network provisioning. The results show that the MC- RMSA with R-NC can effectively improve the performance of all-optical multicast in EONs to reduce the blocking probability.

Energy-Aware Forwarding Strategy for Metro Ethernet Networks.

Energy optimization has become a crucial issue in the realm of ICT. This paper addresses the problem of energy consumption in a Metro Ethernet network. Ethernet technology deployments have been increasing tremendously because of their simplicity and low cost. However, much research remains to be conducted to address energy efficiency in Ethernet networks. In [50], we proposed a novel Energy Aware Forwarding Strategy for Metro Ethernet networks based on a modification of the Internet Energy Aware Routing (EAR) algorithm. Our contribution identified the set of links to turn off and maintains links with minimum energy impact on the active state. Our proposed algorithm could be a superior choice for use in networks with low saturation, as it involves a trade-off between maintaining good network performance and minimizing the active links in the network. Performance evaluation shows that, at medium load traffic, energy savings of 60% can be achieved. At high loads, energy savings of 40% can be achieved without affecting the network performance.

6.3 Advanced optical networks

Participants: Annie Gravey, Moufida Feknous, Ion Popescu, Ahmed Triki.

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. Lastly, energy efficiency is a must, in order to limit Operational Expenditures (OPEX) [16].

In [61], we tried to answer the question "is it worth implementing dynamic resource allocation in a metropolitan network?". We showed that such a dynamic network reconfiguration approach can bring some CAPEX savings and more significant OPEX savings in a realistic metropolitan network scenario, even for rather large configuration periods.

In [55], we compared the respective efficiencies of the control and the management planes in performing resource allocation for Time-domain wavelength interleaved networks (TWIN) used to aggregate and distribute traffic within a metropolitan area. While the Management Plane driven MAC (MP-MAC) protocol is based on a quasi-static configuration derived from optimization model, the Control Plane driven MAC (CP-MAC) protocol is based on adapting Passive Optical Network (PON) upstream traffic control, originally designed to access net-

work, to the metropolitan network. The performance levels delivered by both approaches are compared by simulating a TWIN network applied to a Multi-head subwavelength switching (MEET) architecture that ensures an all optical aggregation between the regional metropolitan and the core networks.

It seems hard to achieve all the aforementioned goals simultaneously. MAN networks currently rely on optical links; in opaque networks, nodes operate in the electronic layer (e.g., Ethernet), while transparent networks are fully optical between source and destination. Electronic switching is a well-established solution but its major disadvantage is high-energy consumption. Optical packet/burst switching (OPS/OBS) combines sub-wavelength granularity, optical transparency and is thus energy efficient. However, 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, as optical buffering is not a currently viable option.

We studied several OPS architectures, based either on Packet Optical Add and Drop Multiplexing (POADM) interconnected rings or on Time-Domain Wavelength Interleaved Network (TWIN), that could be considered as future MAN architectures. We analysed the impact of the various options regarding transceivers on network capacity and delivered performance [62]. We also specified how dedicated MACs and associated protocols can efficiently support unicast, multicast and multi-service features, while providing carrier grade protection mechanisms [26]. Several original issues have to be tackled, for instance, the need to take into account scheduling and stability issues when dimensioning these networks [56].

6.4 QoS and mobility management in mobile networks

Participants: Annie Gravey, Xavier Lagrange, William Diego Maza, Souheir Eido, Pratibha Mitharwal.

LTE/EPC is an all-IP mobile system which provides higher data rates and lower latency. Nevertheless guaranteeing the QoS is a real challenge since the LTE/EPC QoS model inherits many characteristics of circuit oriented legacy standards. Contrary to usual QoS models of the fixed internet (IP networks), additional signalling procedures are required in order to establish a dedicated bearer for each desired QoS level. In [43] we proposed an analytical model to evaluate the impact of such a QoS model in terms of Processing Load. We showed that this cost is important in most cases. As an alternative, we introduced an IP-centric QoS model mainly inspired by IP policies commonly found in fixed networks. We compared the performance of this proposal compared to various implementations of the 3GPP QoS model using the ns-3 simulator in realistic scenarios. Some good properties of our IP-centric proposal compared to the standardized QoS model have been brought into evidence [42].

Nowadays, smartphones are used to download files such as movies, music, etc. These files present some flexibility in delivery time; we exploited this feature to reduce network overload peaks. If the network is overloaded, downloads are postponed, thus reducing the traffic load during rush hours and increasing the QoS of other users. In collaboration with Orange Labs, we proposed an architecture that enables the network to determine the best time to trigger a download that is queued. This architecture is based on a specific server in the network and a

mobile application. We analysed the performance of this novel concept in [12].

Data traffic in mobile networks is likely to exceed data traffic in fixed networks in the near future. Mobility management is going to take considerable importance. Today, the principle is to concentrate the traffic from and to mobile devices on a single gateway (which is called an anchor) in the mobile core network. By use of tunnelling mechanisms, the traffic is forwarded to the location of the mobile terminal. Such a mechanism is used in Mobile IP, Proxy Mobile IP and GTP (LTE mobility). This architecture concentrates the traffic in a single entity and merges mobility signaling and data traffic. It is necessary to develop new mechanisms for mobility management that are more distributed and that are activated only when the user or the service really need it.

The activity of ADOPNET includes the definition of mobility management mechanisms that are dynamic and distributed [3]. It is done in collaboration with OCIF. Dynamic Mobility Anchoring (DMA) is a new mobility protocol jointly proposed by OCIF/ADOPNET and Orange Labs^[Ber10] that is based on IPv6. Part of this work has been used in the DMM (Distributed Mobility Management) working group of IETF. We analysed the performance of DMA and Mobile-IP based schemes. We proposed an analytical model to compute the number of contexts and tunnels with DMA and with PMIP in a homogeneous network with random mobility of mobile nodes [22]. The model was used under different configurations by varying the traffic loads and the capacities of access nodes in order to analyze the distributed and dynamic characteristics of DMA. The results showed that the required number of contexts on an anchor node with DMA is significantly less than that required on an anchor node with PMIP and the required number of visitor contexts with DMA is significantly less in magnitude than that with PMIP for most of the configurations. The results also showed that the number of required tunnels with DMA is less than those required with PMIP for most configurations.

In [52] we focused on boosting network mobility Basic support protocol (NEMO) with the help of existing Multi-Path TCP (MPTCP). Network mobility is studied in the context of vehicles. The current NEMO relies on tunneling in order to use multiple available interfaces on a vehicle but does not reach the goal to provide optimum multi-homing benefits because it is unable to balance the traffic over available network interfaces. Moreover in NEMO, the nodes behind the mobile router cannot participate in multi-homing as the mobile router installed on the vehicle makes the mobility transparent to the nodes. The present work proposes to combine NEMO with MPTCP which enables the host nodes to participate in mobility and multi-homing and thus improving throughput, handover performance and avoiding excess tunneling.

Supporting mobility involves the issue of session continuity, including when mobile traffic is offloaded on the fixed network. 3GPP has designed Selective IP Traffic Offload (SIPTO) to help offloading mobile data traffic either above the RAN or at Local Network. However, this architecture does not always support session continuity when the User Equipment (UE) modifies its attachment to the mobile network as it is necessary to change the IP address allocated to the UE. In [44], we propose a method to support seamless mobility for sessions carried by SIPTO connections. We propose to blend SIPTO with using an MPTCP connection

[Ber10] P. BERTIN, *Gestion de la mobilité dans une architecture d'accès multi-technologies*, PdD Thesis, RSM - Dépt. Réseaux, Sécurité et Multimédia (Institut Mines-Télécom-Télécom Bretagne-UEB), UR1 - Université de Rennes 1, UEB - Université Européenne de Bretagne (UEB), 2010.

to carry the traffic. We identify how MPTCP operates over the LTE architecture, and estimate whether the corresponding delay is compatible with session continuity.

6.5 Multiple Access Technology Selection

Participants: Bernard Cousin, Annie Gravey, Cédric Guéguen, Xavier Lagrange, Samer Lahoud, Younes Khadraoui.

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.

In the framework of the FP-7 COMBO project (CONvergence of fixed and Mobile BrOadband access/aggregation networks), we participated to the definition of the concept of Universal Access Gateway and a unified approach for authentication [51]. We focused on the convergence of the data pathes, we proposed new convergent architectures and analysed their performance. The convergence can be made i) at the IP level and above or ii) at layer 2 and below [49]. In the first case, the problem is related to multi-attachment and multi-homing and is widely addressed by the scientific community. The very-tight coupling concept, which we proposed, is an example of layer-2 convergence solutions in which residential Wi-Fi APs are connected to LTE base stations. This represents an interesting solution to offload the LTE networks even for fast-moving terminals because a dual connection (Wi-Fi 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 [49]. We analysed the performance of very tight-coupling from a theoretical point of view and started to implement the concept in a testbed.

Determining the optimal user association can be a complex combinatorial optimization problem that depends on the SINR for every user to every BS, the instantaneous load at each BS, the choices of other users in the network, and possibly other constraints such as the requirement to utilize the same BS and standard in both uplink and downlink. The user association problem in two-tier heterogeneous networks, with traffic sharing, was studied in [KIC⁺11]. It was shown that, in the optimal case, each user is connected to a single RAT which avoids costly traffic splitting between available RATs. In the same context, we tackle the selection problem from two different perspectives in [18]. We formulate a centralized approach using a mathematical optimization problem. Then, two distributed approaches are proposed for adequate RAT selection: first, we put forward distributed heuristic algorithms based on the peak rate perceived by users from available RATs. Second, we devise a distributed RAT

[KIC⁺11] K. KHAWAM, M. IBRAHIM, J. COHEN, S. LAHOUD, S. TOHME, "Individual vs. Global Radio Resource Management in a Hybrid Broadband Network", *in: ICC 2011 Wireless Networking Symposium, ICC'11 WNS*, Kyoto, Japan, 6 2011.

selection scheme portrayed as a non-cooperative game with a learning-based algorithm to reach the Nash Equilibriums of the RAT selection game.

In [17], we propose a hybrid decision framework that dynamically integrates operator objectives and user preferences. Mobile users are assisted in their decisions by the network that broadcasts cost and QoS information. Our hybrid approach involves two interdependent decision-making processes. The first one, on the network side, consists in deriving appropriate network information so as to guide user decisions in a way to meet operator objectives. The second one, where individual users combine their needs and preferences with the signaled network information, consists in selecting the RAT to be associated with in a way to maximize user utility. We first focus on the user side and present a satisfaction-based multi-criteria decision-making method. By avoiding inadequate decisions, our algorithm outperforms existing solutions and maximizes user utility. Further, we introduce two heuristic methods, namely the staircase and the slope tuning policies, to dynamically derive network information in a way to enhance resource utilization. Following the aforementioned framework, we introduce an optimal approach in [14] where network information is computed using semi-Markov decision process (SMDP), and optimal policies are computed using the Policy Iteration algorithm. Also, and since network parameters may not be easily obtained, a reinforcement learning approach is introduced to derive what to signal to mobiles.

When in presence of multiple operators, the access technology selection needs special attention. In our recent works we adapt the Simple Additive Weighting (SAW) and Nearest Performance Handover (NPH) algorithms for the access selection in a multi-operator environment [46]. We also compare different pricing scenarios for the transaction cost of the inter-operators agreement in a cooperative environment [47]. This enables us to highlight how network conditions and operator's strategy for service price may affect the profitability of the cooperation. Further, a best pricing scenario can be decided depending on the deployed capacity for sharing and the user's service price settings. Finally, we investigate in [45] the access selection and joint pricing problem in multi-operator wireless networks. The problem is formulated as a Stackelberg game, where cooperating service operators first set the service price to maximize their revenue. Then, the home operator of the mobile user performs the access selection process among the service operators, in order to maximize its own profits and its client satisfaction, in terms of perceived QoS.

6.6 Radio Resource Management

Participants: Alberto Blanc, Bernard Cousin, Cédric Guéguen, Xavier Lagrange, Loutfi Nuaymi, Hussein Al Haj Hassan, YangYang Chen, Chiheb Ben Ameer, Mahdi Ezzaouia, Soha Farhat, Qipeng Song, Mohamad Yassin,.

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, energy-efficient power control and selection strategies, scheduling.

Inter-Cell Interference Coordination.

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 [8].

In [32] and [34], we provide a comprehensive survey on Inter-Cell Interference Coordination (ICIC) techniques, and study their performance while putting into consideration various design parameters. This study is implemented throughout intensive system level simulations under several parameters such as different network loads, radio conditions, and user distributions. Simulation results show the advantages and the limitations of each technique compared to frequency reuse-1 model. Thus, we are able to identify the most suitable ICIC technique for each network scenario.

Building on the results of the survey, we made two different contributions to the state-of-the-art: in [64] we introduce a non-cooperative dynamic ICIC technique that dynamically adjusts resource block allocation according to user demands in each zone, in [63] we propose a semi-static frequency allocation algorithm that exploits evolved-NodeBs communications via X2 interface to mitigate inter-cell interference. Cell zone satisfaction is tracked, and the unsatisfied zone gets more frequency resource blocks in a distributed manner.

We also considered radio resource management when there are mobile relays in public transport. We investigated the deployment of mobile relay in LTE network from two aspects: mobility management and performance. We first study the different signaling procedures when a mobile relay is embedded in a public transport vehicle. We propose to keep the protocol stack that was defined for fixed relay and to extend it to mobile relays. The concept of global tunnel, which gathers several tunnels, is proposed to optimize the handover procedure of mobile relay nodes [41]. In the performance study, we studied the data rate gain of a UE provided by a mobile relay deployed in a hexagonal network with Monte Carlo simulation and in a random network by using stochastic geometry. We investigated the capacity gain brought by mobile relays with multiple users and multiple relays. Important metrics like the CDF of the SINR and the CDF of the end-to-end rate are derived. Furthermore, we proposed 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 [3].

Energy-efficient power control and selection strategies.

In [27], we study the energy-efficient cell breathing approach in both macrocellular and heterogeneous networks. An approach based on the use of a traffic threshold is applied in order to control the BS switching-off aggressiveness. We study the the impact of access policies from 3GPP CSGs (Closed Subscriber Groups) on the network performance and how CSG features may be used by operators to set aspects such as pricing policies and QoS provision levels. The obtained results are analyzed showing the importance of proper tuning of energy-efficient algorithms in order to guarantee convenient energy savings and maintaining good QoS levels.

We study the use of renewable energy sources in wireless networks in [35]. While most of the studies in this direction are based on simulation or theory, this paper analyzes the usage of renewable energy in a realistic environment. Our study is based on a live scenario, where real traffic measurements of a major European mobile network operator are used. The effects of renewable energy allocation and base stations switching-off are evaluated in terms of on-grid energy saving and electric bill reduction. Moreover, a new algorithm that combines an intelligent renewable energy allocation and a switch-off mechanism based on renewable energy generation, storage state and price of on-grid energy is proposed. Our results show that switching-off base stations can achieve about 19% energy demand reduction. Moreover, equipping base stations with renewable energy sources that generate 20% of the total network energy demand can lead to 51% reduction in the electric bill.

As an energy provider, the power grid is evolving into a smarter one, which allows more energy-efficient cellular networks and enables cooperation and interaction with the smart grid. On one hand, cellular networks can use harvested renewable energy and on-site energy storage to reduce their energy costs. On the other hand, the price of electricity depends on the energy load, which will eventually contribute to decreasing the peak consumption and global energy cost. In [9], we propose new integration architecture for renewable energy-powered cellular networks and the smart grid. The proposed architecture is designed based on the classification and the analysis of the existing proposals and the requirements of the smart grid, renewable energy systems, and cellular networks.

In [53], we seek to jointly minimize the network power consumption and the user transmission delays in WLANs. We propose a heuristic algorithm that aims to compute the transmit power level of the Access Points (APs) deployed in the network and associate users with these APs in a way that jointly minimizes the total network power and the total network delay. The simulation results show that the proposed algorithm has a low computational complexity, which makes it advantageous compared with the optimal scheme, particularly in dense networks. Moreover, the heuristic algorithm performs close to optimally and provides power savings of up to 45% compared with legacy networks.

Further, we formulate and study the multi-objective optimization with aims of minimizing the network power consumption and transmission delay in [21]. Our general approach covers two different technologies: IEEE 802.11 and LTE. We capture the specificity of each technology in terms of the power model and radio resource allocation. The performance results enable us to assess the tradeoff between power and delay. A thorough analysis of the optimization results reveals the impact of the network topology, particularly the inter-cell distance, on both objectives. For an LTE network, we assess the impact of urban, rural and realistic deployments on the achievable tradeoffs. The power savings mainly depend on user distribution and the power consumption of the sleep mode.

While today's WiFi networks are typically characterized by uncontrolled and unmanaged deployments of Access Points (AP), several measurement studies (including those that we performed with the Wi2Me application, see Section 5.1) have shown that in urban settings there are many APs with significantly overlapping coverage. We believe that it is possible to reduce the energy consumption of these APs by selectively put some of them in sleep mode. We evaluated the potential of switching off APs using real measurements taken in a dense urban area. We collected traces covering more than 20 hours, confirming the high density of

currently deployed APs in such an environment. Based on these traces, we evaluated how many APs can be switched off while maintaining the same coverage. To this end, we proposed two algorithms that select the minimum set of APs needed to provide full coverage. We computed several performance parameters, and evaluate the proposed algorithms in terms of the number of selected APs, and the coverage they provide. Our results show that between 4.25% and 10.91% of the detected APs are sufficient to provide the same coverage, depending on the data set, the mobile terminal and the AP selection algorithm [58].

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 [25, 13] but also to increase network connectivity [10] or provide energy efficient radio communication [11]. Currently we work in order to increase the efficiency of these solutions. these activities can lead to many other subjects, such as opportunistic routing.

Machine Type communication (MTC) in LTE network is expected to gain a great popularity in the next decade. Due to different traffic characteristics, it poses some challenges for traditional random access procedure and resource allocation algorithm in LTE network. Since periodic MTC applications hold a considerable part of all existing MTC applications, we propose in [59] a network-integrated multiple-periodic polling service. This proposed service reduces the transmission overhead and thus improves the energy efficiency for MTC devices. It also reduces access network overload in radio access network by avoiding random access. Compared with traditional random access mechanism, numerical results show that with proposed service one eNodeB (eNB) can easily support up to 15000 MTC devices without network access collision.

[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.

6.7 Autonomous failure localization in GPON-FTTH access networks

Participants: Sandrine Vaton, Serge Romaric Tembo Mouafo.

The spectacular development of telecommunication networks has raised some new challenges in the design of network architectures and their management. The important demand of reliability, availability, robustness and quality of service has led telecommunication operators to trigger intensive research about autonomic networking which aims at automating numerous tedious management operations like multiple faults diagnosis or alarms correlation.

We focus on the design of advanced self-diagnosis and self-healing OAM (Operation, Administration and Maintenance) functions in large scale heterogeneous telecommunication networks. Detecting, isolating and correcting primary faults related to network connectivity and network performance should be automatized as much as possible using tremendous amounts of data generated by network components and services as source of information on the observed network anomalies.

In particular we consider the problem of network behavior modelling. Network behavior modelling is a central issue for model-based approaches of self-diagnosis of telecommunication networks. There are two methods to build such models. The model can be built from expert knowledge acquired from network standards and/or the model can be learnt from data generated by network components by data mining algorithms. In a recent work [60], we proposed a model of architecture and fault propagation for the GPON-FTTH (Gigabit Passive Optical Network-Fiber To The Home) access network. This model is based on a Bayesian network which encodes expert knowledge. This includes dependencies that encode fault propagation and conditional probability distributions that encode the strength of those dependencies. The proposed model has three layers. Layer 1 is an undirected graph which models the network topology. Network behavior, also called fault propagation, is modeled in layer 2 using a set of directed acyclic graphs interconnected via the layer 1. We handle uncertainties of fault propagation by quantifying strengths of dependencies between layer 2 nodes with conditional probability distributions estimated from network generated data. Layer 3 is the junction tree representation of the loopy obtained layer 2 Bayesian networks. The junction tree is the diagnosis computational layer since exact inference algorithms fail on loopy bayesian networks.

This Bayesian network model is used to carry out active self-diagnosis of the GPON-FTTH access network. In order to assess the performance of self-diagnosis with the Bayesian network model we have used different approaches. A first approach was to set up a physical testbed with a PON with two ONTs. Different faults were emulated, and alarms as well as counters were collected. The diagnosis of the root cause of alarms was performed with the Bayesian network approach. Seven usual fault scenarios were considered. Diagnosis results were inspected manually in order to assess their reliability. This demonstrated that self diagnosis based on a BN model was a reliable and promising approach. In a second phase, a database of more than 10000 diagnostic cases collected by Orange on a GPON-FTTH network in july-august 2015 was analysed. Two tools have been compared: PANDA, the self-diagnosis tool based on the Bayesian network approach, and DELC, a self-diagnosis tool based on deterministic decision rules currently used to diagnose faults in the operational network.

Future work will consider different enhancements of the Bayesian network model. First

of all we will take into account the different engineering techniques in the access network. Second, the topology of the Bayesian network will be fine tuned by mining data several months of measurement data from an operational GPON-FTTH network. Last, we will fine tune the conditional probability distributions that encode the strength of dependencies between nodes of our Bayesian network model by mining measurement data. This last problem is a parameter estimation problem under missing data conditions that we can solve with the Expectation Maximization (EM) algorithm.

6.8 Semantics based analysis of botnet activity from heterogeneous data sources

Participants: Sandrine Vaton, Santiago Ruano Rincon.

Networks capability to interconnect different devices, protocols, management systems and information sources necessarily yields to heterogeneous environments. This challenges network managers, for whom it is difficult to holistically manage their systems, having to make use of large, isolated and diverse measurement solutions. Semantics (i.e. the study of the relationship of meanings of a sign) is useful to solve those issues, correlating the different information sources through a high conceptual level. Ontologies, that is to say formal knowledge representations, can provide a semantic layer between concrete data and network concepts. In other words, they make it possible for the network manager to work with instances of concepts (such as latency measurements, a web server address, and timestamps) instead of raw data.

In a recent publication [57] we have used ontologies to evaluate the presence of bots in the local network. Botnets are the most significant way to carry out malicious activities today, such as denying services, spamming, phishing and extorting business data. We have developed a holistic approach to identify bots in the local network. We have correlated two different data sources, DNS traffic from PCAP captures, and TCP level information from IPFIX reports. DNS requests analysis makes it possible to find traces of botnet collective behaviour such as the look up for the IP addresses of the rendezvous point or of the victims. On the other hand some attacks such as TCP SYN flooding can be observed in the TCP information provided by IPFIX reports.

Thanks to ontologies, we see different datasets together, albeit they have been collected in distinct raw formats by different probes. Ontologies provide a common language to find the meaning of different data and then put them into the same network analysis context. In our case study, we have taken advantage of this semantics to identify botnet activity. We have built the ontology as well as an architecture that provides a unique access point to query different network management elements. With this approach we have analyzed a dataset from a university computer room with 19 hosts (students' computers), some of which had been infected by malwares. Our approach made it possible to report possible bots, some of which were certainly carrying out SYN flooding.

6.9 Reputation in Inter-Domain Routing

Participants: Géraldine Texier,.

Inter-domain QoS routing allow end-users to obtain promises from the ASes, which is more and more useful, in particular for video streams. However, ASes may behave maliciously and promise attracting QoS without actually delivering it. Reputation mechanisms are interesting tools that allow end-users to estimate whether the ASes that they might rely on will actually deliver their promises, and thus to better choose an inter-domain routing path. This work has been an opportunity to collaborate with CNRS, ENSAI, and University of Rennes 1.

We have identified the requirements of a reputation mechanism applied to inter-domain QoS routing, and design such a mechanism. In a publication [38] we propose a method allowing end-users to evaluate to what extent they can trust the QoS promised by ASes, and thus to better evaluate the reliability of routing paths. The reputation mechanism proposed is directly integrated within the path computation and ensures security properties such as ratings unforgeability, reputation scores unforgeability, ratings undeniability, ratings linkability and ratings consistency. Our proposition is scalable thanks to the use of efficient tools, such as the DHT, and the overhead is low: each user only needs to sign few messages. However, since end-users cannot observe the behavior of individual ASes, reputation scores cannot be extremely precise: if an AS is faulty, every AS of the used path receives a negative rating, which is not necessarily representative of their behavior. Improving this requires measuring elements that would be able to detect precisely which AS did not deliver the promised QoS, and which did. We proposed mechanism to associate reputation scores to routing paths to help end-users. Reputation mechanisms could assist inter-domain QoS routing in a second way, that is by associating reputation scores on ASes to help determine to which extent they cooperate with each other. An AS could use such a mechanism to decide whether to maintain a link with a neighboring AS: if the neighbor is not cooperative, it might be more interesting to drop the link. Integrating a double reputation mechanism - both for end-users and for ASes - would greatly improve the trust of all entities in inter-domain QoS routing.

7 Contracts and Grants with Industry

7.1 Contracts with Orange

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

- A grant (Contrat de Recherche, 2014-2016, 150 kE, holder: Gwendal Simon) on the study of the impact of Content Delivery Networks on the network neutrality. This grant targets the development of new strategies for network operators to operate their content delivery networks.
- CIFRE thesis (2013-2016) on detection and correction of faults in networks (Sandrine Vaton)
 - Application of swarm intelligence to the detection, isolation and correcting of multiple faults in telecommunication networks.
- CIFRE thesis (2013-2016) on traffic engineering for mobile networks (Xavier Lagrange).

- The objective of the work is to propose in 4G mobile networks IP centric mechanisms that can be both simple and cheap to deploy and efficient enough to provide several levels of QoS.
- CIFRE thesis (2012-2015) on gateway-based shaping methods of HTTP streams (Bernard Cousin)
 - Our investigation is mostly when several HAS clients compete for the bandwidth inside the same home network.
- CIFRE thesis (2013-2016) on Smart Management of Optical Networks (Bernard Cousin)
 - Software-defined-networking could revolutionize network management. It remains to be seen whether advanced optical functionalities (as, for instance, advanced grooming functionalities, advanced optical modulation formats, differentiated optical services, optical power management or advanced flex-grid WDM networks) can be efficiently managed by SDN.
- CIFRE thesis (2014-2017) on Traffic Monitoring and Forecasting based on Big Data (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.
- 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.

7.2 SYSTUF

Participants: Xavier Lagrange, Yang Yang Chen.

- Title: SYStèmes télécoms pour les Transports Urbains du Futur

- Framework: Fonds national pour la Société Numérique - Usages, services et contenus numériques innovants, Consultation AAP Systèmes de Transport Intelligents
- Duration: 2012-2015 (extended to march 2016)
- Partners : IFSTTAR (formerly INRETS), Eurecom, MERCE (Mitsubishi Electric), Alcatel-Lucent, RATP, ALSTOM
- Abstract: the objective of SYSTUF is to define and implement a new broadband multiservice wireless communication system for public transportation systems (bus, tram, metro). The technology is based on (LTE, Long Term Evolution) and more specifically on LTE mobile relays. On major constraint is to use the same system for critical communications (Communication Based Transport Control), Video transmission (CCTV), passenger information and infotainment. Reop is involved in the performance analysis of the gain provided by mobile relays and the protocols to develop to optimize mobility management.
- See also : <http://systuf.ifsttar.fr/>

7.3 CELTIC SASER-SAVENET

Participants: Annie Gravey, Ion Popescu, Ahmed Triki.

- Title: Safe and Secure European Routing
- Framework: CELTIC project
- Duration: 2012-2015
- Partners : Alcatel-Lucent, Nokia Siemens Networks, ADVA Optical Networking, Deutsche Telekom, Orange Labs, INRIA, Telecom Bretagne²
- Abstract: The Internet has become an indispensable part of the infrastructure for most of the aspects of daily life and has developed to a fundamental infrastructure for Europe. The uninterrupted, reliable and secure access to the Internet is seen as a basic right for all citizens and a significant economical factor. The number of attacks on Internet-connected systems are growing and the attacks have become more serious and more technically complex than in the past and can affect an increasing number of sensitive applications, e.g. e-government or e-commerce. It is then critical to ensure security and privacy, service quality and reliability, instantaneous and protected access, scalability. The goal of the SASER research programme is to provide the scientific, technical, and technological concepts and solutions for secure transport networks in the 2020 time frame. A European solution envisaged by SASER is based on the strengths and expertise in security and high-speed optical transport networks to overcome the bottlenecks and vulnerabilities of today's electronic all-IP based infrastructure.

²In the list of participants above, only REOP participants are cited.

- See also : <http://www.celtic-initiative.org/Projects/Celtic-Plus-Projects/2011/SASER/saser-default.asp>

7.4 CELTIC Opera Net 2

Participants: Loutfi Nuaymi, Hussein Al Haj Hassan.

This project also includes some researcher from the "Micro Ondes" Department of Telecom Bretagne: Francois Le Penec, Christian Person and Vu La Tran.

- Title: Optimising Power Efficiency in Mobile RAdio Networks 2
- Framework: Celtic (European) Projects
- Duration: dec 2011 - may 2015
- Partners : In addition to Telecom Bretagne, the other partners are: Orange, Alcatel Lucent, Thompson Broadcast, Université de Caen, Nheolis (From France), Nokia Siemens Networks, VTT, Efore (from Finland), University of Cardiff (from UK), Mitra Innovation (from Belgium)
- Abstract: Reducing the overall environmental impact of mobile radio networks is a central factor in achieving improved mobile services and enabling a growing telecommunications industry in emerging markets. The OPERA-Net-2 (Optimising Power Efficiency in Mobile Radio Networks 2) project concentrates on this challenge, addressing both energy and material efficiencies of 3G, 4G and heterogeneous networks, while also considering the use of renewable energy sources.
- See also : <http://projects.celticplus.eu/opera-net2/>

7.5 FP7 COMBO

Participants: Annie Gravey, Xavier Lagrange, Souheir Eido, Moufida Feknous, Younes Khadraoui.

- Title: COvergence of fixed and Mobile BrOadband access/aggregation networks (COMBO)
- Framework: EU FP7
- Duration: january 2013 – september 2016
- Partners : In addition to Telecom Bretagne³, the other partners are: JCP-connect, Deutsche Telekom AG, Orange, Telefonica, FON Wireless Ltd, Argela, Ericsson, Alcatel Lucent, ADVA Optical Networking Ltd, Telnet, Aitia, Centre Tecnologic de Telecomunicacions de Catalunya, Politecnico di Milano, Lund University.

³In the above list of participants, only Adopnet participants are cited

- Abstract: COMBO will propose and investigate new integrated approaches for Fixed / Mobile Converged (FMC) broadband access / aggregation networks for different scenarios (dense urban, urban, rural).
- See also : <http://www.ict-combo.eu/>

Intermediate results of the COMBO project have been presented in a tutorial during the conference HPSR 2015 [54].

7.6 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 (Telecom Bretagne, partner and coordinator for IMT, Télécom Sud Paris and Télécom Ecole de Management), Lemasson, ATAWAY, Université de Caen Basse Normandie, Elisa, Polaran, Tele2, Energiforsk, Flexenclosure, BioSyncTechnology, INESC TEC, Eurico Ferreira.
- Abstract: Mobile networks are witnessing an exponential growth of traffic volumes, associated with the emergence of new services. In particular, video services constitute a major part of the traffic and their share is expected to increase. In the same time, Internet of Things (IoT) related traffic will gain in importance with the explosion of the number of connected objects. This situation pushes towards an evolution of network architectures (e.g. LTE-A features on centralized/virtual RAN) and of content delivery solutions (e.g. in network caching). SooGREEN is built around the need of reducing the energy consumption of services in light of the traffic evolutions and exploiting the new network architectures, while keeping in mind the development of smart grids. This includes: Modeling the energy consumption of services in different mobile network architectures and taking into account the end-to-end path, A joint dynamic optimization of the mobile access network and the content delivery solutions, Proposal of solutions for enabling the bi-directional interaction of the mobile network and the smart grid by exploiting the flexibility of some services and the energy storage capabilities in the network.

7.7 ANR N-GREEN

Participants: Annie Gravey, Ahmed Triki.

- Title: New-Generation of Routers for Energy Efficient Networks

- Framework: ANR 2015
- Duration: October 2015- September 2018 (3 years)
- Partners : Nokia Bell Labs, Institut Mines-Telecom (Telecom Bretagne, , 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.

8 Other Grants and Activities

8.1 International Collaborations

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 co-operations are supported by formal agreements where Adopnet members are the collaboration leaders :

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

Visiting researchers

- Lambert TANOH from Institut Polytechnique Houphouet Boigny, Yamoussoukro, Ivoir Coast.
- Traoré ISSA from Institut Polytechnique Houphouet Boigny, Yamoussoukro, Ivoir Coast.
- Omar SMAIL from Université des sciences et de la technologie d'Oran - Mohamed-Boudiaf, Oran, Algeria.

8.2 National Collaborations

- Members of Adopnet team (Bernard Cousin, Samer Lahoud, Cédric Géguen) have been detached (for a part of their time) to B<>com. B<>com 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.
- Bernard Cousin is IRISA's representative to the Traffic Management forum (TM Forum) while Annie Gravey is Telecom Bretagne'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.

9 Dissemination

9.1 Organization of conferences

Le numérique: des métiers en tous genres Sandrine Vaton took part in the organization of "Le numérique: des métiers en tous genres". This day was organized on October 15th, 2015 in different locations in Brittany (Rennes, Brest, Lannion, Vannes and Lorient). The tele-amphitheatres of the UBL (Université Bretagne Loire) have been used. Over 600 pupils aged 14 to 17 took part to this event. The scope was to illustrate the diversity of jobs in digital technologies and to examine the place occupied there by women. After having organized this event we have published an article on a subject in touch with the topic of this day [29].

ICT-DM'2015 Samer Lahoud co-chaired the local organizing committee of the second International Conference on Information and Communication Technologies for Disaster Management (ICT-DM'2015). ICT-DM'2015 took place in Rennes from 30 November to 2 December 2015. More than 50 researchers from 29 countries attended the conference. 108 scientific papers were submitted and only 34% were accepted for appearing in the conference proceedings published by IEEE. Sessions were organized in different topics such as wireless networks or routing for disaster management.

9.2 Program committees

Bernard Cousin is member of the Editorial Board for the International Journal of Computer Network and Information Security (IJCNIS). He is member of IEEE Communications Society (ComSoc) Technical Committee on Information Infrastructure and Networking (TCIIN). He served, in 2015, in the Program Committees of the following conferences :

- CFIP-NOTERE 2015, a joint national conference from "Colloque francophone sur l'ingénierie des protocoles" and "Nouvelles Technologies de la Répartition"
- CITIM 2015, 2nd International Conference on Multimedia Information processing
- DRCN 2016(sic), 12th International Conference on the Design of Reliable Communication Networks
- FNC 2015, 10th International Conference on Future Networks and Communications
- HPSR 2015, 16th IEEE International Conference on High Performance Switching and Routing
- ICC-MWN 2015, IEEE International Conference on Communications, Mobile and Wireless Networking Symposium
- ICCCA 2015, IEEE International Conference on Computing, Communication & Automation
- ICCCS 2015, First IEEE International Conference on Computer and Computational Sciences
- ICCVE 2015, IEEE International Conference on Connected Vehicles & Expo
- INTGAST 2015, International Conference on Integrated and Sustainable Transportation
- ISSPIT 2015, 15th IEEE International Symposium on Signal Processing and Information Technology
- MobiApps 2015, 2nd International Workshop on Mobile Applications
- MICC 2015, IEEE 12th Malaysia International Conference on Communications
- OPTICS 2015, 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 2015, she served in the Program Committee of the following conferences:

- APWiMob 2015, Asia Pacific Conference on Wireless and Mobile 2015
- WCNC 2015, IEEE Wireless Communications and Networking Conference
- Wimob 2015, 9th International Conference on Wireless and Mobile Computing, Networking and Communications
- Globecom 2015, IEEE Global Communications Conference, GC' 15 - SAC - E-Health
- ICC'15 CQRM (2015 IEEE International Conference on Communications)
- SETCAC'15 (Symposium on Emerging Topics in Computing 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:

- GC'15 (IEEE Globecom 15) - Wireless Networks track
- VTC 2015 Spring, Vehicular Technology Conference,

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'15 (2015 IEEE Online Conference on Green Communications)
- VTC 2015 Spring, Vehicular Technology Conference,
- VTC 2015 Fall, Vehicular Technology Conference Fall 2015

Gwendal Simon is in the editorial board of the IEEE MMTC R-letters related to Multimedia ACM SIG chapter. He also serves in the Program Committee of the following conferences:

- ACM Multimedia 2015, ACM flagship conference on Multimedia
- IEEE ICC 2015, IEEE International Conference on Communications
- IEEE Globecom 2015, IEEE Global Communications Conference
- Packet Video 2015, 22th IEEE International Packet Video Workshop
- ACM Netgames 2015, 13th ACM Workshop on Network and Systems Support for Games
- ACM Nossdav 2015, 25th ACM workshop on Network and Operating System Support for Digital Audio and Video
- ACM MMSys (Multimedia System Conference, the premier event for multimedia system)
- IEEE/IFIP CNSM (International Conference on Network and Service Management, which is the flagship conference for the network management community)

Sandrine Vaton was TPC chair of TRAC 2015, the 7th International Workshop on Traffic Analysis and Characterization. She also serves in the Program Committees of the following conferences:

- IWCMC 2015, 11th International Wireless Communications & Mobile Computing Conference
- DCNET 2015, 6th International Conference on Data Communication Networking
- IFIP Networking 2015, 14th International Conference on Networking

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