



Research Team ATNET

# ***Advanced Technology in Networking***

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*Activity Report*

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## 1 Team

### Team leader

Bernard Cousin, Professor, University of Rennes 1

### Administrative assistant

Nadia Saintpierre, INRIA

### Permanent Researchers

Cédric Guéguen, Assistant Professor, University of Rennes 1

Samer Lahoud, Assistant Professor, University of Rennes 1

### Post-docs and Temporary Lecturers (ATER)

Siwar Ben Hadj, ATER at University of Rennes 1, since October 2014

### Ph.D. students

Chiheb Ben Ameer, *CIFRE* grant, since December 2012

Melhem El Helou, joint Ph.D. with University Saint Joseph (Lebanon), till December 2014

Soha Farhat, joint Ph.D. with Lebanese University (Lebanon), since November 2012

Mohamad Kanj, *CIFRE* grant, since October 2013

Farah Moety, *MENRT* grant, till December 2014

Han Yan, *CIFRE* grant, till December 2014

Mohamed Yassin, joint Ph.D. with Lebanese CNRS, since October 2012

## 2 Overall Objectives

### 2.1 Overview

AtNet team aims at elaborating advanced technology (i.e. network architectures, network protocols and distributed algorithms) for the next generation of the Internet. The design of Next Generation Networks is a big challenge.

Next Generation Networks will offer high value transport services and should provide High Capacity, High Survivability, High Flexibility, High Energy Efficiency and High Performances Efficiency for the new generation of multimedia distributed applications. Next Generation Networks will have High Capacity: the network should support very high throughput (for instance Tbit/s optical links are expected to be deployed in the next years), and a huge number of network flows with a world-wide coverage. Next Generation Networks will have High Survivability: network service reliability and protection should be assured, and data loss should be avoided by efficient flow control. Next Generation Networks will have High

Flexibility: protocols and algorithms should be adaptive to application requirements (for instance wireless mobile multimedia applications), network load, or network policy. Next Generation Networks will have High Energy efficiency: network energy consumption must be reduced in order to decrease world greenhouse gas emission and increase battery lifetime. This should be provided with High Performances Efficiency since high Quality of Service must be reached with expensive and/or rare resources.

AtNet team focuses on *Scheduling*, *Routing* and *Management* issues of Next Generation Networks.

- Scheduling is the process of selecting the best resources for each network user in order to maximize global network throughput while ensuring the best Quality of Service (QoS), fairness and energy efficiency.
- Routing is the process of selecting paths in a network along which to send network traffic. Most usual routing algorithms use only one network path at a time. Our team studies advanced routing protocols (and route computation heuristics) for QoS traffic requirements, load balancing or network protection purposes. For instance, some advance routing techniques enable the use of multiple alternative paths.
- Network management refers to the activities, methods, procedures, and tools that pertain to the operation, administration, maintenance, and provisioning of networked systems. Network operation deals with keeping the network (and the services that the network provides) up and running smoothly. It includes monitoring the network to spot problems as soon as possible, ideally before users are affected. Network provisioning is concerned with configuring resources in the network to support a given service. For example, this might include setting up the network so that a new customer can receive real-time video service. In this network management domain, we focus on network monitoring and network design.

## 2.2 Key Issues

The key issues of the AtNet research are: Network Resource Allocation, QoS Routing, Energy efficiency and Optical Networks.

### 1. *Network Resource Allocation*

Network resource allocation in next generation broadband networks is a challenging issue. For instance, in new wireless networks (5G systems), a solution shall guarantee mobile multimedia transmission services with an adequate QoS. These new multimedia services with tight QoS constraints require to avoid one major issue of computer networks : increase of system capacity while providing high fairness. The past decades have witnessed intense research efforts on this problem. However, network resource allocation considering several metrics is NP-difficult. For example, wireless transmissions are subject to many channel impairments such as path loss, shadowing and multipath fading which cannot be neglected. Similarly in all-optical networks, lightpaths are

subject to wavelength impairment, bandwidth granularity and regenerator placement. These phenomena severely affect the transmission capabilities (and/or network cost) and in turn the QoS experienced by applications, in terms of supplementary delays or packet losses which appear when the effective bit rate at the physical layer is too low.

## 2. *QoS Routing*

Nowadays, diverse advanced applications are provided over IP-based networks (e.g. IPTV, video-on-demand, telemedicine, e-health, ...). Guaranteeing the Quality of Service (QoS) to such applications remains a challenging problem. Routing is one of the primary mechanisms for providing QoS. It consists of the computation of an end-to-end path which ensures the delivery of the service while meeting the QoS constraints. QoS routing taking into account several metrics is NP-difficult. It is even more complex when multi-domain networks (with confidentiality constraints) or multicast communications or optical constraints have to be taken into account. Indeed, Multicast Routing has been one of the most studied routing issue of the AtNet team. The team members have produced numerous solutions adapted to routing problems on these aforementioned issue. They have been published in high quality scientific publications (see for instance [2, 3, 4, 7, 8, 17, 18, 24, 26]).

The research of efficient but low cost heuristics to find feasible paths from a source to a destination has been studied by the team. For instance, in [BML09] a heuristic was proposed and deeply analyzed. It provides the first shortest paths in increasing order to find a first feasible one. The results show that this polynomial time computation often provides good paths. A review of the proposed inter-domain and intra-domain QoS routing algorithms was presented. An exact distributed method of intra-domain QoS route computation was proposed in [4]. MPLS-TE mechanisms can help the establishment of QoS inter-domain routes. Some very good results in this domain were presented in [3].

## 3. *Energy Efficiency*

In the last decade, many research efforts have been done in order to increase the spectral efficiency of communication networks. Then, some solutions have emerged as good way to guarantee high system throughput and high Quality of Service (QoS). None of them take into account the energy cost of the solution. However, today, it is not sufficient anymore. Many climate problems have been underlined by the majority of world scientists and decreasing world greenhouse gas emission has become a necessity for the world's environment preservation. This requires to also reduce energy consumption in as much sectors as possible including communication networks. Current solutions are not well adapted to this new performance criterion and need active research in diverse domains like home networks or urban MIMO cell networks.

## 4. *Optical Networks*

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[BML09] A. BELLABAS, M. MOLNAR, S. LAHOUD, "Heuristics for Multicriteria Routing Problem", *in: International Conference on Communications Computers and Applications*, Amman, Jordan, 2009.

Due to the physical constraints and characteristics in all-optical WDM networks, their management and routing are a challenging work [Muk00]. First, in the absence of any wavelength conversion device in optical nodes, the same wavelength should be employed over a light-path which may pass through several nodes (this is referred as the wavelength continuity constraint). Second, any large network (like most of optical networks) requires sophisticated control and management tools for network reconfiguration, and fault recovery. Third, optimized multicast routing touches well-known but NP-difficult problems. Thus routing or management of optical networks are challenging works. For instance, the reduction of power in an optical fiber should be compensated by internal active amplifiers like erbium-doped fiber amplifier, which, however, introduce many problems such as gain dispersion, gain saturation and noise. Consequently, the complex architectures along with the high-cost of optical nodes make wavelength routing and optical network management a domain which are worth the research effort. Currently we explore smart management for flexible optical networks and transparent reconfiguration of light-trees in WDM networks.

## 5. *Wireless Network*

Wireless network required innovative solutions and new paradigms due to its specificities. Indeed, in contrast with wired communications, wireless transmissions are performed thanks to scarce and tight radio resources. This induces limited system capacity which is acknowledged as the main weakness of these networks. In addition, these radio resources are not only rare but also subject to many channel impairments such as path loss, shadowing, multipath fading and Inter Cell Interference (ICI) [Pro95, Gol05] that widely increase Radio Resource Management (RRM) complexity. These phenomena severely affect the transmission capabilities and in turn the QoS experienced by applications (in terms of data integrity but also in terms of the supplementary delays or packet losses which appear when the effective bit rate at the physical layer is low). Consequently users satisfaction rely on efficient RRM taking into account both physical layer and higher layer information.

Our research is intended to be *vertical* in the sense that all aspects of network scheduling, network routing and network management are of interest: design, evaluation and implementation. Similarly our research is intended to tackle simultaneously several of the above issues. For instance "energy-efficient resource allocation", "multi-criteria routing in optical network", etc.

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- [Muk00] B. MUKHERJEE, "WDM optical communication networks: progress and challenges", *IEEE Journal on Selected Areas in Communications* 18, 10, 2000, p. 1810 – 1824.  
 [Pro95] J. G. PROAKIS, *Digital Communications*, 3rd ed. New York: McGraw-Hill, 1995.  
 [Gol05] A. GOLDSMITH, *Wireless Communications*, Cambridge University Press, 2005.

### 3 Scientific Foundations

#### 3.1 Introduction

**Keywords:** graph theory, linear programming, network routing, network resource scheduling, distributed algorithm, heuristic, branch and bound, integer linear programming.

Research activities in the AtNet team deal with architectures, protocols and algorithms for data communication networks. Currently, the evolution of the communication networks follows the increasing demand for bandwidth and services by providing a tighter integration between wireless networks and optical networks. Thus, network architectures, protocols and algorithms have to be re-explored to meet the challenge. In our research team, we deal with various aspects related to the evolution of the communication networks: Network Routing (QoS routing, multi-domain routing, multicast routing and routing for multimedia applications) and Network Management (resource allocation, network monitoring, network configuration, and energy optimization). Our research is mainly characterized by architectural, protocol and algorithmic contributions. Particularly, we use the scientific foundations of graph theory and combinatorial optimization. Moreover protocols and algorithms are often tested by simulations to mimic the behavior of large scale networks. In the following, we provide a presentation of the scientific foundations associated with our works.

#### 3.2 Multi-domain routing

**Keywords:** large scale network, inter-domain routing, multi-domain routing, QoS, autonomous systems, network operator cooperation, cloud infrastructure.

The objective of multi-domain routing is the computation of routes (unicast paths or multicast routing structures) knowing that the routes should cross several interconnected network domains, and the operators of the different routing domains want to preserve the confidentiality of topology and routing information. On the one hand, the organization of the network in domains agrees with the typical autonomous system decomposition, and is a pragmatic way to ensure the scalability of the problem. On the other hand, the routing problem has to be solved with only partial information, thus there is a trade-off between the quality of the routing and the amount of information which can be uncovered.

Our activities are related to the distributed PCE-based route-computation architecture which is standardized and extensively discussed in international forums such as IETF. The most relevant works on the inter-domain routing can be represented with the references [DdOV07], [FVA06]. Moreover, the computation of QoS aware inter-domain routes in a given network architecture needs a distributed algorithm that enables to solve an NP-difficult optimization problem: the multi-constrained routing. We propose the adaptation of exact multi-

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[DdOV07] S. DASGUPTA, J. DE OLIVEIRA, J.-P. VASSEUR, "Path-Computation-Element-Based Architecture for Interdomain MPLS/GMPLS Traffic Engineering: Overview and Performance", *IEEE Network* 21, 4, Jul.-Aug. 2007, p. 38 – 45.

[FVA06] A. FARREL, J.-P. VASSEUR, J. ASH, "A Path Computation Element (PCE)-Based Architecture, Request for Comments: RFC4655", August 2006, RFC 4655.

constrained route computations as in [KM02] to our network context, and also some approximated heuristic solutions.

### 3.3 Resource allocation in wireless networks

**Keywords:** network resource allocation, opportunistic scheduling, multipath fading, cross layer design, QoS, QoE, multi-objective optimization.

In contrast with wired communications, wireless transmissions are subject to many channel impairments such as path loss, shadowing and multipath fading [Pro95] and [Gol05]. These phenomena severely affect the transmission capabilities and in turn the system transmission capacity and the QoS. The past decades have witnessed intense research efforts on wireless digital communications in order to provide optimal resource allocation algorithms or heuristics able to bring together high system throughput, high mobile user satisfaction and, when possible, low energy consumption. Several scheduling schemes are proposed and evaluated in the literature. The references [KH95] and [WC99] can be acknowledged as the most relevant works.

Contrary to conventional access methods like Round Robin (RR) and Random Access (RA), primarily designed for the wired local area network context, opportunistic scheduling techniques that take advantage of multi-user diversity are well adapted to the wireless environment and provide high throughput. Indeed, resources are preferably allocated to active mobile(s) with the most favourable channel conditions at a given time (often to the mobile with the greatest SNR). Dynamically adapting the channel modulation and coding allows then to make an efficient use of the radio resource and come closer to the Shannon limit. This maximizes the system capacity from an information theory point of view. However these works fail to reach the multiple-objective goal and often propose a trade-off. In addition, they generally take questionable assumptions such as the hypothesis that the user with the most favourable transmission conditions has always data packets to transmit at a considered time instant. Moreover, they do not take into account the variability of the traffic and the queuing aspects.

Based on previous works [13], our research deals with these issues. 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 requirement. Frequency diversity, added to time and multi-user diversity are also exploited in a cross layer design and allow to significantly improve opportunistic scheduling approaches.

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- [KM02] F. A. KUIPERS, P. V. MIEGHEM, "MAMCRA: a constrained-based multicast routing algorithm", *Computer Communications* 25, 8, 2002, p. 802 – 811.
- [Pro95] J. G. PROAKIS, *Digital Communications*, 3rd ed. New York: McGraw-Hill, 1995.
- [Gol05] A. GOLDSMITH, *Wireless Communications*, Cambridge University Press, 2005.
- [KH95] R. KNOPP, P. HUMBLET, "Information capacity and power control in single-cell multiuser communications", in: *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 in Communications* 17, 10, 1999.



### 3.4 Resource allocation in optical networks

**Keywords:** routing and wavelength assignment problem, wavelength allocation, traffic aggregation, all-optical networks, optical constraints.

In order to support traffic growth, optical networks have already evolved towards wavelength routed networks. It is well known that an efficient allocation of networks resource (*i.e.*, wavelength) is determined by the resource granularity. However, in a wavelength routed network, the minimum granularity of an optical connection is the capacity of a wavelength. With capacity growing up to 100 Gbit/s per wavelength, this granularity is becoming larger than common traffic flows generated by users. Thus the requirement for traffic aggregation into the wavelength channels is expected to grow. Today, this aggregation is done at the end points thanks to electrical switching. But with traffic increase, the use of electrical switching generates an important growth in power consumption and network cost. Thus, network operators intend to find solutions that offer such functionality with reduced impact on power consumption and cost. These solutions should switch in the optical layer which may indeed provide cost and power reductions thanks to the corresponding savings in optical-electrical conversions.

In this context, optical multi-band OFDM (orthogonal frequency division multiplexing) technology is a very interesting candidate for future optical networks [Shi11]. Optical multi-band OFDM can handle ultra high bitrates (100 Gbit/s and more). Multi-band OFDM could benefit from an access to finer granularity than the aggregated 100 Gbit/s data rate while remaining in the optical domain. Indeed, using adequate add and drop sub-band functions in optical nodes, optical multi-band OFDM offers all optical switching and aggregation flexibility at granularities finer than the original 100 Gbit/s data stream. OFDM technology appears to be a particularly well adapted technology to sub-band generation thanks to a low modulation rate per sub-carrier leading to very square sub-band spectrum. Moreover one specificity of OFDM modulation is its adaptability to the physical transmission condition. Let us recall that the sub-band optical reach depends on the bit rate carried by this sub-band. A service with a given data rate having to be delivered at a certain distance exceeding the maximum reach of the sub-bands, can be split between two or more sub-bands with reduced bit-rate. This is an alternative solution to regeneration.

### 3.5 Energy Optimization

**Keywords:** energy efficiency, transmit power, home networks, wireless networks, resource allocation.

Taking into account the energy efficiency when optimizing network design is a challenging task. Particularly, legacy network algorithms need to be tuned in order to attain a trade-off between the inevitable user requirement for quality of service and the network operator requirement for network resource minimization (specifically in total energy consumption). Taking for example the radio resource allocation in a wireless network, new algorithms should adapt the user association to the base station and the transmit power of the base stations in order to

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[Shi11] W. SHIEH, "OFDM for Flexible High-Speed Optical Networks", *Journal of Lightwave Technology* 29, 10, 2011, p. 1560 – 1577.

achieve energy efficiency. The same goes for home networks, where the scheduled downtime of each device should be astutely configured in order to minimize the energy consumption, while keeping satisfying service availability. In both study cases, the optimization comes from a first step that consists of devising realistic energy consumption models for the network devices. For instance, the Earth project introduced an energy consumption model for base stations that linearly scales with their transmit power. The second step consists in formulating and solving a multi-objective problem that balances the total energy consumption in the network devices with the quality of service metrics, such as the user throughput, delay, or the service availability.

## 4 Application Domains

### 4.1 New Generation Internet

The application domains of our scientific contributions are mainly related to communication networks. These networks use various types of infrastructure:

- Wireless network infrastructure: our studies focus on wireless cellular communications but also cover ad-hoc and sensor networks. For instance we study WiFi, LTE, and 5G green wireless mobile network.
- Wired network infrastructure: our studies focus on optical networks with automatic control planes (based for instance on G/MPLS).

ATNET team provides adapted solutions that inherit from the particularities of each infrastructure. Solutions for wireless networks take into account the scarcity of the radio resource, the transmission interference, and the access mechanisms (such as OFDMA). Solutions for wired networks take into account the survivability constraints and the optical impairments.

The direct beneficiaries of our work are the telecommunication companies because most of our algorithms or protocols fit into network equipments, and ease the network management. For instance:

- Internet service providers,
- Added value service providers,
- Network operators,
- Network equipment manufacturers.

### 4.2 Services on Communications Networks

When applicable, our contributions consist of proposing novel architectures for communications networks including protocols and algorithms. This eases the deployment of added value services at lower cost. For instance:

- Always best connected services over heterogeneous access networks,

- Home Networking,
- IPTV with IMS,
- Digital TV broadcasting,
- Video streaming,
- Cloud Network,
- Software-Defined Networking,
- Automatic VPN interconnection.

## 5 Software

### 5.1 Network Softwares

**Participants:** Bernard Cousin [contact point].

The main objective of the AtNet team is to develop network algorithms and protocols which fit as driver software into network equipments. To produce performance evaluation results, these algorithms and protocols are generally implemented into a network simulator (e.g. NS-2, Opnet, etc). They are discrete event network simulators. They support popular network protocols, offering simulation results for wired and wireless networks alike. NS is popular in networking research given its open source model and online documentation.

Websites have been built to provide an online access to our network Softwares:

- On Internet DNSSEC (cf. <http://www.idsa.prd.fr/index.php?lang=en>)
  - KROD is a program that performs automatic DNSSEC key rollover and automatic conversion from DNS to DNSSEC.
  - A patch of BIND which modifies the behavior of the DS field. Generalized DS allows to have build a DNSSEC chain of trust over a succession of secure and insecure domains (a domain that has insecure parents).
  - libsrsvolv is a library built with the BIND toolkit. It comes as a patch over the BIND 9.3 sources. It contains a DNSSEC resolver and validator. The goal is to show anything that can be proved from a DNSSEC answer. The validator proves positive and negative answers (it can prove that a domain doesn't exist), it can also prove that some domain are empty non-terminal ones. libsrsvolv performs bottom-up validation, it is signature oriented.
- On Explicit Multicasting:
  - Into the NS simulator, we have included the Xcast protocol according to the Explicit Multicast (Xcast) concepts. (<http://boudania.free.fr/research/xcast/index.htm>)

- Simple Explicit Multicast (SEM) uses an efficient method to construct multicast trees and deliver multicast packets. SEM is original because it adopts the source-specific channel address allocation, reduces forwarding states in non branching node routers and implements data distribution using unicast trees. (<http://boudania.free.fr/research/sem/index.htm>)
- Generalized Explicit Multicast (GXcast) is a generalized version of the Xcast protocol. It permits Xcast packet fragmentation and support an increasing number of members in a multicast group. (<http://boudania.free.fr/research/xcast/gxcast/index.htm>)
- On Multicasting in MPLS Networks:
  - The MPLS Multicast Tree (MMT and its extension MMT2) is a new approach to construct multicast trees in MPLS networks. This approach utilizes MPLS LSPs between multicast tree branching node routers in order to reduce forwarding states and enhance scalability. In our approach only routers that are acting as multicast tree branching node for a group need to keep forwarding state for that group. All other non-branching node routers simply forward data packets over traffic engineered unicast routes using MPLS LSPs. (<http://boudania.free.fr/research/mmt/index.htm>)
- On Optical Networks:
  - In our study OMNeT++ is used to design and simulate multi-band optical networks. OMNeT++ is an object-oriented modular discrete event network simulation framework. It has a generic architecture, so it can be (and has been) used in various problem domains: modeling of wired and wireless communication networks, protocol modeling, modeling of queuing networks, modeling of multiprocessors and other distributed hardware systems validating of hardware architectures. In general, modeling and simulation of any system where the discrete event approach is suitable, and can be conveniently mapped into entities communicating by exchanging messages.
  - We developed a simulator for node and link protection using p-cycles for dynamic multicast traffic in optical DWDM networks. This simulator is implemented in MATLAB.
- On Network Monitoring:
  - This simulator is written in C++ under Linux. it uses the ILP solver CPLEX for solving integer linear programs, and the topology generator BRITE for generating random test topologies. It ensures the following features: (i) Given an input network topology, it computes an optimal set of monitor locations and an optimal set of detection paths that can detect all potential link-level anomalies, while minimizing the inherent costs jointly. (ii) Given an input network topology, it computes an optimal set of monitor locations and an optimal set of localization paths that can pinpoint unambiguously the localization of all potential link-level anomalies,

while minimizing the inherent costs jointly. (iii) Given an input network topology, it assesses the cost and the speed of continuous anomaly localization (detection and localization procedures are ran simultaneously), and the cost and the speed of reactive anomaly localization (the localization procedure is run only upon detecting an anomaly). On the light of this comparative assessment of the two localization approaches, it suggests a localization configuration (localization approach and monitoring frequency) that offers a good balance between cost and speed for the input topology.

Note that the simulator computes optimal solutions, when the exact solutions (ILP based solutions) are used. However, exact solutions are not scalable. Thus, heuristic solutions are used for large topologies.

- On Resource Allocation in Wireless Networks:
  - The object-oriented programming capabilities of the Matlab language enable us to develop our discrete event simulator for network selection in heterogeneous environments:. The goal is to elaborate an optimized simulation environment where session arrivals, network selection algorithms, traffic generation, and session departures are implemented. Our simulator is used to evaluate the performance of the different network selection methods, and to compare them to our proposed solution.
  - The OPNET simulation platform has been used in order to design and evaluate the performances of our proposals relating to new opportunistic schedulers. They allow maximizing global system throughput while ensuring fairness without any trade-off. In these works, we have had implemented realistic channel model and traffic sources.
- On Home Power Efficiency for a Green Network:
  - This Home Network demonstrator aims at reducing power consumption at both the device and network level. At the device level, the system can turn the devices off when they are not in operation and quickly turn them on when they are predicted to be needed. At the network level, the solution is based on a new convergence layer denoted inter-MAC, which provides a common infrastructure to the different home network paths. HOme Power Efficiency (HOPE) experimental platform reproduces a home wireless network. During its process, energy control messages are sent on a low-power consumption network like ZigBee or by using a low-power consumption protocol like UPnP Low Power. The demonstration shows that the platform can drastically reduce the consumption of home networks. Users can benefit from enriched home multimedia services and efficiently manage their power consumption. This demonstrator has been exhibited at Infocom ([23]).

## 6 New Results

### 6.1 Multi-domain Routing and Monitoring

**Participants:** Bernard Cousin, Samer Lahoud, Nabil Djarallah, Aymen Belghith.

**Keywords:** Networking, Routing, Autonomous System, Monitoring.

Network control tasks become challenging and necessitate special attention in research when the network is managed by multiple operators aiming to preserve control autonomy and confidentiality. In our latest results, we explore two typical control tasks that consist of computing paths for routing traffic in a multi-domain network and monitoring the quality of the communications.

### **Multi-Constrained Path Computation for Inter-Domain QoS-capable Services**

Computing inter-domain MultiProtocol Label Switching Traffic Engineering Label Switched Path (MPLS-TE LSP) using the Path Computation Element (PCE) through a pre-determined sequence of domains is quite straightforward. Each PCE, using the Backward Recursive PCE-based Computation (BRPC), knows who is the next to be contacted in order to continue the computation. The optimality of the inter-domain MPLS-TE LSP path depends strongly on the choice of the pre-determined sequence of domains on which the calculation works. In our work [6], we propose a novel procedure allowing a forward discovery of multiple inter-domain sequences and the computation of constrained inter-domain paths for MPLS-TE LSPs over these domains sequences. We also explore relevant issues related to the inter-domain path computation, such as route discovery and inter-domain loop avoidance. Experimental evaluation shows that our solution is effective in terms of protocol and algorithmic efficiency and provides satisfying performance with high success rate, reasonable message overhead and runtime.

**Configurable Monitoring For Multi-Domain Networks** Monitoring is used to extract measurement results for performance analysis and, in multi-domain networks, these measurement results may have to be exchanged between different domains or sent to a third party for aggregation and multi-domain analysis. In order to have efficient and meaningful measurement results, we prove in our work that the export parameters such as the export methods and the export protocols have to be configurable. We propose a configurable multi-domain network monitoring architecture that resolves the heterogeneity problems by providing the adaptive measurement process and the adaptive export process requirements [4]. The adaptive measurement process is mandatory especially when active measurements are performed between two domains because these domains have to agree on the measurement process. Moreover, when the measurement parameters of the different domains are configurable, we can modify, for example, the measurement protocol used by two domains without applying any modification on other domains along the path of the monitored service. This modification allows the providers, for example, to use a more efficient measurement protocol without requiring implementing the same measurement protocol in all domains. This configuration capability also offers more flexibility since multi-domain measurements can be provided even if a non-collaborative domain exists in the path of the monitored service. Indeed, multi-domain measurements can be performed measurements between two adjacent domains and these multi-domain measurements require the configuration of these adjacent domains.

## 6.2 Interference Mitigation

**Participants:** Samer Lahoud, Mohamad Yassin.

**Keywords:** Wireless Networks, Intercell Interference, OFDMA, Power Control, Interference Reduction.

The recent development of mobile terminals, the proliferation of mobile applications and the increasing need for mobile data have led to a dense deployment of mobile networks. In this context, the Long Term Evolution (LTE) standard is adopted by a large number of mobile network operators. LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) technique on the downlink of the radio interface along with frequency reuse-1 model. However, Inter-Cell Interference (ICI) and system power consumption will cause limitations in terms of mean user throughput and system performance. Indeed, several recent works focus on the minimization of ICI and power consumption in multi-user OFDMA networks. In our work, we use propose ICI Coordination (ICIC) techniques and provide distributed algorithmic solutions that enable to attain high spectral efficiency without sacrificing the quality of service cell edge users.

**A downlink power control heuristic algorithm for LTE networks** In our work [23], we propose a distributed heuristic power control algorithm that aims at minimizing the total downlink power of an LTE system. Our algorithm aims at reducing power wastage especially for cell-center users that usually have good radio conditions. Moreover, this algorithm increases downlink transmission power on the RB allocated for cell-edge users that suffer the most from interference and path loss problems. We also study the impact of the power control algorithm on ICI and system performance. Simulation results show that the proposed algorithm largely reduces the downlink power consumption without degrading system performance. In addition, it increases the mean throughput for cell-edge users that are mainly affected by ICI problems.

### **Game theoretic framework for power control in intercell interference coordination**

We address the problem of ICIC in the downlink of cellular OFDMA systems where the power level selection process of resource blocks (RB) is apprehended as a sub-modular game [15]. The existence of Nash equilibriums (NE) for that type of games shows that stable power allocations can be reached by selfish Base Stations (BS). We put forward a semi distributed algorithm based on best response dynamics to attain the NEs of the modeled game. Based on local knowledge conveyed by the X2 interface in LTE (Long Term Evolution) networks [1], each BS will first select a pool of favorable RBs with low interference. Second, each BS will strive to fix the power level adequately on those selected RBs realizing performances comparable with the Max Power policy that uses full power on selected RBs while achieving substantial power economy. Finally, we compare the obtained results to an optimal global solution to quantify the efficiency loss of the distributed game approach. It turns out that even though the distributed game results are sub-optimal, the low degree of system complexity and the inherent adaptability make the decentralized approach promising especially for dynamic scenarios.

### 6.3 Radio Access in Heterogeneous Wireless Networks

**Participants:** Bernard Cousin, Samer Lahoud, Melhem El Helou, Soha Farhat, Aymen Belghith.

**Keywords:** Wireless Network, Energy Saving, Green Networking, Radio Resource Management, Radio Access Selection, Game Theory.

The rapid proliferation of radio access technologies (e.g., HSPA, LTE, WiFi and WiMAX) may be turned into advantage. When their radio resources are jointly managed, heterogeneous networks inevitably enhance resource utilization and user experience. Moreover, the pricing schemes traditionally used in wireless access networks need to be revised to cope with the increasing heterogeneity.

**Optimizing Network Information for Radio Access Technology Selection** We tackle the Radio Access Technology (RAT) selection and propose a hybrid decision framework that integrates operator objectives and user preferences [12]. Mobile users are assisted in their decisions by the network that broadcasts cost and QoS parameters. By signaling appropriate decisional information, the network tries to globally control users decision in a way to meet operator objectives. Besides, mobiles combine their needs and preferences with the signaled network information, and select their access technology so as to maximize their own utility. Deriving network information is formulated as a Semi-Markov Decision Process (SMDP). We show how to dynamically optimize long-term network reward, aligning with user preferences.

**Hybrid Decision Algorithm for Access Selection in Multi-Operator Networks** In the challenging case of multi-operator networks [14], we propose a hybrid decision algorithm for the selection of the access, where competing operators share their radio access networks to meet traffic and data rate demands. The proposed algorithm guarantees the user satisfaction and a global gain for all cooperating operators. Simulation results prove the efficiency of the proposed scheme and show that the cooperation between operators achieves benefits to both users and operators; user acceptance as well as the operator resource utilization and the operator revenue increase.

**Realistic Per-category Pricing Schemes for LTE users** As demand on data access and bandwidth explodes, service providers across cellular network infrastructures are struggling to find effective ways to manage the data traffic on their network, and meet customer expectations without eroding profitability, or attracting regulatory attention. Pricing schemes are designed to offer profitable business to the operators as well as to create favorable services for the mobile subscribers. In this work [11], we analyze three well-known pricing schemes (Fixed PRB Pricing, Subscriber Class based Pricing, and Network Load based Pricing) proposed for Long Term Evolution (LTE) mobile networks. We then propose a realistic per-category pricing (R2P) scheme for LTE. Our pricing scheme takes into account QoS parameters, physical resource block utilization, user valuation, and user price categories: Gold, Silver and Bronze. Extensive simulations show that our proposed pricing scheme provides higher revenue for the operator. Indeed, R2P benefits from the diversity of services and user willingness-to-pay and



provides the highest revenue. Moreover, this pricing scheme takes into account the congestion periods and allow users to profit from the whole bandwidth.

## 6.4 Energy management in Networks

**Participants:** Bernard Cousin, Cédric Guéguen, Samer Lahoud, Rihab Maaloul, Farah Moety, Omar Smail, Han Yan.

**Keywords:** Wireless Local Area Network, Energy Saving, Green Networking.

Reduction of unnecessary energy consumption in wired and wireless networks is becoming an important matter of public concern. Due to the impact of electricity consumption on the economic, environmental, and marketing fields, the energy saving in ICT sector and more specifically in networking is becoming a fundamental key issue. For example, nowadays networking infrastructures connecting data centers to users through clouds use high-capacity components and over-provisioning architectures to ensure service availability which result in high power consumption. In addition, worldwide Internet Service Providers (ISPs) and Telecom operators have been confirmed, in recent reports, the user concerns on the energy price. These statements trigger many efforts which have been dedicated to cut unnecessary energy dissipation. Our objective is to have a better understanding how we can apply energy saving on networking. This introduces the notion of green networking which can be defined as the production of sufficient networking performance with minimum energy cost. Specifically, in networking, energy saving may be achieved, first, by dynamically selecting either the adequate paths or the adequate level of transmission power which result in efficient use of energy, second, by switching off unnecessary links or network devices. Our works, described below, cover all that ways: in wireless networks, home networks, ad hoc networks and Ethernet networks.

**Joint Power-Delay Minimization in Wireless Networks** We study the joint power-delay minimization in wireless access networks implementing a WLAN technology such as WiFi or a cellular one such as LTE. When dealing with realistic deployments, the MILP formulation of the optimization problem could not deliver solutions in a reasonable amount of time due to computational complexity issues. Therefore, we revert to heuristics that deliver satisfying solutions while keeping low complexity. In our work [17], we formulate an optimization problem that jointly minimizes the network power consumption and transmission delay in broadband wireless networks. Power saving is achieved by adjusting the operation mode of the network Base Stations (BSs) from high transmit power levels to low transmit levels or switched-off. Minimizing the transmission delay is achieved by selecting the best user association with the BSs. We study the case of a realistic Long Term Evolution (LTE) Network where the challenge is the high computational complexity necessary to obtain the optimal solution. We propose a simulated annealing based heuristic algorithm for the power-delay minimization problem. The proposed heuristic aims to compute the transmit power level of the network BSs and associate users with these BSs 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. Moreover, the heuristic algorithm performs close to optimally and outperforms the existing

approaches in realistic deployments.

When dealing with WLAN deployments [18], we propose a greedy heuristic algorithm that computes 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 WLAN networks.

**Energy conservation in home networks** Today, reducing global greenhouse gas emissions has become a crucial issue for protecting the earth environment. This requires the reduction of energy consumption in as many sectors as possible, including home networks. Home network represents an increasingly large portion of a household's electrical consumption due to the increasing number of digital home devices and the increasing complexity of the underlying communication infrastructure. Limiting a home network's power consumption is a priority for institutions and consumers. We proposed solutions that aims at reducing power consumption at both the device and network level. At the device level, control system can turn the devices off or on according to their usage. At the network level, the solution is based on a inter-MAC layer to choose a greener path. In [3], we proposed an Overlay Energy Control Network (OECN) which can efficiently control devices. HOPE: HOme Power Efficiency System for a Green Network A home network represents an increasingly large portion of a household electrical consumption due to the increasing number of digital home devices and the increasing complexity of the underlying communication infrastructure. Limiting power consumption of a home networks is a priority as witnessed by evolving regulation, and a priority for individual consumers wishing to reduce their electric bills. In the papers [21, 22], we proposed a solution that aims at reducing power consumption at both the device and network level. At the device level, our system can turn the devices off when they are not in operation and quickly turn them on when they are needed. At the network level, the solution is based on a new convergence layer denoted inter-MAC, which provides a common overlay infrastructure for the control of the different home network devices. In particular, the inter-MAC can be used to choose a greener path. Our solution on both levels is compatible and complementary to home network energy saving.

**Energy conservation in ad hoc networks** Traditional techniques of routing are not well adapted to wireless mobile networks. Indeed, their lack of reactivity with respect to the variability of network changes makes them difficult to use. Moreover, conserving energy is a critical concern in the design of routing protocols for ad hoc networks, because most mobile nodes operate with limited battery capacity, and the energy depletion of a node affects not only the node itself but also the overall network lifetime. In single-path routing schemes, a new-path-discovery process is required when a path failure is detected. This process causes delay and wastage of node resources. A multipath routing scheme is an alternative to maximize the network lifetime.

In our works [8], [9], we present a multipath extension of the well-known routing protocol AODV (Ad hoc On-demand Distance Vector). Multiple paths are exploited in order to ensure reliability and a quick reaction to changes in topology with a low overhead generated by the control messages. Indeed, our energy-efficient multipath routing protocol, called AOMR-LM (Ad hoc On-demand Multipath Routing with Lifetime Maximization) preserves the residual energy of nodes and balances the consumed energy to increase the network lifetime. To achieve this goal, we used the residual energy of nodes for calculating the node energy level. The multipath selection mechanism uses this node energy level to classify the paths. Two parameters are analyzed: the energy threshold ( $\beta$ ) and the coefficient ( $\alpha$ ). These parameters are required to classify the nodes and to ensure the preservation of node energy. Our protocol improves the performance of mobile ad hoc networks by prolonging the lifetime of the network. This novel protocol has been compared with well known protocols: AOMDV and ZD-AOMDV. The protocol performances have been evaluated in terms of network lifetime, energy consumption, and end-to-end delay.

Clustering has been proposed as a promising method for improving the scalability of routing process in mobile ad hoc networks when network size increases. In [20], we propose an energy-efficient multipath routing protocol, called ES-CMR (Energy aware and Stable Clustered based Multipath Routing protocol), which preserves the residual energy of nodes and increases the network lifetime. To achieve this goal, we use a single objective model to select energy-efficient paths with stable links. Simulation results demonstrate that ES-CMR has better performance in terms of energy consumption, network lifetime, and end-to-end delay.

**Energy conservation in Ethernet networks** Energy saving has recently received considerable attention, as a promising approach for delivering ICT services with environmentally conscious use of technology. We propose to implement energy aware strategies in network infrastructures which will lead to improve network resources utilization. In this work, we are mainly concern with data center network infrastructures. Thus in [16], we address the issue of energy consumption in Carrier-Ethernet networks. We review and describe relevant works currently proposed for energy-efficient operations in wired network infrastructure. We survey the main technical issues that we are currently facing to reduce energy consumption in networking. Some major solutions are described. However we identify some remaining key research challenges that arise when such energy-saving solutions must be applied to Carrier-Ethernet networks (for instance, compliance with Ethernet Bridging).

## 6.5 Protection and Reconfiguration of Optical Networks

**Participants:** Joel Adepo, Ahmed Frikha, Bernard Cousin.

**Keywords:** Optical Network Protection, P-cycle, All-Optical Network, Optical Multicasting, Network Routing, Network Management.

Optical Networks are a solution for a better future : it will provide high bitrate, low latency and advanced services. Multicasting and Network Survivability are two of of these

advanced services In our works, we study optical network management, namely optical path routing and optical path configuration, to offer an enhanced reliability to all-optical network.

Today, TV over IP service (IPTV) has become very popular and service providers must deal with the rapid growth of the number of IPTV customers. Service providers must also ensure the IPTV reliability to satisfy the customer needs, as one network failure could disrupt IPTV broadcasting. Thus a reliable IPTV service requires network providers to ensure link or router failure recovery within a short restoration time. One key issue for providing a reliable IPTV service is survivable multicast routing. Generally, most of the network providers route IPTV multicast traffic using the multicast protocol based on standard Internet routing protocol. Restoration using these protocols is slow, and typically takes several seconds. To ensure a fast restoration, we consider node and link failure recovery in the optical layer. The backup path is provided in this layer. Thus, the multicast tree restoration is not managed at the IP layer and restoration time is faster.

P-cycle protection approach enables node and link failure recovery in the optical layer while maintaining a short restoration time (typically in the order of some 10 ms). Moreover, the p-cycle protection approach achieves an efficient use of the network capacity compared to the other protection approaches. In this work ([7], we apply p-cycles in optical networks to provide robust IPTV services. P-cycle is known to achieve efficient resource utilization. We extend the concept of node protection using p-cycles to deal with multicast traffic. We propose a new algorithm. The algorithm ensures both link and node failure recovery for a dynamic multicast traffic in the optical layer. Extensive simulations show that our proposition outperforms the existing approaches in terms of blocking probability, resource utilization efficiency, and computational speed.

Path reconfiguration is used by network providers to improve network performance. It consists of moving a connection from an initial path to a new one. Since networks are disturbed by failures, overloads, and deployments of new network resources or maintenance operations, network reconfiguration becomes very important because it enables the fulfillment of QoS requirements with the available network resources. In a previous work, we have studied tree reconfiguration without data flow interruption in wavelength division multiplexing optical networks. In our previous work, the available resources of the network (the wavelengths) were not considered as limited. In this work ([5], we study tree reconfiguration in a network which has a limited number of wavelengths per link. This paper proposes an algorithm which reconfigures an optical tree without data flow interruption in a network with a limited number of wavelengths. The objectives of this work are, first, tree reconfiguration without data flow interruption; second, reduction of the latency between the triggering event and the effective reconfiguration of the nodes on the optical paths; and third, reduction in the optical resources used during the tree reconfiguration process.

## 6.6 TCP Flow Adaptation for Streaming Traffic

**Participants:** Chiheb Ben Ameer, Bernard Cousin.

**Keywords:** TCP Congestion Control, Traffic Shaping, Streaming traffic, Home Gateway.

HTTP adaptive streaming (HAS) is a streaming video technique largely employed over best effort networks (I.e. using TCP connections over Internet). Specific flow control mechanisms have been deployed in TCP to control network congestion. However, it still has some issues that harm user quality of experience (QoE). The main use case of our investigation is when several HAS clients compete for the bandwidth inside the same home network. The two main causes of QoE degradation are congestion events and competition between HAS streams. In fact, congestion events -which may occur frequently in wireless home network- reduce the bitrates sent to the HAS clients which in turn degrade the user QoE. Based on related works, we found that one of the most convenient solution for this use case is to use a bandwidth manager, into the home gateway, that divides the available home bandwidth between concurrent HAS clients. However the performance of bandwidth manager depends on the accuracy of its bandwidth estimation.

HTTP Adaptive Streaming (HAS) downloads video segments of short duration (two seconds in general), called chunks, from a HAS server to a HAS client (the player). Each chunk is encoded at multiple quality levels. After filling its playback buffer with chunks, the player in the HAS client request for chunk periodically, in the steady-state phase. The steady-state phase includes periods of activity (ON periods) followed by periods of inactivity (OFF periods). The player tries to estimate the available bandwidth during the ON period to select the best video quality level for the next chunk. However when several players compete, they can do wrong estimation of available bandwidth.

Our Receive Window Tuning Method method, ([10]) is based on TCP flow control. In fact, TCP uses this flow control mechanism in order to prevent a sender from sending more packets than the receiver or network capacities. The idea is to modify, at the gateway, the value of the receiver's advertised window field in each TCP packet, and thus, to enable the home gateway to control the sending rate of each TCP flow.

We measure and compare performances of our proposed method with the case without traffic shaping. Our method improves the performances for the three metrics measured (instability, fidelity, and convergence speed).

## 6.7 SDN integration in LTE networks

**Participants:** Siwar Ben Hadj-Said.

**Keywords:** LTE networks, 3GPP, Software-defined Networks, OpenFlow, signaling load.

Nowadays, mobile operators face the challenge to sustain the future data tsunami. In fact, today's increasing data and control traffic generated by new kinds of network usage puts strain on mobile operators, without creating any corresponding equivalent revenue. In our previous

work [BHSSG<sup>+</sup>13], we analyzed the 3GPP LTE/EPC architecture and showed that a redesign of this architecture is needed to suit future network usages and to provide new revenue generating services. Moreover, we proposed a new control plane based on the OpenFlow (OF) protocol for the LTE/EPC architecture that enables flexibility and programmability aspects. In this work [19], we are interested in the programmability aspect. We show how the data plane can be easily configured thanks to OF. In addition, we evaluate the signaling load of our proposed architecture and compare it to that of 3GPP LTE/EPC architecture. The preliminary findings suggest that managing the data plane with OF has little impact on the signaling load while the network programmability is improved.

## 6.8 Assessment of Achievements

The results achieved by Atnet team must be compared with the key issues presented in the objective part. Not all key issues have deserved complete attention yet. However, in the past years, most of them have been sufficiently well explored to start and draw relevant conclusions.

We have gained experience in network resource allocation, energy saving in WLANs and home networks, management in optical networks. Nevertheless, there is plenty of left points to be studied. Most of our future researches will deal with the combination of several of the issues cited in the overall objectives section: advanced network management, optimization of network resource scheduling, routing, etc.

In 2014, Atnet team counted three permanent members (one professor and two associate professors), one temporary lecturer and seven PhD students. During 2014 year, Atnet team members have published

- 20 scientific papers (6 in international journals, 14 in international conferences with a selection committee),
- 4 patents,
- 4 Atnet members (M. El Helou, F. Moety, S. Ben Hadj, Han Yan) have successfully defended their doctoral thesis Ph.D. in 2014.

### Awards :

- Our work [22] presented in the IEEE Third International Conference on Future Generation Communication Technologies (FGCT 2014) received a Best Paper Award.
- Our work [13] presented in the third IEEE International Conference on e-Technologies and Networks for Development (ICeND 2014) received an Award of Appreciation.

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[BHSSG<sup>+</sup>13] S. BEN-HADJ-SAID, M. R. SAMA, K. GUILLOUARD, L. SUCIU, G. SIMON, X. LAGRANGE, J.-M. BONNIN, "New Control Plane in 3GPP LTE/EPC Architecture for On-Demand Connectivity Service", *in: CLOUDNET'13: 2nd IEEE International Conference on Cloud Networking*, IEEE (editor), p. 205 – 209, San Francisco, USA, 2013.

## 7 Contracts and Grants with Industry

### 7.1 Grants with Industry

In 2014, some of our team members are supported by the following grants :

- Cifre Grant on green management of home networks using low power wireless network. Our studies have been patented ([FY13], [YFV13], [YF13], [24], [26], [27], [25]). Our works have been published in the following papers: [22], [21]. With Orange Labs.
- Cifre Grant on smart management of flexible all-optical networks. With IRT B-Com.
- Cifre Grant on optimization of Internet transport protocols for real time data content broadcasting systems. Our work has been published in the following paper: [10]. With Orange Labs.

## 8 Other Grants and Activities

### 8.1 International Collaborations

We are collaborating with standardization bodies and collaborative forums on the ICT domain, for instance IETF for Internet (DNSSEC WG, MPLS WG, XCAST WG, etc.) or with IEEE on wireless network protocols. In 2014, we are member of IEEE P1903 Next-Generation Service Overlay Network (NGSON) working group, and member of the Traffic Management (TM) forum.

- The IEEE NGSON working group scopes are as follows: To specify protocols among NGSON functional entities (FEs) to support advanced content delivery capability in next generation service overlay networks. The content delivery capability aims to support content discovery, content cache and storage management, content delivery control, and transport Quality of Service (QoS) control including context-aware and dynamically adaptive content delivery operations. To specify protocols among NGSON functional entities to support service composition capabilities in next generation service overlay network. The capabilities of service composition aim to support service chaining and instantiation, specification interpretation, service brokering and execution, and context-aware and dynamically adaptive service composition. To specify protocols between NGSON FEs to enable self-organizing management capability. This capability includes activation and deactivation of an NGSON node and addition, deletion, movement and copy of an NGSON function entity from or to NGSON node. This standard also specifies protocols among Service Routing FEs to enable re-organization of overlay structure among multiple

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[FY13] F. FONTAINE, H. YAN, “Technique de communication dans un réseau local”, Patent 1362832 - France, 2013.

[YFV13] H. YAN, F. FONTAINE, J.-P. VUICHARD, “Procédé de contrôle de la consommation énergétique d’équipements d’un réseau de communication local”, Patent 1352881 - France, March 2013.

[YF13] H. YAN, F. FONTAINE, “Gestion améliorée des connexions réseau”, Patent 1359446 - France, 2013.

SR FEs for recovery from a failed or overloaded SR FE or for performance improvement of service routing.

- TM Forum is a global trade association trusted by the world's largest enterprises, service providers and suppliers to help them continuously transform to succeed in the digital economy. It bring together professionals from member companies to share experiences, collaborate and rapidly solve critical business challenges including IT transformation, business process optimization, big data analytics, cloud management, customer experience management and cyber security.

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

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

Numerous personnel exchanges have been generated by these international collaborations. Through them we have enhanced the scientific expertise of team members and produced several scientific papers these last years. The main activities developed in our collaborative projects concerned routing and management of networks: uncertainty of routing in dynamic networks, energy conservation in wireless network, multicast routing with QoS, multipath in adhoc networks and multicast connection reconfiguration. In 2014, several mobility grants from University of Rennes 1, Rennes Metropole, french MENRT, Agence universitaire de la Francophonie (AUF), Tunisian department of education, Algerian department of education, Lebanese CNRS, and St Joseph university have supported our research collaborations.

- Melhem El Helou (Ph.D. student) received several mobility grants from AUF, French Consulate at Beyrouth and University St Joseph to work with Atnet (June to July 2014 and in November 2014). Mr. El Helou works on a hybrid approach for radio access technology selection in heterogeneous wireless networks.
- Mohamad Yassin (Ph.D. student) was accepted on September 2012 for a Ph.D. grant from CNRS Lebanon and started working on his Ph.D. thesis with AtNet. He has received a mobility grant from Rennes Metropole for a 6 months stay in France (December 2013 - June 2014).
- Soha Farhat (Ph.D. student) got a three months grant from lebanese "association islamique pour la spécialisation et l'orientation scientifique" (June 2014 - August 2014). Mrs Farhat works on resource allocation and access selection algorithms for heterogeneous wireless communication networks, in a multi-operator environment.



- Maaloul Rihad (Ph.D. student) got a tunisian mobility grant to work with us at Irisa (June - July 2014) on control protocols for energy saving in metro-Ethernet networks.
- Hela Mliki (Ph.D. student) obtained a mobility grant from Tunisia to work with us at Irisa (August 2014) on Ethernet congestion control for multicast traffic in data centers.
- Joel Adepo (PhD student) obtained a mobility grant from Rennes Metropole to work at Irisa (May - July 2014) on tree reconfiguration without lightpath interruption in wavelength division multiplexing optical networks with limited resources.
- Omar Smail received a mobility grant from Mascara University (Algeria) where he is currently working. He has been invited at Rennes in April 2014. It has worked with us on multipath routing in ad hoc wireless networks with the goal to reduce energy consumption (and thus to enhance network lifetime) and to improve network QoS.
- Marc Ibrahim (Assistant Professor at University Saint Joseph, Lebanon) has benefited from AUF and CNRS grants to stay and work at Irisa in November 2014.
- Oriol Sallent (professor at Polytechnic University of Catalonia, Spain) has presented his works in the field of radio resource and spectrum management for heterogeneous cognitive wireless networks during his stay at AtNet (November 2014).
- Souleyman Oumtanaga (professor at Polytechnic University Houphouet-Boigny from Ivoire Coast) has visited us in June 2014 to extend our academic cooperation.

## 8.2 National Collaborations

Previously, we have leaded or participated to several national projects with academic and industrial partners, within the ANR (French National Science Foundation) collaborative programs or European research programs. We have also a long term partnership with industrial partners such as Orange R&D, and Alcatel-Lucent/Bell Labs. Moreover, we very actively collaborate with major research institutions into the Brittany region:

- IRT B-com is a new Technological Research Institute dedicated to boost development and marketing of tools, products and services that improve everyday life, thanks to research and innovation in digital technologies. In concrete terms, B-com innovates at the highest level in the areas of smarter and faster networks, hypermedia applications (ultra high definition images, 3D, intelligent content, virtual and augmented reality, etc.), and e-health. Since 2013, several members of Atnet team are involved in B-com activities in the network area.
- Brittany is the main region in France in the field of networking. Our research team has established collaboration with various research institutions including Telecom-Bretagne in Brest and Rennes.
- Most of our research projects have been labelled by the Images and Networks cluster. It gathers key players in the information, telecommunications and multimedia fields. It is

mainly located in Brittany and Pays de la Loire regions. Together, we are working on the future uses of the internet, television, and mobility.

## 9 Dissemination

### 9.1 Involvement in the Scientific Community

**Member in the Technical Program Committee** In 2014, Bernard Cousin has served as member in the Technical Program Committee of the following conferences:

- 5<sup>th</sup> International Conference on Ambient Systems, Networks and Technologies (ANT-2014) held on June 2-5, 2014 in Hasselt, Belgium.
- 10<sup>th</sup> European Dependable Computing Conference (EDCC 2014) held on May 13-16, 2014 in Newcastle upon Tyne, UK.
- 9<sup>th</sup> International Conference on Future Networks and Communications (FNC 2014) held on August 17-20, 2014 in Niagara Falls, Canada.
- 15<sup>th</sup> IEEE International Conference on High Performance Switching and Routing (HPSR 2014) held on July 1-4, 2014, in Vancouver Canada.
- Mobile Wireless Networking Symposium of 9<sup>th</sup> IEEE International Conference on Communications (ICC 2014) held on June 10-14, 2014 in Sydney, Australia.
- 5<sup>th</sup> International Conference on Computer and Communication Technology (ICCCT 2014) held on September 26-28, 2014 in Allahabad, India.
- 3<sup>th</sup> International Conference on Connected Vehicles and Expo (ICCVE 2014) held on November 3-7, 2014, in Vienna, Austria.
- 2<sup>nd</sup> International Conference on New Technologies and Communication (ICNTC 2014) held on December 2-3, 2014 in Chlef, Algeria.
- 4<sup>th</sup> IEEE International Conference on Photonics (ICP 2014) held on September 2-4, 2014 at Kuala Lumpur, in Malaysia.
- Optical Communications (OC) Symposium of the Photonics Global Conference held on 28 June-3 July 2015, in Singapore.
- 9<sup>ème</sup> conférence sur la Sécurité des Applications et des Réseaux et Sécurité des Systèmes d'Informations (SAR-SSI 2014) held on May 13-16, 2014, in Lyon, France.
- 2014 World Symposium on Computer Applications & Research (WSCAR 2014) held on 18-20 January 2014, at Sousse, in Tunisia.

**Member of an Editorial Board** In 2014, Bernard Cousin was member of the Editorial Boards of:

- International Journal of Computing and Network Technology ( IJCNT).
- International Journal of Communication Networks and Information Security (IJCNIS)
- International Journal of Networks and Communications (IJNC)

**Member of Ph.D. committee** Samer Lahoud has served in 2014 as a member of the following PhD committees:

- Farah Moety, "Joint Minimization of Power and Delay in Wireless Access Networks" [2], Ph.D. from University of Rennes 1, on 4th December 2014. Co-Supervisor of the Ph.D. and member of the jury.
- Melhem El Helou, "Radio Access Technology Selection in Heterogeneous Wireless Networks" [1], Ph.D. from University of Rennes 1, on Friday 28th November 2014. Co-Supervisor of the Ph.D. and member of the jury.

In 2014, Bernard Cousin has participated in the following Ph.D. committees:

- Farah Moety, "Joint Minimization of Power and Delay in Wireless Access Networks" [2], Ph.D. from University of Rennes 1, on 4th December 2014. Director of the Ph.D. and member of the jury.
- Han Yan, "Smart devices collaboration for energy saving in home networks" [3], Ph.D. from University of Rennes 1, on 19th December 2014. Director of the Ph.D. and member of the jury.
- Melhem El Helou, "Radio Access Technology Selection in Heterogeneous Wireless Networks" [1], Ph.D. from University of Rennes 1, on Friday 28th November 2014. Director of the Ph.D. and member of the jury.
- Maksym Nikolayev, "Contribution à l'amélioration de l'efficacité des réseaux IP sur WDM en évaluant et en dépassant les limites du dimensionnement multicouche", PhD from Paris 6 University, 29 September 2014. Reviewer and member of the jury.
- Mariem Graa, "Hybrid Code Analysis to Detect Confidentiality Violations in Android System", Ph.D. from Télécom Bretagne jointly with University of Rennes 1, 18 June 2014. Member of the jury.
- Samar Sindian, "Resource Allocation with Optimization for High Data Rate Mesh Wireless Personal Area Networks", Ph.D. from INSA Rennes jointly with University of Rennes 1, 17 September 2014. President of the jury.
- Do Kien, "Domain/Multi-Domain Protection and Provisioning in Optical Networks", Ph.D. from University of Montreal, 8 July 2014. External reviewer of the jury.

- Wei You, "A Content-Centric Networking Node for a Realistic Efficient Implementation and Deployment", Ph.D. from Télécom Bretagne jointly with University of Rennes 1, 20 January 2014. Member of the jury.

**Member of HDR committee** In 2014, Bernard Cousin has participated in the following H.D.R. committees:

- Vincent Rocca, "Codes AL-FEC et protocoles de diffusion robuste de contenus", H.D.R. from University of Grenoble, 22 September 2014. Reviewer and member of the jury.
- Stefano Secci, "Strategic Decisions and Diversity Benefits for Networked Communications Systems", H.D.R.. from University of Paris 6, 19 June 2014. Member of the jury.

**Scientific expertise** Bernard Cousin, in 2014, served as scientific expert in:

- ANR Cifre program.
- Call for projects for Digiteo-DigiCosme.

**Other Scientific Responsibility** Permanent members of AtNet teams are Professors or Associate Professors at University of Rennes 1. They have scientific responsibilities in University of Rennes 1.

- In 2014, Bernard Cousin is a member of the scientific board ("Conseil scientifique") of the Engineering department (ESIR) at University of Rennes 1.
- In 2014, Bernard Cousin is a member of Technical Committee of IEEE Communications Society (ComSoc) : TCII, since 2011.

## 9.2 Conferences, seminars, and abroad invitations

- Samer Lahoud visited Ajou University in South Korea in August 2014. The stay focused on starting an international collaboration on 5G Cloud-RAN networks and was partially funded by the service of international affairs (SAI) of the University of Rennes 1.

## 9.3 Teaching

Permanent members of AtNet teams are Professors or Associate Professors at University of Rennes 1. They have administrative responsibilities and teaching activities in University of Rennes 1.

- Bernard Cousin teaches high speed networking, network security, network survivability, and multicasting at the Master level in the Electronics and Computer Science department (ISTIC) of University of Rennes 1. He gives an introduction to networking at the Licence level in the Electronic and Computer Science department (ISTIC) of University of Rennes 1 (ISTIC). He also teaches computer networking at the Engineering department (ESIR) of University of Rennes 1.

- In 2014, Bernard Cousin is an elected member of the administrative board (“Conseil d’administration”) of the Engineering department (ESIR) at University of Rennes 1.
- Samer Lahoud teaches courses on IP networks, MPLS networks, and network administration at IUT of Saint-Malo. He is an invited expert at Telecom ParisTech for training sessions for professionals on new technologies in IP networks, with emphasis IP quality of service.
- Cédric Guéguen teaches on queuing theory and sensor network at the Superior Engineering Department of Rennes (ESIR). He also teaches about networks at Licence level and Master level of the University of Rennes 1.
- Cédric Guéguen is in charge of the Master in Network Engineering of University of Rennes 1, since September 2012.

## 10 Bibliography

### Major publications by the team in recent years

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