Research Team ATNET

Advanced Technology in Networking

Rennes

Activity Report

2011

1   Team

Team leader
> Bernard Cousin, Professor, University of Rennes 1

Administrative assistant
> Nadia Saint-Pierre, IRISA, until May 2011
> Maud Deschamps, IRISA, until May 2011
> Elodie LeQuoc, IRISA, since June 2011

University of Rennes 1 personnel
> Cédric Guéguen, Assistant Professor, since October 2011
> Samer Lahoud, Assistant Professor
> Hamza Drid, ATER until September 2011
> Alia Bellabas, ATER since October 2011

PhD students
> Sofiene Blouza, *CIFRE* grant, since December 2009
> Nabil Djarallah, *CIFRE* grant, until November 20011
> Melhem El Helou, grant from University Saint Joseph (Libanon), since September 2011
> Ahmed Frikha, grant from University of Rennes 1, since October 2009
> Farah Moety, MENRT grant, since October 2011
> Emna Salhi, grant from University of Rennes 1, since June 2009
> Houssein Wehbe, *CIFRE* grant, until November 2011
> Han Yan, *CIFRE* grant, since November 2011

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, and Network Survivability.

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 [1, 2, 3, 5, 6, 11, 12, 16, 17]). 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 [3]. MPLS-TE mechanisms can help the establishment of QoS inter-domain routes. Some very good results in this domain were presented in [2].

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.

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. We are concerned about the areas of recent challenges: Network Routing (multi-domain routing, multicasting and routing for multimedia applications) and Network Management. Our research is mainly articulated by architectural, protocol and algorithmic works. In this latter, we use the scientific foundations of the graph theory and the combinatorial optimization. Protocols and algorithms are often tested by simulations. 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.

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 are a good way to keep the scalability problem tractable. From another 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 algorithms wich is enable to solve a basic NP-difficult optimization problem: the multi-constrained routing. We have proposed the adaptation of known exact multi-constrained route computations as it is in [KM02] but also 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 very large NP-difficult problems. Without any constraint, the 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 the 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 optical networks, the physical constraints of optical switches give upper bounds on the node degrees in the optical multicast routes. Consequently, the optimal

[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.

[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.

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 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 of 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 describe very well the 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. Our research also deals with finding good heuristics for network applications.

3.5 Multi-constrained resources allocation in wireless network

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

[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.

[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.

able to bring together high system throughput, high mobile 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 of 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 information 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 of these issues [9]. We have proposed new efficient heuristics avoiding the supposed necessary trade-off between system capacity and QoS. The queuing aspect are take into consideration as well as the 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.

4   Application Domains

4.1   New Generation Internet

Internet at large is our applicative domain. Any distributed application using Internet will benefit from our research. For instance on the application side, Atnet team explores the transport requirements of the most stringent multimedia applications, like:

- IPTV (with IMS),

- video streaming,

- video conferencing tool,

- digital TV broadcasting, etc.

However, the direct beneficiaries of our works will be the telecommunication companies because most of our algorithms or protocols will fit into network equipments, and ease the network management. For instance:

[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.

- internet providers,

- advanced innovative service providers,

- network operators,

- network equipment manufacturers.

Almost all kind of networks received our attention (in network management and routing) :

- IPv6 networks,

- MPLS infrastructures,

- Optical networks,

- Wireless networks,

- Adhoc networks,

- Sensor networks.

Currently our main research effort is aimed at all-optical networks because the connection-oriented feature of light-paths and the optical constraints of optical networks can offer a perfect support for our fundamental results (on advanced network management and routing). However Wireless Adhoc Mobile Networks are also under close studies.

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.

6   New Results

6.1   Network Survivability

Participants: Bernard Cousin, Hamza Drid, 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 [7]. In our most current works, we address the survivability in DWDM optical networks and the protection of multicast traffic.

Multicast traffic protection Maintaining survivability of DWDM networks is crucial to multicast traffic. A link-or-node failure has a severe impact on optical multicast sessions as it can prune several communications simultaneously. In [19], we consider link-and-node failure recovery in dynamic multicast traffic in WDM networks. We extend the node protection concept of the p-cycle approach to achieve more efficient resource utilization. Then, we propose a novel algorithm that integrates our concept for the node protection, named node-and-link protecting p-cycle based algorithm (NPC). We also propose a second algorithm, named node-and-link protecting candidate p-cycle based algorithm (NPCC). This algorithm deploys our concept for node protection and relies on a candidate p-cycle set to speed up the computational time. We compare our proposed algorithms to the ESHN algorithm, which is reported to be the most efficient algorithm for protecting dynamic multicast sessions. Extensive simulations show that the NPC algorithm achieves the lowest blocking probability, but has the highest computational time among the NPCC and ESHN algorithms. The NPCC algorithm outperforms the ESHN algorithm in terms of resource utilization efficiency and computational time. In [20], we present a novel candidate-cycle-based heuristic algorithm for node-and-link protection (CCHN) in dynamic multicast traffic. 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.

DWDM Network Survivability As optical networking deployments increase, multi-domain provisioning and survivability are becoming major concerns. A key challenge in multi-domain survivability is the scalability problem. Fast recovery time and reduced resource utilization are the two main criteria for determining the quality of survivability mechanism. Now, it is well known that link-based protection and path-based protection provide, respectively, a short recovery time and reduced use of resources. To benefit from both advantages of these mechanisms, we propose in [17], [18] and in [6] to use these mechanisms simultaneously. Indeed, demands requesting shorter recovery time will be protected using link-based protection. Meanwhile, other demands (e.g., no-critical) will be protected using path-based protection. Simulation results show that the proposed solution achieves a good trade-off between resource utilization and recovery time

6.2 Multicasting in All-optical Networks

Participants: Bernard Cousin, Shadi Jawhar, Samer Lahoud, Fen Zhou.

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.

In WDM networks, the particular challenge of multicasting resides in the specific constraints imposed by optical switches and fibers. For instance the splitting 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 [17]. 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 [18]. A survey of the possible and actual solutions for multicasting in optical access networks can be founded in [11]. 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 we have produced of bounds or approximation ratios for some route computation algorithms.

Cost Bounds and Approximation Ratios of Multicast Light-trees in WDM Networks   The construction of light-trees is one of the principal subproblems for all-optical multicast routing in sparse splitting wavelength division multiplexing (WDM) networks. Due to the light splitting constraint and the absence of wavelength converters, several light-trees may be required to establish a multicast session. However, the computation of the cost-optimal multicast light-trees is NP-hard. In [8], first we study the cost bounds of the light-trees built for a multicast session in unweighted WDM networks. Second, partially based on this result, the approximation ratios of some classical multicast light-tree computation algorithms, i.e., the reroute-to-source (R2S) and member-only (MO) algorithms, are derived in both unweighted and non-equally-weighted WDM networks. Moreover, integer linear programming formulations are introduced and carried out to search the optimal light-trees for multicast routing. The cost bounds and approximation ratios of the R2S and MO algorithms in some candidate WDM backbone networks are examined through simulations.

Power-based Design of Multicast Light-trees in WDM Networks   Given a multicast session in Wavelength Division Multiplexing (WDM) networks, in paper [9], we try to find the multicast lighttrees with the minimum power budget while taking into account the optical power loss as light splitting loss, node tapping loss and light attenuation loss. Although light splitting causes nonlinear power relationship, we succeed to formulate this problem as a Mixed-Integer Linear Programming (MILP) by developing a set of equivalent linear equations to replace the non-linear ones. The distribution of power loss is analyzed by simulations, which suggests to bound the combined power loss ratio of the node tapping loss and the light attenuation in each source-destination path, and make power-symmetric light-trees by properly using light-splitters in order to minimize the overall power loss.

Splitter Density for Multicast Trees in All-optical Networks   Many algorithms are developed to deploy multicast in optical networks. Those algorithms are designed to resolve the main issue of multicasting in optical networks: some of optical switches in the network are not capable to split an incoming light signal to more than one output interface. Some of those algorithms are based on additional signaling exchanged to generate the appropriate multicast trees, some use rerouting to source, and some generate multiple multicast trees for the same multicast session. The performance of those algorithms depends basically on the number and location of multicast-capable optical switches. A multicast-capable optical cross-connect (MCOXC) is an optical node equipped with light splitter that allows splitting an incoming light signal to any two or more output interfaces.[24] and [25] study how many nodes in optical networks must be equipped with light splitters to assure good performance of multicast algorithms in sparse splitting networks. This depends basically on the topology in terms of number of nodes, the average node degree and the variation of the node degree distribution over the network nodes. The more the variation of the node degree is, the more splitters are required.

Splitting Factor on Multicast Trees in All-optical Networks   Enhanced optical switches structure can now handle multicast routing in the optical layer. For an optical node to be able to do branching in the physical layer, it must be equipped with a light splitter. Light splitters are expensive equipment. A lot of work had been done in order to reduce the cost of implementing splitters within the network. Moreover, the internal structure of a splitter is enhanced to reduce its cost, and reduce the power loss produced by multiple splitting. Efficient placement of splitters in the network leads to a reduction in the cost of the network design, and the cost of the generated trees. The splitting capability of each splitter plays an important role on how much branching can be done on the optical node. Also, the splitting capability affects the power loss done on each branching node, and consequently the final power received by each member.[23] studies the effect of the splitting factor on the cost of the generated trees and the value of the power received by each of the multicast group members.

PhD on Splitters in All-Optical Networks   Previous and above works on splitter locations, splitting factor, splitter density, and splitter-aware multicast protocol have been gathered in Shadi Jawhar's PhD document [3].

6.3   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.

Multi-Domain Monitoring Architecture   In [11], we review the state-of-the-art monitoring architectures proposed for multi-domain networks. We note that these architectures do not support measurement configuration that enables the providers to perform flexible multi-domain measurements. Therefore, we present our proposal for the configuration of the multi-domain network monitoring architecture in order to give more flexibility in network monitoring and solve the heterogeneity and interoperability problems. We also present our collaboration schemes that can be applied in our configurable monitoring architecture. These collaboration schemes, based on the proactive selection and reactive selection, are used to select the measurement points that participate in the multi-domain monitoring and configure the parameters of the measurement points selected. We show in [12] through extensive simulations on the network simulator NS-2 that the proactive collaboration scheme provides a more flexible multi-domain monitoring and reduces the delay and the overload of the monitoring establishment.

Global Vs. Per-Domain Monitoring Schemes for Multi-Domain Networks   As noted in the previous sections, It is often desirable to perform global monitoring to guarantee end-to-end QoS for services across domains and to reduce the monitoring cost. However, global monitoring might be infeasible due to confidentiality constraints. The alternative solution is to perform per-domain monitoring. In [30], we propose to evaluate global and per-domain monitoring techniques. For this end, we study the properties of multi-domain networks and the requirements of multi-domain monitoring. We formulate the problem as an Integer Linear Program (ILP). We show that it is a Nondeterministic Polynomial Time Hard (NP-Hard) problem, and therefore, we devise a heuristic that meets multi-domain properties. We show that confidentiality is far from being the only constraint to global multi-domain monitoring. In our evaluation, the confidentiality constraint has been relaxed, in order to investigate other performance metrics; namely, the monitoring cost, the quality of monitored paths, the anomaly detection delays, and the fairness of monitoring load distribution among domains. Simulation results on random topologies show that per-domain monitoring outperforms global monitoring for all these metrics, except the monitoring cost that is slightly lower for global monitoring.

Mechanisms and Methods for Anomaly Detection and Localization   In our work, we also investigate the challenging problem of anomaly detection and localization. In [13], we propose several mechanisms for anomaly detection and localization. In this context, an anomaly is detected when an end-to-end contract is not respected. Anomalous domains are domains that do not fulfill their Quality of Service (QoS) requirements. Our three proposed anomaly detection and localization mechanisms 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 mechanism, we propose two sub-schemes that use different detection strategies. We describe these mechanisms and evaluate their performance using Network Simulator (NS-2).

In [31], we tackle the algorithmic problem based on our previous work in the domain. In 2010, we demonstrated, using ILP formulations, that there is a trade-off between theses two minimization objectives. However, we have shown that the trade-off could be efficiently balanced by jointly optimizing monitor location and anomaly detection costs. The problem is

NP-complete, hence ILPs could not deliver solutions for large networks. In [31], we address the scalability issues. We propose two greedy algorithms that jointly optimize monitor location cost and anomaly detection cost. The first algorithm is based on an exhaustive heuristic that explores all paths that are candidate to be monitored, in order to select a subset of paths that reduces the total monitoring cost. On the opposite, the second algorithm is based on a selective heuristic that avoids exploring all the candidate paths to further improve the scalability. The main challenge of this heuristic is to not degrade the solution quality. The two algorithms have been evaluated through extensive simulations on networks with large number of paths. The comparison of the solutions delivered by the two algorithms to each other and to the solutions delivered by the ILP demonstrates that the selective algorithm provides near-optimal solutions, while achieving a desirable scalability with respect to the network size and significant reduction of the computation time.

6.4 Multiconstrained QoS Routing

Participants: Ahmed Frikha, Alia Bellabas, Samer Lahoud.

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

Internet usages have changed with the emergence of value added services relying on a higher interactivity and needs for a better quality of service. Telecommunication operators have to face a continuing growth of new types of Internet traffic (video, games, telepresence, etc.) imposing not only a more efficient utilization of their network infrastructure resources, but also the generation of new revenues to pursue investments and sustain the increasing demand. Such services generally cross multiple domains, but inter-domain routing protocols still have some limitations in terms of service assurance. For example, BGP's single route announce for a destination limits potential traffic engineering features (e.g. no quality of service price/efficiency optimization, inter-domain shared route protection, inter-domain load balancing, etc.).

Particularly, 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. In our new results, we continue to explore two facets of the QoS Routing problem. First, we extend the QoS routing to the inter-domain level to enable the communications between different operator networks. This extension faces two major challenges: scalability and domain confidentiality. 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.

Computation Schemes for Multi-Domain QoS Routing In [16], we introduce an on-line scheme in order to provision end-to-end inter-domain connections that obey to constraints such as bandwidth, delay, jitter, and packet loss for these services. This approach computes e2e paths over multiple inter-domain routes. This will allow establishing more

efficiently the inter-domain connections with respect to requested QoS constraints and sharing these constraints (and associated revenues) among multiple operators to globally accept more demands in the system, while keep satisfying the customer QoE. To address these challenges, we propose an efficient distributed inter-domain algorithm that computes such constrained paths among a set of domains, exploring multiple inter-domain routes. We demonstrate that our algorithm not only increases success rate in delivering feasible paths, but also admits more connections and keeps a reasonable runtime.

In [21], we investigate the pre-computation scheme for the multi-domain QoS problem. Although the pre-computation scheme has been studied in several previous studies for a single routing domain, applying pre-computation on an inter-domain level is not straightforward and necessitates deeper investigation. In our work, we study different algorithms for QoS routing based on pre-computation. First, we investigate an exact algorithm. This algorithm provides an optimal solution for the QoS routing problem. However, its application in large scale networks is not always practical. Second, heuristic solutions are also investigated in this work. Particularly, a detailed study of the ID-MEFPA and the ID-PPPA heuristics is provided. Analytical studies and extensive simulations confirm that the exact algorithm achieves the best success rate, but has a very high computational complexity. The ID-MEFPA heuristic has a lower complexity and provides a success rate always close to the exact algorithm. When inter-domain connectivity is high, the ID-PPPA heuristic is the most appropriate with the lowest computation complexity and a success rate very close to the exact algorithm.

In [7], we combine our previous knowledge of the multi-domain QoS routing problem and propose a novel inter-domain QoS routing algorithm named HID-MCP. HID-MCP benefits from two major concepts that ensure high performance in terms of success rate and computational complexity. First, HID-MCP is a hybrid algorithm that combines the advantages of pre-computation and on-demand computation to obtain end-to-end QoS paths. Second, HID-MCP integrates crankback mechanisms for improving the path computation results in a single domain or in multiple domains. Extensive simulations confirm the efficiency of our algorithm on randomly generated topologies.

The QoS Multicast Routing Problem   In [14], we provide a deep study of the QoS multicast routing problem. We propose a classification of the QoS routing problems according to three parameters: the number of destinations, the number of constraints and the number of objectives. Then, we present the most relevant algorithms to exactly or heuristically solve each of the cited problem classes [5]. At the end of each problem class, we summarize the proposed algorithms and their combinatorial complexities. We also present our innovative approach based on new structures called hierarchies. Precisely, we show that the optimal solution of QoS multicast routing problem is always a hierarchy. After the definition the hierarchy and the associated properties, we provide an ILP formulation of the problem and review our efficient heuristics that were introduced in our previous work.

6.5 Advanced Management for New Generation Networks

Participants: Bernard Cousin, Cédric Guéguen, Houssein Wehbe, Omar Smail.

Keywords: Networking, Routing, Network Management, Ad hoc Networks, Sensor Network, Energy Conservation, Sensor Scheduling, WiFi Network, WIMAX Network, Optical Burst Switching, Packet Scheduling, Peer-to-peer network, Video Streaming, Packet Recovery, Packet Retransmission.

New generation networks will use advanced transmission technologies, such as wireless heterogeneous networks, optical burst switching, sensor networks, P2P networks. All these network technologies require an efficient, autonomic, adapted and flexible management. Moreover networks are highly heterogeneous. It exists many types as example wireless, cooperative, P2P, ad-hoc, mobile, etc. This requires to focus our studies of them in order to propose the adequate solutions adapted to theirs specific requirements.

Cooperation in Wireless Networks We have proposed a new scheduler able to extend the wireless coverage by using an incentive approach for potential mobile relaying nodes in [22]. Indeed, the cost of cooperation can be expensive in terms of QoS and energy consumption which do not motivate the nodes to cooperate. Our incentive approach rewards the cooperative nodes. The percentage of cooperation was considered in the QoS management in order to incite the border nodes to cooperate and then to extend the wireless area. Moreover, the monitoring mechanism was proposed to correctly evaluate the cooperation rate of each node. The results have shown that not only the proposed solution allows the border nodes to cooperate without negative impact but also it enhances the QoS performances.

Multipath over Wireless Networks We have studied routing in ad hoc mobile networks. Indeed, traditional techniques are not well adapted to these new networks. They lack of reactivity with respect to the traffic and network changes, making them not efficient since highly power greedy which is a crucial problem in these highly mobile context. The studies have been performed in order to solve this energy and routing problem [28]. We have extended the well-known routing protocol AODV (Ad hoc On-demand Distance Vector). This extension improves the multipath routing strategy with a path classification enabling the choice of the paths having the best energy level.

P2P Networks Other type of networks have specifically draw our attention : Peer-to-Peer (P2P) networks. Indeed, live streaming applications over P2P have attracted great interest. Despite the fact that numerous systems have been proposed in the past, there are still problems concerning delay and quality requirements of live video distribution. We have considered a pull-based P2Plive video streaming system where the video is disseminated over an overlay network [32]. The proposed mesh-based overlay construction mechanism enhances the received video quality while minimizing, as much as possible, the play-out delay. The results show that the developed solution is particularly efficient in heterogeneous systems.

6.6   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, 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 2011, Atnet team has counted only two permanent members (one professor and one associate-professor). However during 2011 year, Atnet team members have published 28 scientific papers (5 in international journals or book chapters, 23 in international conferences with a selection committee). And 4 Atnet members has successfully defended their doctoral thesis PhD. A young permanent member has been recruited in October 2011 to strengthen Atnet team.

7   Contracts and Grants with Industry

7.1   Rapido research project

We develop a bi-partite project with Alcatel-Lucent-Bell-Labs on architectures and algorithms for the monitoring of multi-domain services. This project has started in January 2009 and will end in January 2012. The goals of this project are an efficient management of network resources when the service path goes through several routing domains operated by different network operators. We are 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 ([2]) on network architectures and algorithms to compute and establish inter-carrier services over multi-domain networks ([16]). Monitoring reaction ([34]), global or per-domain monitoring ([31]), flexible monitoring configuration ([11]), proactive or reactive collaboration schemes ([12]), QoS fault detection and localization ([13]), and joint optimization of monitor location and anomaly detection ([30]) are some of the studies produced in this multi-domain network context.

7.2   Scientific cooperation

In 2011, our team is supported by Orange Labs:

- Grant on Overlay optimization and efficient packet retransmission for P2P video streaming system (Houssein Wehbe has successfully defended his doctoral thesis ([4]),

- Grant on green and flexible wavelength management in optical networks ([15], [33], [29]).

- Recently a grant on green management of home networks using a sensor network.

Our team is supported by Alcatel-Lucent Bell-Labs:

- A grant on inter-carrier services and path computation algorithm over multi-domain networks ([2]).

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.).

Since the 2000s, we have very good and long-lasting ties with some international universities, namely Tunisia (Manouba University), Lebanon (Lebanese University, Saint Joseph University, Antonine University), Ivory Coast (Cocody University and INPHB) and Hungary (Budapest University of Technology and Economics - BUTE). Numerous personnel exchanges have been generated by these international collaborations. Through them we have obtained enhancement of team members' expertise and produced many papers.
There was a formal cooperation between French AtNet, Tunisian Cristal and Lebanese teams. It was funded by l'Agence Universitaire Francophone. It started in January 2006 and has ended in December 2007. 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.We have obtained two successive supports on the Balaton project which associated our French team with a Hungarian team of BUTE, in 2005-2007 on dependable web service architectures for real time applications in intelligent networks, then in 2008-2010 on measurement methods for highly dependable applications.

- We received a grant from the University of Rennes 1 (actions incitatives pour collaborations internationales). In the context, Farah Moety visited our team to work on her master thesis and specifically on heuristics for radio access selection in heterogeneous networks ([27]). At the end of her master thesis, Farah got an MENRT grant to continue working on a PhD thesis with emphasis on green wireless communications.

- Melhem Helou (University Saint Joseph) has got a grant (August 2011) to work and visit us at Irisa on the selection of radio access technologies in heterogeneous wireless networks.

- Marc Ibrahim (University Saint Joseph) has been invited by University of Rennes 1 (July 2011). We worked on radio resource management in an hybrid broadband network ([26] and [27]).

- Hela Mliki has got a grant to visit (December 2011) and work with us at Irisa, on Ethernet congestion management for data centers.

- Souleymane Oumtanaga (INPHB) and Joel Adepo on multicast tree reconfiguration. Bernard Cousin and Souleymane Oumtanaga are the leaders of a cooperation agreement which has been signed between University of Rennes 1 and INPHB.

- With Redouane Belbachir and Zoulikha Mekkakia (University Mohamed Boudiaf, Oran) we study bandwidth reservation in mobile adhoc networks ([10]). Redouane has got a grant (USTO-MB) to visit (January 2012) and work with us at Irisa.

- Tibor Cinkler from Budapest University of Technology and Economics (Hungary) where he is currently associate professor at the Department of Telecommunications and Telematics has been invited in September 2010. Our scientific discussions focus on routing, design, configuration, dimensioning and resilience of MPLS and WR-DWDM based multilayer networks.

- Omar Smail from Mascara University (Algeria) where he is currently assistant professor has been invited at Rennes in April 2010. It has worked with us on energy efficiency in ad hoc wireless networks with node-disjoint path routing.

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, Alcatel-Lucent/Bell Labs, Orange, and Thomson Grass Valley.

- 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.

- In addition, two collaborations began since September 2011 with the Laboratory of Computer-Gaspard Monge (LIGM) and the Laboratoire d'Informatique de Paris 6

(LIP6). The first one consists in the research of new way to perform resource alloca-
tion in wireless networks (more stable and secure). The second collaboration focuses
on the performance evaluation on OFDM-based wireless systems considering different
implementation hypothesis.

9 Dissemination

9.1 Involvement in the Scientific Community

In 2011, Bernard Cousin has served in the technical Program Committees of :

- High Performance Switching and Routing Workshop (HPSR) Cartagena (Spain), July
  2011.

- 2nd International Conference on Ambient Systems, Networks and Technologies (ANT-
  2011) Niagara Falls, Ontario (Canada) in September 2011.

- 2nd colloquium on "Réseaux à large bande et Internet rapide" (Relabira 2011) Beyrouth
  (Lebanon) in March 2011.

- 2nd IEEE International Conference on Computer and Communication Technology (IC-
  CCT) Allahabad (India) in September 2011.

- Sécurité des Applications et des Réseaux et Sécurité des Systèmes dÍnformations (SAR-
  SSI) La Rochelle (France) in June 2011.

In 2011, Cédric Guéguen has served in the Technical Program Committee of:

- IFIP Wireless Days 2011 (http://www.wireless-days.org/, "sensor network" track), Nia-
  gara Falls (Canada) in October 2011.

In 2011, Bernard Cousin was in the editorial boards of:

- Network Protocols and Algorithms (NPA) international online journal (since journal
  creation in 2009).

- International Journal of Communication Networks and Information Security (IJCNIS)

- International Journal of Networks and Communications (IJNC)

- He has also been a member of the program committee of special edition of Int. Journal
  on Computing and Information Sciences (IJCIS)

In 2011, Bernard Cousin participated in Reviewing Committee of:

- Nature and Technology journal

In 2011, Samer Lahoud has been a member in the following PhD committee:

- Alia Bellabas, "Quality of Service Multicast Routing Subject to Multiple Constraints", October 2011. [1]

- Shadi Jawhar, "Multicast over Optical Networks", June 2011. [3]

- Nabil Djarallah, "Network Architectures for Inter-Carrier QoS-Capable Services", November 2011. [2]

- Maria Sokhn, "Ontology driven framework for multimedia retrieval in P2P network", August 2011

In 2011, Bernard Cousin has been a member in the following PhD committees:

- Aroua Biri, "Proposition de mécanismes de protection contre l'usurpation d'identité pour les réseaux des fournisseurs de services Internet", February 2011.

- Dali Ayachil, "Contributions à la détection des comportements malhonnêtes dans les réseaux ad hoc AODV par analyse de la confiance implicite", February 2011.

- Houssein Wehbe, "Transmission de flux vidéo en direct sur les réseaux pair-à-pair : optimisation de l'overlay et de la retransmission", September 2011.   [4]

- Mayssa Youssef, "WDM Core Networks: Regenerator Placement and Green Networking", November 2011.

- Nabil Djarallah, "Network Architectures for Inter-Carrier QoS-Capable Services", November 2011. [2]

- Patrick Battistello, "Mécanisme d'établissement d'appels sécurisés limitant les risques de SPIT et de (D)DoS à l'interconnexion entre opérateurs", April 2011.

- Shadi Jawhar, "Multicast over Optical Networks", June 2011. [3]

Bernard Cousin, in 2011, serves as expert:

- in committees of European Economic Community.

- for Belgian "Fonds National de la Recherche Scientifique".

9.2   Conferences, seminars, and abroad invitations

- Bernard Cousin has been an invited speaker at Global Photonics Conferenceat Singapoure in December 2010 and at Relabira 2011 colloquium at Beyrouth in March 2011.

9.3   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 University of Rennes 1. He gives an introduction to networking at the Licence level.

- Samer Lahoud teaches courses on IP networks, advanced routing, MPLS networks, network administration and network security 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 on MPLS networks and VPN services.

- 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 responsible for the International Affairs of the Engineering department (ESIR) at University of Rennes 1.

10   Bibliography

Major publications by the team in recent years

[1]   N. Ben Ali, J. Moulierac, A. Belghith, M. Molnar, "QoS Multicast Aggregation under Multiple Additive Constraints", *Computer Communications 31*, 15, August 2008, p. 3564–3578.

[2]   G. Bertrand, S. Lahoud, G. Texier, M. Molnar, "Computation of Multi-Constrained Paths in Multi-Domain MPLS-TE Networks", *in : Fifth Euro-NGI Conference on Next Generation Internet Networks (NGI'09)*, IEEE (editor), p. 1–8, Aveiro, Portugal, July 2009.

[3]   G. Bertrand, S. Lahoud, G. Texier, M. Molnar, "A Distributed Exact Solution to Computed Inter-Domain Multi-Constrained Paths", *in : EUNICE - The Internet of the Future*, L. N. i. C. S. Springer (editor), *5733*, p. 21–30, Barcelona, Spain, August 2009.

[4]   W. Bigos, B. Cousin, S. Gosselin, M. Le Foll, H. Nakajima, "Survivable MPLS Over Optical Transport Networks: Cost and Resource Usage Analysis", *IEEE Journal on Selected Areas in Communications 25*, 5, June 2007, p. 949–962.

[5]   A. Boudani, B. Cousin, "An hybrid explicit multicast/recursive unicast approach for multicast routing", *Computer Communications 28*, 16, October 2005, p. 1814–1834.

[6] B. Cousin, "Multicast chapter", *in : IPv6, théorie et pratique*, G. Cizault (editor), O'Reilly, 2005, ch. 11, p. 201–240.

[7] H. Drid, B. Cousin, S. Lahoud, M. Molnar, "A Survey of Survivability in Multi-Domain Optical Networks", *Computer Communications*, 2010.

[8] H. Drid, B. Cousin, M. Molnar, S. Lahoud, "Multi-Criteria p-Cycle Network Design", *in : 33rd IEEE Conference on Local Computer Networks*, IEEE Computer Society, p. 336–344, Montreal, Canada, October 2008.

[9] C. Gueguen, S. Baey, "A Fair Opportunistic Access Scheme for Multiuser OFDM Wireless Networks", *EURASIP Journal on Wireless Communications and Networking 2009*, 1, 2009, p. 726495, http://jwcn.eurasipjournals.com/content/2009/726495.

[10] D. Hamza, L. Samer, C. Bernard, M. Miklos, "Survivability in multi-domain optical networks using p-cycles", *Photonic Network Communications 19*, 1, 2009, p. 81–89.

[11] M. Molnar, F. Zhou, B. Cousin, "Multicast Routing in Optical Access Networks", *in : Optical Access Networks and Advanced Photonics: Technologies and Deployment Strategies*, I. Chochliouros (editor), IGI Publishing, July 2009, ch. 8, p. 162–183.

[12] J. Moulierac, A. Guitton, M. Molnar, "Hierarchical Aggregation of Multicast Trees in Large Domains", *Journal of Communications (JCM) 6*, 1, September 2006, p. 33–44.

[13] M. Y. Saidi, B. Cousin, J.-L. Le Roux, "PLR-based Heuristic for Backup Path Computation in MPLS Networks", *Computer Networks 53*, 09, June 2009, p. 1467–1479.

[14] M. Y. Saidi, B. Cousin, J.-L. Le Roux, "Using Shared Risk Link Groups to Enhance Backup Path Computation", *Computer Networks Volume 53*, 09, June 2009, p. 1341–1353.

[15] G. Simon, M. Molnar, L. Gonczy, B. Cousin, "Robust k-coverage algorithms for sensor networks", *Special Issue of the IEEE Transactions on Instrumentation and Measurement 57*, 8, August 2008, p. 1741–1748.

[16] F. Zhou, S. Mohand, M. Molnar, B. Cousin, "Supporting Multipoint-to-Point Communications in All-Optical WDM Networks", *in : 33rd IEEE Conference on Local Computer Networks*, IEEE Computer Society, p. 209 212, Zurich, Switzerland, October 2009.

[17] F. Zhou, M. Molnar, B. Cousin, "Avoidance of Multicast Incapable Branching Nodes for Multicast Routing in WDM Networks", *Photonic Network Communications 18*, 3, 2009, p. 378–392.

[18] F. Zhou, M. Molnar, B. Cousin, "Is Light-Tree Structure Optimal for Multicast Routing in Sparse Splitting WDM Networks?", *in : 18th IEEE International Conference on Computer Communications and Networks (ICCCN 2009)*, San Francisco, USA, 2009.

Doctoral dissertations and "Habilitation" theses

[1] A. Bellabas, *Quality of Service Multicast Routing Subject to Multiple Constraints*, PhD Thesis, INSA Rennes, 2011.

[2] N. Djarallah, *Network Architecture and Inter-Carrier Services*, PhD Thesis, University of Rennes I, 2011.

[3] S. Jawhar, *Multicast over Optical Networks*, PhD Thesis, University of Rennes I, 2011.

[4] H. Wehbe, *Live Video Streaming on Peer-to-Peer Networks: Overlay Optimization and Packet Retransmission*, PhD Thesis, University of de Rennes I, 2011.

Articles in referred journals and book chapters

[5] A. Bellabas, S. Lahoud, M. Molnar, "Performance Evaluation of Efficient Solutions for the QoS Unicast Routing", *Journal of Networks*, 2011, To appear.

[6] H. Drid, N. Ghani, B. Cousin, "Application-Aware Protection in DWDM Optical Networks", *Photonic Network Communications 22*, 3, 2011, p. 240–244, `http://dx.doi.org/10.1007/s11107-011-0323-1`.

[7] A. Frikha, S. Lahoud, B. Cousin, "Hybrid Inter-Domain QoS Routing with Crankback Mechanisms", *in: Smart Spaces and Next Generation Wired/Wireless Networking*, S. Balandin, Y. Koucheryavy, and H. Hu (editors), *Lecture Notes in Computer Science*, Springer Berlin / Heidelberg, 2011, p. 450–462, `http://dx.doi.org/10.1007/978-3-642-22875-9\_41`.

[8] F. Zhou, M. Molnar, B. Cousin, C. Qiao, "Cost Bounds and Approximation Ratios of Multicast Light-trees in WDM Networks", *Journal of Optical Communications and Networking 3*, 4, 2011, p. 323–334, `http://dx.doi.org/10.1364/JOCN.3.000323`.

[9] F. Zhou, M. Molnar, B. Cousin, G. Simon, "Power-optimal Design of Multicast Light-trees in WDM Networks", *IEEE Communications Letters 15*, 11, 2011, p. 1240 − 1242, `http://dx.doi.org/10.1109/LCOMM.2011.090611.111529`.

Publications in Conferences and Workshops

[10] R. Belbachir, Z. Mekkakia, A. Kies, B. Cousin, "Bandwidth Reservation in Mobile Adhoc Networks", *in: IEEE Wireless Communications and Networking Conference (WCNC 2012)*, IEEE (editor), Paris, France, 2012.

[11] A. Belghith, B. Cousin, S. Lahoud, S. B. Said, "Proposal for the Configuration of multi-domain Network Monitoring Architecture", *in: The International Conference on Information Networking (ICOIN 2011)*, p. 7 − 12, Kuala Lumpur, Malaysia, 2011, `http://dx.doi.org/10.1109/ICOIN.2011.5723105`.

[12] A. Belghith, S. B. Said, B. Cousin, S. Lahoud, "Proactive and Reactive Collaboration Schemes for Multi-domain Networks Monitoring", *in: Engineering-IT applications 2012 (EITA 2012)*, Hong Kong, P.R. China, 2012.

[13] A. Belghith, S. B. Said, B. Cousin, S. Lahoud, "QoS Fault Detection and Localization Mechanisms (FDLM) in Multi-domain Networks Adapted to Export Methods", *in: 4th International Conference on Advanced Communication Technology 2012 (ICACT 2012)*, PyeongChang, Korea, 2012.

[14] A. Bellabas, G. Texier, S. Lahoud, A. Najah, "Convergent IPTV Services over IP Multimedia Subsystem", *in: The 14th International Symposium on Wireless Personal Multimedia Communications (WPMC'11)*, Brest, France, 2011.

[15] S. Blouza, J. Karaki, N. Brochier, E. L. Rouzic, E. Pincemin, B. Cousin, "Multi-Band OFDM Networking Concepts", *in: Conference on telecommunications (EuroCon 2011)*, p. 1 − 4, Lisbon, Portugal, 2011, `http://dx.doi.org/10.1109/EUROCON.2011.5929191`.

[16] N. Djarallah, N. L. Sauze, H. Pouyllau, S. Lahoud, B. Cousin, "Distributed E2E QoS-Based Path Computation Algorithm Over Multiple Inter-Domain Routes", *in: Sixth International Conference on P2P, Parallel, Grid, Cloud and Internet Computing (3PGCIC 2011)*, p. 169 − 176, BARCELONA, Spain, 2011, `http://dx.doi.org/10.1109/3PGCIC.2011.34`.

[17] H. Drid, N. Ghani, B. Cousin, "Application-Aware Protection in DWDM Optical Networks", *in: Wireless and Optical Communications Conference (WOCC 2011)*, p. 1 − 4, Newark, New Jersey, 2011, `http://dx.doi.org/10.1109/WOCC.2011.5872276`.

[18] H. Drid, L. Gonczy, S. Lahoud, G. Bergmann, M. Molnar, "Dependable Routing Protocol Considering the k-Coverage Problem for Wireless Sensor Networks", *in: ICNS 2011: The Seventh International Conference on Networking and Services*, IARIA (editor), Venice/Mestre, Italy, 2011.

[19] A. Frikha, B. Cousin, S. Lahoud, "Extending Node Protection Concept of P-Cycles for an Efficient Resource Utilization in Multicast Traffic", *in: 36th Annual IEEE Conference on Local Computer Networks (LCN 2011)*, Bonn, Germany, 2011.

[20] A. Frikha, S. Lahoud, B. Cousin, "Candidate-Cycle-based Heuristic Algorithm for Node-and-Link Protection of Dynamic Multicast Traffic in Optical DWDM Networks", *in: The International Conference on Information Networking (ICOIN 2012)*, Bali, Indonesia, 2012.

[21] A. Frikha, S. Lahoud, "Performance Evaluation of Pre-computation Algorithms for Inter-Domain QoS Routing", *in: 2011 18th International Conference on Telecommunications (ICT 2011)*, Ayia Napa, Cyprus, 2011.

[22] C. Gueguen, A. Rachedi, "Coverage Extension Based on Incentive Scheduler for Mobile Relaying Nodes in Wireless Networks", *in: Proc. IEEE International Conference on Local Computer Networks (LCN)*, Bonn, Germany, 2011.

[23] S. Jawhar, B. Cousin, S. Lahoud, "Effect of Splitting Factor on the Generated Multicast Trees in Optical Networks", *in: International Conference on Network Communication and Computer (ICNCC 2011)*, p. 127 − 130, New Delhi, India, 2011.

[24] S. Jawhar, B. Cousin, S. Lahoud, "Required Density of Multicast Capable Optical Cross-Connects to Assure Efficient Multicasting", *in: First International Conference on Networking and Future Internet (ICNFI 2011)*, Paris, France, 2011.

[25] S. Jawhar, B. Cousin, S. Lahoud, "Required Density of Multicast Capable Switches in All-optical Networks to Assure Efficient Multicasting", *in: 2nd Colloquium on broadband networks and Fst Internet (RELABIRA 2011)*, Beyrouth, Libanon, March 2011.

[26] K. Khawam, M. Ibrahim, J. Cohen, S. Lahoud, S. Tohme, "Individual vs. Global Radio Resource Management in a Hybrid Broadband Network", *in: ICC 2011 Wireless Networking Symposium (ICC'11 WNS)*, kyoto, Japan, 2011.

[27] F. Moety, M. Ibrahim, S. Lahoud, K. Khawam, "Distributed Heuristic Algorithms for RAT Selection in Wireless Heterogeneous Networks", *in: 2012 IEEE Wireless Communications and Networking Conference: Mobile and Wireless Networks (IEEE WCNC 2012 Track 3 Mobile & Wireless)*, Paris, France, 2012.

[28] S. OMAR, M. ZOULIKHA, B. COUSIN, "Energy Efficiency in Ad Hoc Wireless Networks with Node-disjoint Path Routing", *in : 7th International Workshop on Systems, Signal Processing and their Applications (WOSSPA 2011)*, p. 127 – 130, Tipaza, Algeria, 2011, `http://dx.doi.org/10.1109/WOSSPA.2011.5931431`.

[29] E. L. ROUZIC, N. BROCHIER, S. BLOUZA, E. PINCEMIN, "Optical Networking Based on Multi-Band Optical OFDM at Ultra-High Bit Rates", *in : 2ème colloque sur les Réseaux à large bande et Internet rapide (Relabira)*, Beyrouth, Liban, April 2011.

[30] E. SALHI, S. LAHOUD, B. COUSIN, "Global Vs. Per-Domain Monitoring of Multi-Domain Networks", *in : 36th Annual IEEE Conference on Local Computer Networks (LCN 2011)*, p. 391 – 398, Bonn, Germany, 2011, `http://dx.doi.org/10.1109/LCN.2011.6115321`.

[31] E. SALHI, S. LAHOUD, B. COUSIN, "Heuristics for Joint Optimization of Monitor Location and Network Anomaly Detection", *in : ICC 2011 Communications QoS, Reliability and Modeling Symposium (ICC'11 CQRM)*, Kyoto, Japan, 2011.

[32] H. WEHBE, G. BABONNEAU, B. COUSIN, "Mesh-based Overlay Enhancing Live Video Quality in Pull-based P2P Systems", *in : 3rd IEEE International Conference on Communication Software and Networks (ICCSN 2011)*, IEEE (editor), p. 326 – 332, Xi'an, China, 2011, `http://dx.doi.org/10.1109/ICCSN.2011.6013604`.

Miscellaneous

[33] S. BLOUZA, E. PINCEMIN, J. KARAKI, "Procédé et dispositif de filtrage optique coupe-bande et dispositif d'insertion/extraction de sous-bande optique multiplexage en fréquence dans un signal optique", Brevet Numéro 11 51082, 2011.

[34] E. SALHI, S. LAHOUD, B. COUSIN, "Monitoring Reaction", Rapport dans le projet Rapido, D2.7, 2011, D2.7.