Research Team ATNET

Advanced Technology in Networking

Rennes

Activity Report

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2 Overall Objectives

2.1 Overview

The 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 and High 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. This should be provided with High Efficiency since network resources are expensive and could be rare.

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

- 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: Multicasting, Multi-constrained and Multi-criteria (QoS) Routing, Multi-domain Network Management, Network Survivability, and Network Resource Allocation.

1. *Multicast Routing*

   Multicast Routing is the most studied issue of the AtNet team. The team members have produced numerous solutions adapted to specific problems on this issue. They have been published in high quality scientific publications (see for instance [2, 3, 4, 7, 8, 16, 17, 24, 26]). However there are many pending multicast problems to be resolved. In computer networking, multicasting is the delivery of a data message to a group of destination computers simultaneously in a single transmission from the source. Multicasting is commonly employed in distributed multimedia applications using media streaming media like video-conferencing or Internet television (IPTV). In IP multicasting, the implementation of the multicast concept occurs at the IP routing level, where routers create optimal distribution paths for IP packets sent to a multicast address which identifies a group of destination computers. In a similar way, the multicast concept has to be adapted to high-speed optical networks because optical networks have new specific constraints (wavelength continuity, sparse splitting capability, wavelength converter).

2. *Multi-criteria (QoS) Routing*

   Nowadays, diverse advanced applications are provided over IP-based networks (e.g. IPTV, video-on-demand, telemedicine and 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 difficult if multi-domain networks (with confidentiality constraints) or multicast communications are taken into account.

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 provide 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. *Optical Routing*

   Due to the physical constraints and characteristics in all-optical WDM networks, routing is a challenging work [Muk00]. First, in the absence of any wavelength conversion device, the same wavelength should be employed over the light-tree, which is referred as the wavelength continuity constraint. Second, two or more light-trees traversing the same fiber link must be assigned different wavelengths, so that they do not interfere with one another, which is referred as the distinct wavelength constraint. Multicast routing in optical networks is an even more challenging work, since all-optical multicast has to distribute packets in the optical domain, thus branching nodes (or switch nodes) in a light-tree is required to be equipped with light splitters. By employing the light splitting capability, the branching node is able to replicate the incoming packets in the optical domain and forward them to all the required outgoing ports. Usually, a node capable of light splitting is named as a multicast capable node. Generally not all the network nodes are equipped with splitters. However, the network nodes at least have the tap and continue (TaC) capability to tap into the light signal for local consumption and forward it to only one outgoing port. From the point of optical energy budget, a light splitter reduces the power level of a light signal by a factor equal to the number of optical copies. The reduction of power 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 amplification make multicast capable nodes much more expensive than incapable nodes. That is why we propose to study routing in this multi-constraint context.

4. *Multi-domain Network Management*

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

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

High speed, world-wide networks have well known issues: scalability of routing is one of the mains. As network size grows, it becomes very unrealistic to broadcast complete topology information to every network node. This scalability challenge is further complicated when networks are delineated into multiple domains, each with its own policy and administrative privacy constraints. Moreover the confidentiality aspect of the world wide network management makes the inter-domain QoS routing a very hard problem. Especially when service data delivery requires crossing heterogeneous domains under the responsibility of different operators, or when the applications necessitate a multicast communication between different entities.

5. *Network Survivability*

   As networking deployments increase, survivability is becoming major concern. Survivability refers to the ability of a network to continue to provide services even in the presence of a failure. In general, this consists of two main tasks. The first task is to collect and maintain up-to-date network state (e.g., link resources, link usage, etc). Whereas, the second task is to find and reserve working and backup resources for the data paths based upon the above-collected information. Computation of optimal working and backup paths is a difficult computational problem in a mesh networks. In optical networks (i.e. with specific optical constraints) it is even more challenging. Moreover we are interested with survivability in multi-domain optical networks which entails the ability to recover end-to-end light-paths crossing multiple domains.

6. *Network Resource Allocation*

   Network resource allocation in next generation broadband networks is a challenging issue. For instance, in new wireless networks (4G systems) the 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 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, bandwitdh 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.

Our research is intended to be *vertical* in the sense that all aspects of 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 "network monitoring of multidomain networks", "protection of multidomain networks", "survivability of multicast routing", etc.

3 Scientific Foundations

3.1 Introduction

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

Research activities in the AtNet research team deals with architectures, protocols and algorithms for the Next Generation Networks. Next Generation Networks will be larger, will offer higher bandwidth, and should be more flexible to cope with new data transmission technologies proposes, for instance, by wireless networks or all-optical networks. Thus network architectures, protocols and algorithms have to be re-explored. We are concerned about the areas of recent challenges: Network Routing (multi-domain routing, multicasting and routing for multimedia applications) and Network Management (resource allocation, network monitoring). Our research is mainly articulated by architectural, protocol and algorithmic works. In this latter, we use the scientific foundations of graph theory and combinatorial optimization. Moreover protocols and algorithms are often tested by simulations because they are no easy access to large scale test 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 infrestructure.

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, whereas the operators of the different routing domains want to preserve the confidentiality of their topology and routing information. From one point of view, the organization of the network in domains fits to the usual way social organizations are organized, and is a good way to keep the scalability problem tractable. From a second point of view, the routing problem has to be solved with only partially available information, thus there is a trade-off between the quality of the routing and the amount of information which can be uncovered.

From the point of view of the network architecture, our activities are related to the distributed PCE-based route-computation architecture which is 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]. From the point of view of the algorithms, the computation of QoS aware inter-domain routes in a given network architecture needs a distributed algorithm enables to solve a basic NP-difficult optimization problem: the multi-constrained routing. We propose the adaptation of exact multi-constrained route computations

[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.

as it is in [KM02]to our network context, and also some approximated heuristic solutions.

3.3 Multicasting

Keywords: multicast, Steiner problem, constrained Steiner problem, QoS, optical multicasting.

The scientific foundation of the optimized multicast routing touches well known and NP-difficult problems. Without any constraint, minimum cost multicast routing corresponds to the well known NP-difficult Steiner problem (cf. [HRW92]). To cope with the routing scalability, efficient heuristics (with guarantees on the approximation ratio when possible) are in the focus of research works. Particular spanning problems are implicated in two recent multicast routing cases: in future all optical networks and in multiconstrained multicast multimedia applications.

In the first case, in all- optical networks, the physical constraints of optical switches give upper bounds on the node degrees in the optical multicast routes. Consequently, the optimal routes are not always constrained partial spanning trees. Supposing spanning trees, the basic problem is known as the degree-bounded Steiner problem [RMR+01] and corresponds to an not approximable hard problem. Recently, we proposed hierarchical solutions which are not trees and which can solve the spanning problem more efficiently than spanning trees. Generally, the constrained Steiner problems and the constrained minimum partial hierarchy problems are NP-difficult. Algorithms from the combinatorial optimization domain and ILP formulations can be used to computes optimal hierarchies. Our research also deals with finding good heuristics for some specific networks applications.

The scientific foundation of the multi-constrained QoS multicast routing is discussed in the next subsection.

3.4 Multi-constrained and QoS routing

Keywords: unicast, multicast, constrained Steiner problem, QoS, multi-objective optimization.

The multi-objective routing is known as an NP-complet problem or as an NP-difficult optimization even if the route request concerns only one destination (unicast request). Several multi-constrained multicast models are formulated and analyzed in the literature (cf. [KM02]). Similarly to some other constrained minimum partial spanning problems in graphs, the optimal (and in some cases the feasible) multi-constrained multicast route does not correspond to a spanning tree. The analysis of the optimal solution and the research on approximated solutions are important challenges today. Our hierarchical spanning structure describes very well the

[KM02] F. A. Kuipers, P. V. Mieghem, "MAMCRA: a constrained-based multicast routing algorithm", *Computer Communications 25*, 8, 2002, p. 802–811.

[HRW92] F. K. Hwang, D. S. Richards, P. Winter, "The Steiner Tree Problem", *Annals of Discrete Mathematics 53*, 1992.

[RMR+01] R. Ravi, M. V. Marathe, S. S. Ravi, D. J. Rosenkrantz, H. B. H. Iii, "Approximation algorithms for degree-constrained minimum-cost network-design problems", *Algorithmica 31*, 1, 2001, p. 58–78.

optimum and is a good starting point of the algorithmic research in the domain. Algorithms from the combinatorial optimization domain and ILP formulations can be used to computes optimal hierarchies.

3.5 Resource allocation in wireless networks

Keywords: opportunisitc 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, as 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, these new propositions are well adapted to the wireless environment and provide high throughput with the use of opportunistic scheduling techniques that take advantage of multi-user diversity. Indeed, the resources are preferably allocate to the active mobile(s) with the most favourable channel conditions at a given time (often to the mobile with the greatest SNR). Dynamically adapting the 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-objectives 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 the considered time instant. They do not take into account the variability of the traffic and the queuing aspects.

Based on previous works, our researches deals with these issues [13]. 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 approach.

[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: 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 in Commununications*, 1999.

3.6 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 aim thus 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. 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. We have introduced this concept in [**?**]. 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. Reversely, service to be delivered at a very short reach can benefit from the highest bit rate of the sub-band. [10]. Reversely, service to be delivered at a very short reach can benefit from the highest bit rate of the sub-band. For instance, we want to study the performance of this multi-band OFDM concept in terms of used resources and blocking probability compared to legacy scenario based on mono-band opaque or mono-band transparent.

techniques.

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.
- 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:

- IPTV with IMS,
- Video streaming,
- Video conferencing tool,
- Digital TV broadcasting,
- 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 keyrollover 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).
  - libsresolv 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. libsresolv 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 it's 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 queueing 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 Globecom ([23]).

6 New Results

6.1 Multicast Protection

Participants: Bernard Cousin, Ahmed Frikha, Samer Lahoud.

Keywords: Networking, Routing, Network Survivability, All-optical Networks, WDM, Muticast Traffic, P-cycles.

Survivability is becoming an important issue in Next Generation Networks, and particularly in optical mesh networks because optical mesh networks make most of the Internet backbone. For instance in optical networks due to the huge bandwidth offered by optical technology, a node or link failure may have a major impact on the network performances. Similarly protection of multicast traffic presents difficult issues and are critical. However the majority of previous works are designed to simple networks. The members of the team have a long expertise in network survivability. For instance, an overview of survivability in multi-domain optical networks was presented in [11]. In our most current works, we address the survivability in DWDM optical networks and the protection of multicast traffic.

Reliable Multicast Sessions Provisioning in Sparse Light-Splitting DWDM Networks using P-Cycles In this work [13], [1] we study the node and link protection using p-cycles for dynamic multicast sessions in all-optical DWDM networks. First, we propose a new concept for protecting nodes of light-trees under the sparse light-splitting and wavelength continuity constraints. Then, we integrate our concept in a novel algorithm, named node and link protecting candidate p-cycles based algorithm with sparse light-splitting constraints (NPCC-SSC). Our algorithm enables both node and link failure recovery in dynamic multicast traffic. Extensive simulations show that the NPCC-SSC algorithm achieves the best resource utilization, and outperforms the existing approaches in terms of blocking probability and computational time.

Candidate-Cycle-based Heuristic Algorithm for Node-and-Link Protection of Dynamic Multicast Traffic in Optical DWDM Networks When dealing with dynamic multicast traffic, we introduce in [14], [1] a novel candidate-cycle-based heuristic algorithm for node-and-link protection (CCHN). CCHN is based on p-cycle protection concept. The p-cycle concept ensures a fast restoration time and an efficient use of network capacity. Extensive simulations show that the blocking probability of our algorithm is lowest. Furthermore, the computational time of our algorithm is very low compared with the existing approaches, especially when traffic load is high.

6.2 Multicasting in All-optical Networks

Participants: Bernard Cousin, Shadi Jawhar, Samer Lahoud.

Keywords: Networking, Routing, All-optical Networks, Multicast Routing, Optical Multicasting, WDM, Sparse Splitting Network, Multicast Protocol, Light-tree, Light hierarchy, Light-Splitter, Multicast-capable Optical Cross-connect, Light-tree reconfiguration, Lightpath interruption.

In WDM networks, the particular challenge of multicasting resides in the specific constraints imposed by optical switches and fibers. For instance the same wavelength should be employed over the lightpath, which is referred as the wavelength continuity constraint. Second, two or more lightpaths traversing the same fiber link must be assigned different wavelengths, so that they do not interfere with one another, which is referred as the distinct wavelength constraint. Moreover light splitting (which is required to build ligth-trees) is a very expensive operation, thus all the optical switches are rarely capable to have a splitting device. Similarly wavelength converters are not present in all optical switches of the network. Avoidance of multicast incapable nodes (nodes which cannot split the light) is one of the objectives of optical multicast routing algorithms [26]. Another possibility to improve the performance of optical multicat routing algorithms is to find more appropriate routes than light-trees. Generally, the optimal (minimum cost) optical routes between a source and the members of a multicast group is not a tree but routing structure called a hierarchy. So, hierarchy based routing algorithms can be designed in optical networks and was presented in [27]. A survey of the possible and actual solutions for multicasting in optical access networks can be founded in [16]. This year, we have explored more deeply the same issues. Especially the impact of splitter density and splitting factor of splitters on multicast trees and the capacity to reconfigure ligthtree without any ligthpath interruption.

Tree reconfiguration without lightpath interruption in WDM optical networks Efficient reconfiguration of optical multicast trees in all-optical networks is required. Today, networks are facing many phenomena such as changes in the network load, failures, additions or deletions of some network resources due to a maintenance operation. To cope with these phenomena, network operators compute new routes according to the application requirements. Some real-time multicast applications are not indulgent with lightpath interruptions. So the configuration of the routes must be done as quickly as possible to deal with the problem before any other event appears. To the best of our knowledge, there is no work in the literature that considers the reconfiguration of an optical multicast tree into another one without ligthpath interruption. Existing works on multicast reconfiguration are interested by the computing of new multicast tree, the reconfiguration triggering strategies and the reconfiguration frequency. In this work [5], first, we prove that it is impossible to reconfigure any given initial tree into any given final tree using only one wavelength and without connection interruption. Second we propose an algorithm, called BpBAR, using two wavelengths to reconfigure any ligthtree. It is a branch by branch, back and forth, reconfiguration process. This algorithm does tree reconfiguration without lightpath interruption, and it reduces the reconfiguration setup time and the cost of used wavelengths.

Power fairness over multicast tree in all-optical networks with adaptive light splitters Enhanced structure of optical switches can now handle multicast routing in the optical layer. To perform data multicasting in the optical layer, optical nodes must be equipped with light splitters. Light splitters can split one wavelength to more than one node output. A lot of work had been done in order to enhance the structure of the trees (tree routing) or the architecture of the light splitter in a way to reduce the cost and enhance the performance in terms of the power loss resulted of multiple splitting. We have in the past propose many works to improve tree routing [27, 25, 15]. However these works assume that the light splitters split an equal portion of the input signal power to each selected node output. To guarantee the fairness of power received by different members of a same multicast group, the use of adaptive light splitters is required. Adaptive light splitters allow splitting an incoming light signal into two or more node outputs with the ability of varying the individual power of each output signal. This work [15] studies the benefits of using adaptive splitters and dynamically modifying their splitting output ratios in a way to enhance the power received by all the group members. Power received by group members is evaluated based on the criteria of fairness of power received at all destinations of the multicast group, which enhance the minimum received signal to noise ratio under a total power constraint. Obviously the advantage of our adaptive splitting solution comes at a cost. Currently at less, the cost of an adaptive light splitter is higher than the cost of an ordinary light splitter. The real additional cost remains to be evaluated. However we could hope that this additional cost will be drastically reduced if adaptive splitter solutions are widely deployed.

6.3 Multiconstrained QoS Routing

Participants: Ahmed Frikha, Alia Bellabas, Samer Lahoud.

Keywords: Networking, Routing, Multicast Routing, QoS Routing, Multi-constrained Routing.

Quality of Service (QoS) routing known as multiconstrained routing is of crucial importance for the emerging network applications and has been attracting many research works. In our new results, we continue to explore two facets of the QoS Routing problem. First, we study unicast routing that is an NP-hard problem and aims to compute paths that satisfy the QoS requirements based on multiple constraints such as the delay, the bandwidth or the jitter. Second, we study the multicast QoS routing problem for providing multicast routes to enable the communications between a source node and multiple destination nodes. In such a case, the computation problem becomes even more challenging and necessitates special attention.

Performance Evaluation of Efficient Solutions for the QoS Unicast Routing In [4] we propose two fast heuristics that quickly compute feasible paths for the QoS routing problem. These heuristics are compared to the exact QoS routing algorithm: Self Adaptive Multiple Constraints Routing Algorithm (SAMCRA). For that, two main axes are explored. In the first axis, we limited the execution time of our heuristics. The simulation results show that the length of the computed paths is very close to the optimal ones that are computed by SAMCRA. Moreover, these heuristics satisfy more than 80% of the feasible requests. In the second axis, to enforce our hypothesis about the relevancy of the proposed heuristics, we force our algorithms to compute paths until a feasible path is found if such a path exists. The success rate becomes then 100%. Moreover, the qualities of found solutions as well as the combinatorial complexity of our heuristics are still attractive.

The cost optimal solution of the multi-constrained multicast routing problem In [7], we define the cost optimal solution of the multi-constrained multicast routing problem. This problem consists in finding a multicast structure that spans a source node and a set of destinations with respect to a set of constraints, while minimizing a cost function. This optimization is particularly interesting for multicast network communications that require Quality of Service (QoS) guarantees. Finding such a structure that satisfies the set of constraints is an NP-hard problem. To solve the addressed routing problem, most of the proposed algorithms focus on multicast trees. In some cases, the optimal spanning structure (i.e. the optimal multicast route) is neither a tree nor a set of trees nor a set of optimal QoS paths. The main result of our studies is the exact identification of this optimal solution. We demonstrate that the optimal connected partial spanning structure that solves the multi-constrained multicast routing problem always corresponds to a hierarchy, a recently proposed generalization of the tree concept. We define the directed partial minimum spanning hierarchies as optimal solutions for the multi-constrained multicast routing problem and analyze their relevant properties. Our work consists of the first study that exactly describes the cost optimal solution of this NP-hard problem.

6.4 Multi-domain Network Monitoring

Participants: Bernard Cousin, Aymen Belghith, Emna Salhi, Samer Lahoud.

Keywords: Networking, Routing, Multi-domain Network, Network Monitoring, Anomaly Detection, Monitor Location, Anomaly Localization.

In Internet networks, monitoring is necessary to guarantee the performance of the services. In our work, we consider the monitoring of multi-domain networks, the monitor location problem, as well as the related anomaly detection and localization problem.

Localization of Single Link-Level Network Anomalies Prior works examining the problem of single link-level anomaly localization have claimed that a necessary condition for localizing anomalies unambiguously is to deploy resources that enable the monitoring of a set of paths distinguishing between all links of the network pairwise. In our work [17], we show that the number of pair of links that are to be distinguished can be cut down drastically using an already established anomaly detection solution. This results in reducing the localization overhead and cost significantly. Furthermore, we show that all potential anomaly scenarios can be derived offline from the anomaly detection solution. Therefore, we compute full localization solutions, i.e. monitors that are to be activated and paths that are to be monitored, for all potential anomaly scenarios offline. This results in a significant minimization of the localization delay. We devise an anomaly localization technique that selects monitor locations and monitoring paths jointly; thereby enabling a trade-off between the number and locations of monitoring devices and the quality of monitoring paths. The problem is formulated as an integer linear program (ILP), and is shown to be NP-hard through a polynomial-time reduction from the NP-hard facility location problem. The effectiveness and the correctness of the proposed anomaly localization scheme are verified through theoretical analysis and extensive simulations.

Collaboration Schemes Evaluation in Multi-domain Networks A multi-domain service is a service that crosses several domains which can be managed by different providers. Since each domain can be managed with its own policies and may require confidentiality of its topology and its monitoring processes, we propose in [2] and [9] that the monitoring architecture has to be configurable. We introduce two collaboration schemes that are based on the reactive and the proactive modes. Both of collaboration schemes allow the multi-domain monitoring architecture to select the measurement points that will participate in the multi-domain monitoring and to configure the selected measurement points. Using extensive simulations on NS-2, we have shown that the proactive mode outperforms the reactive mode in terms of blocking percentage, monitoring throughput, and delay of monitoring establishment. By increasing the measurement points capacity, the number of the measurement points, or the number of the domains, we have shown that the proactive mode becomes more and more interesting compared to the reactive mode.

Export Methods in Fault Detection and Localization Mechanisms In [3] and [10] we propose several mechanisms for fault detection and fault localization. A fault is detected when an end-to-end contract is not respected. Faulty domains are domains that do not fulfil their Quality of Service (QoS) requirements. Our three proposed fault detection and localization mechanisms (FDLM) depend on the export method used. These export methods define how the measurement results are exported for analysis. We consider the periodic export, the triggered export, and a combined method. For each FDLM, we propose two sub-schemes that use different fault detection strategies. In our work, we identify specific use cases that take advantage of each of the export methods. Our assumptions are validated by simulation on NS-2.

6.5 All-optical Swtiching

Participants: Sofiene Blouza, Bernard Cousin.

Keywords: Networking, Routing, All-optical network, Optical switching, WDM, Multi-band OFDM, sub-wavelength switching.

The evolution of new internet services, such as TV on demand which requires large bandwidth, challenges bit-rates transported by each optical channel of a WDM network. Bit-rates of optical channels have now reached 100 Gbit/s. This increase in bit-rate must be supported by new features in optical network. Improve flexibility and ensure transparency of optical network, are very important challenges that internet operators face today. An optical network is called transparent, if the transported optical signals are not converted in electrical domain except at the time of their insertion and extraction in/from the optical network. Flexibility concerns mainly the aggregation/disaggregation functions. Today, the functions of aggregation/disaggregation are made on the electrical domain. This generates a significant cost for operators. One way to avoid this would be to find a technology which offers high bit-rates and enable the aggregation and disaggregation functions in the optical domain.

Multi-band OFDM switching In [11], [12], we introduce an all-optical switching technology at the sub-wavelength granularity. This technique, called multi-band OFDM, consists in dividing a WDM channel into multiple entities, called sub-bands. The number of sub-bands depends on the technological constraints of optical components used to transport the optical signal (optical filters, digital analogical converters, analogical digital converters, optical transponders, optical multiplexers, etc.). We compare the multi-band OFDM technology to two legacies scenarios: mono-band opaque and mono-band transparent OFDM technologies. We demonstrate that the multi-band OFDM technology can be a trade-off between these two legacies scenarios. To do that, we studied the performance in terms of blocking ratio on the multi-band and mono-band OFDM technologies. We study the impact of increasing the number of sub-bands on network performances. We also investigate the technical limits of this technology. Moreover, we demonstrate the economic interest of the multi-band OFDM. We expose the gain on the number of transponders when the multi-band OFDM technology is deployed first on metropolitan network and second on core network.

6.6 Radio Resource Allocation

Participants: Bernard Cousin, Cédric Guéguen, Farah Moety, Omar Smail.

Keywords: Networking, Routing, Network Management, Energy Conservation, WiFi Network, Radio Resource Allocation, Bandwidth Estimation.

New generation wireless networks will use advanced transmission technologies. All these network technologies require an efficient, autonomic, adapted and flexible management. Moreover networks are highly heterogeneous. It exists many types of wireless technology : WiFi, WiLAN, 4G, etc. This requires to focus our studies of them in order to propose the adequate solutions adapted to theirs specific requirements.

OFDM Scheduling Techniques in Wireless Networks Advanced MAC scheduling schemes provide efficient support of multimedia services in multiuser OFDM wireless networks. Designed in a cross layer approach, they opportunistically consider the channel state and are well adapted to the wireless multipath fading environment. These schedulers take advantage of time, frequency, and multiuser diversity. Thereby they maximize the global system throughput while ensuring the highest possible level of fairness. However their performances heavily depend on the bandwidth granularity (i.e., the number of elementary resource units) that is used in the resource allocation process. This work ([6]) presents and compares the main OFDM scheduling techniques. In particular it studies the influence of bandwidth granularity on the resource allocation strategies performances. Our work reveals that though bandwidth granularity has never been considered in former studies, it is of major importance for determining the application range of advanced OFDM scheduling techniques.

Radio Access Selection in Heterogenous Wireless Networks In wireless heterogeneous networks, one of the most challenging problems is Radio Access Technology (RAT) selection that must be designed to avoid resource wastage. In this work [16], we adopt a hybrid model for RAT selection where the system allocates the down-link traffic between two different technologies in order to enhance global network performance. We study the case of an integrated hybrid Wireless Local Area Network environment where the challenge we face is the high computational complexity necessary to obtain the global optimal solution. Therefore, we propose four distributed heuristic algorithms for RAT selection, where two of them are based on the distance between the user and the access points (APs), namely, distance based and probabilistic distance based algorithms. While the two others schemes are based on the peak rate that each user receives from these APs (peak rate based and probabilistic peak rate based algorithms). Results show that the proposed algorithms give efficient results compared to the optimal one depending on the spatial users distribution. Moreover these algorithms have a low computational complexity which makes them more advantageous compared to the optimal scheme in presence of a large number of users.

Bandwidth estimation in WLAN Bandwidth reservation is one of most frequent solutions to meet QoS requirements in 802.11 ad hoc networks. The efficiency of these solutions depends to the accuracy of their estimations of available bandwidth. Bad estimation can be catastrophic on loss rate. Therefore, accurate bandwidth estimation is fundamental, where each network characteristics must be taken into consideration, including mobility and medium sharing in such networks. Current solutions do not take into account all network characteristics, resulting to wrong bandwidth estimations and QoS violations. In this work [8], we present a new approach for bandwidth reservation, called Accurate Bandwidth Reservation (ABR), that is embedded with a new available bandwidth measurement method, where all criteria of such networks are considered. Evaluation of ABR is performed by simulations and comparisons with recent existing approaches.

6.7 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 now gained sufficient experience to claim that the optimal structure for minimizing the cost of multicast routing is a set of light-hierarchies rather than the light-trees in sparse splitting WDM networks. Integer linear programming formulations have been developed to find the optimal light-hierarchies and confirm this point. Furthermore numerical simulation results verified that light-hierarchy structures can save more cost than light-tree structures.

Nevertheless, there is plenty of work left. Most of our future researches will deal with the combination of several of the issues cited in the overall objectives section: advanced network management or monitoring, multicasting, multi-constrained routing, multi-domain network, survivability, etc.

In 2012, Atnet team counted three permanent members (one professor and two associate professors), and eight PhD students. During 2012 year, Atnet team members have published 16 scientific papers (6 in international journals, 10 in international conferences with a selection committee), and one patent. One Atnet member has successfully defended his doctoral thesis PhD in 2012.

7 Contracts and Grants with Industry

7.1 Rapido research project

A research project with Alcatel-Lucent-Bell-Labs has been developed on architectures and algorithms for the monitoring of multi-domain services. This project has started in January 2009 and has ended in 2012. The goals of this project was an efficient management of network resources when the service path goes through several routing domains operated by different network operators. We were considering the QoS of the user requests, the economic policy of the service provider and the confidentiality level required by each operator. The main issues are the combination of several service providers to propose enhanced services, the potential existence of trusted thrid party (network service broker), the lack of global information and the exponential combination of this optimization problem. We work in the context of the network service model proposed by IPShere Forum and, we propose a distributed domain-oriented solution.
Nabil Djarallah has successfully defended his doctoral thesis ([10]) on network architectures and algorithms to compute and establish inter-carrier services over multi-domain networks ([9]). Global or per-domain monitoring ([21]), flexible monitoring configuration ([1]), proactive or reactive collaboration schemes ([9]), fault detection and localization ([3]), and localization of single link-level anomaly detection ([17]) are some of our most recent studies produced in this multi-domain network context.

7.2 Scientific cooperation

In 2012, our team is supported by the following grants :

- Grant on green management of home networks using a sensor network. Our first studies have been patented ([18]). Orange Labs.
- Grant on green and flexible wavelength management in optical networks ([6], [18], [11]). Orange Labs.
- Grant on Optimization of Internet Transport protocols for real time data content broadcasting systems. 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. We participated to international projects with academic and industrial partners, within different collaborative programs (for instance the IST ASSET -Architectural Solutions for Service Enhancing digital Television- project which focuses on broadcast system integration and explores this innovative approach) and within European clusters of excellence (for instance Euro-NGI, EuroNFI, etc.).

We have very good and long-lasting ties with some international universities, namely Tunisia (Sfax or Manouba University), Lebanon (Lebanese University, Saint Joseph University, Antonine University), Ivory Coast (Cocody University and INPHB) and Algeria (Mascara university). Numerous personnel exchanges have been generated by these international collaborations. Through them we have obtained enhancement of team members' expertise and produced many papers.
For instance, there was a formal cooperation between French AtNet, Tunisian Cristal and Lebanese teams. It was funded by l'Agence Universitaire Francophone. The main activities developed in this project concerned the routing in networks: uncertainty of routing in dynamic networks, energy conservation in wireless network, multicast routing with QoS and multicast aggregation. In 2012, several master and PhD grants from University of Rennes 1, Rennes Metropole, french MENRT, libanese CNRS, and St Joseph university have supported and extended our research collaboration.

- With Redouane Belbachir (PhD student) and Zoulikha Mekkakia (Associate professor at University Mohamed Boudiaf, Oran, Algeria) we study bandwidth reservation in mobile adhoc networks ([8]). Redouane has got a grant (USTO-MB) to visit and work with us at Irisa iin January 2012.
- Lamia Chaari (associate professor at Sfax university, Tunisia) has worked with AtNet research team during April 2012. She has given a seminar on "Contrôle d'admission pour les nouvelles générations de réseaux locaux sans fil" at IRISA. We have designed

a research proposal, called GreenMAN, on energy efficient routing for Metro-Ethernet Networks.

- Emna Charfi (associate professor from Sfax national engineering school (ENIS) in Tunisia) has visited us between November and December 2012. We have worked on medium admission control of wireless local area networks.

- Elias Doumith, research engineer from Telecom ParisTech, was invited by AtNet team. He has given a seminar on Network Monitoring in July 2012 at Irisa.

- Melhem Helou (Ph.D. grant from Saint Joseph University) received a grant from the French embassy at Beirut to travel to Rennes and work with ATNET for two months starting from september 2012. Mr. El Helou finished his work on a Hybrid Approach for Radio Access Technology Selection in Heterogeneous Wireless Networks and submitted his work to European Wireless 2013. The paper was accepted and presented later.

- Professor Dany Mezher, from Saint-Joseph University Lebanon visit our research team in Mars 2012.

- Hela Mliki has got a grant to visit and work with us at Irisa (May-July 2012), on Ethernet congestion control for multicast traffic in data centers.

- Souleymane Oumtanaga (Professor) is the leader (ith Bernard Cousin) of a cooperation agreement which has been signed in 2012 between University of Rennes 1 and INPHB (Ivory Coast). In this cooperation Joel Adepo (PhD student) works on multicast tree reconfiguration in all-optical networks without light path interruption.

- Omar Smail from Mascara University (Algeria) where he is currently assistant professor has been invited at Rennes in June 2012. It has worked with us on multipath routing in ad hoc wireless networks wit the goals to reduce energy consumption (enhance network lifetime) and improve network QoS.

- Mohamad Yassin (University Saint Joseph) has been invited by University of Rennes 1 (Actions Internationales) to work on his master thesis on dynamic radio resource management in a hybrid broadband network. Mr. Yassin was accepted on september 2012 for a Ph.D. grant from CNRS Lebanon and started working on a Ph.D. thesis with ATNET.

8.2 National Collaborations

We leaded or participated to several national projects with academic and industrial partners, within the different ANR (French National Science Foundation) collaborative programs. We have also a long term partnership with industrial partners such as Orange R&D, and Alcatel-Lucent/Bell Labs.

- 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 and the Institut National des Sciences Appliquées (INSA) in Rennes.

- Most of our research projects have been labeled by the Images et Reseaux cluster which gathers key players in the information, telecommunications and multimedia fields, based in Brittany and Pays de la Loire. Together, we are working on the future uses of the internet, television, and mobility.

9 Dissemination

9.1 Involvement in the Scientific Community

In 2012, Bernard Cousin has served as co-chair in the Technical Program Committees of:

- IEEE third Symposium on Broadband Networks and Fast Internet (RELABIRA 2012), Beyrouth (Lebanon) in May 2012.

In 2012, Bernard Cousin has served as member in the Technical Program Committees of the following conferences:

- 2nd International Conference on Ambient Systems, Networks and Technologies (ANT-2012) Niagara Falls, Ontario (Canada) in August 2012.
- Advanced Optical Communications Symposium (AOCS) inside the 3rd Photonics Global Conference held in Singapore on December 2012.
- the 9th European Dependable Computing Conference (EDCC-9), held in Sibiu (Romania), on May 2012.
- High Performance Switching and Routing Workshop (HPSR) in Belgrade (Serbia), June 2012.
- IEEE International Conference on Communication in China (ICCC) - Optical Networks and Systems, in China, 2011.
- International Conference on Networks and Cyber Security (ICNCS), Vijayawada, Andhra Pradesh (India), January 2012.
- First International Conference on New Technologies and Communication (ICNTC'2012), Chlef (Algeria), November 2012.
- IEEE 3rd International Conference on Photonics (ICP 2012). Pulau Pinang (Malaysia), October 2012.
- 7ème conférence sur la Sécurité des Applications et des Réseaux et Sécurité des Systèmes dÍnformations (SAR-SSI) Cabourg (France) in may 2012.

In 2012, Bernard Cousin was in the Editorial Boards of:

- International Journal of Communication Networks and Information Security (IJCNIS)
- ICACT Transactions on the Advanced Communications Technology

- International Journal of Computing and Network Technology (IJCNT)
- International Journal of Networks and Communications (IJNC)
- Network Protocols and Algorithms (NPA), international online journal (since journal creation in 2009).

In 2012, Bernard Cousin participated in Reviewing Committee of:

- Nature and Technology journal

In 2012, Samer Lahoud has been a member in the following PhD committee:

- Patricia Kaiser, "Optimization of a software defined radio multi-standard system using graph theory", December 2012.
- Ahmed Frikha, "On Providing QoS and Reliability for Next Generation Networks: Multi-Domain QoS Routing and Multicast Reliability ", September 2012. [1]

In 2012, Bernard Cousin has been a member in the following PhD committees:

- Ahmed Frikha, "On Providing QoS and Reliability for Next Generation Networks: Multi-Domain QoS Routing and Multicast Reliability ", September 2012. [1]
- Christopher Kiennert, "Elaboration d'un modèle d'identité numérique adapté à la convergence", July 2012.
- Hilal Houssain, "Power Analysis Attacks Aware Elliptic Curve Cryptoprocessor for Wireless Sensor Network", October 2012. Reviewer.
- Ilhem Fajjari, "Resource Allocation Algorithms for Virtual Networks within Cloud Backbone Network", September 2012. Reviewer.
- Jelena Pesic, "Etudes des mécanismes réseaux associés à la restauration préventive dans le réseau coeur à fibre optiques", April 2012. Reviewer.

In 2012, Bernard Cousin has been a member in the following HDR committees:

- Loutfi Nuaymi, "Gestion des ressources radio dans les réseaux cellulaires", March 2012.
- Yacine Challal, "Sécurité de l'Internet des Objets : vers une approche cognitive et systémique", June 2012. Reviewer.

Bernard Cousin, in 2012, serves as expert:

- in "Futur et Ruptures" research program of Mines-Telecom academic group.
- for Belgian "Fonds National de la Recherche Scientifique".

9.2 Teaching

Permanent members of AtNet teams are Professors or Associate Professors at University of Rennes 1. They have important 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 Computer Science department of University of Rennes 1. He gives an introduction to networking at the Licence level in the Computer Science department. He also teaches computer networks at the Engineering department of 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 queueing 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.
- Bernard Cousin is an elected member of the administrative board ("Conseil d'administration") of the Engineering department (ESIR) at University of Rennes 1.
- Bernard Cousin is an elected member of the scientific board ("Conseil scientifique") of the Engineering department (ESIR) at University of Rennes 1.
- Bernard Cousin is in charge of the International Affairs of the Engineering department (ESIR) at University of Rennes 1.

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