UMR IRISA

Team AtNet

Advanced Technology in Networking

Rennes

Activity Report

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1 Team

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2 Overall Objectives

2.1 Overall Objectives

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, 9, 10, 14, 16]). 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. *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.

3. *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 contraints) 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].

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

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

4. *Multi-domain Network Management*

   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, Distributed Algorithm, heursitic, 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.

4 Application Domains

4.1 New Generation Internet

Participants: Bernard Cousin.

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 (for instance internet providers, advanced and innovative service providers, network operators, or network equipment

[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.

manufacturers) because most of our algorithms or protocols will fit into network equipments, and ease the network management.

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

- IPv6 networks
- MPLS infrastructures
- Optical networks
- Wireless networks or 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).

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 anwsers(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.
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- 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)

6 New Results

6.1 Multicasting in All-optical Networks

Participants: Bernard Cousin, Fen Zhou, Miklos Molnar, Shadi Jawhar.

Keywords: Networking, Routing, All-optical Networks, Multicast Routing, Optical Multicasting, WDM, Sparse Splitting Network, Multicast Protocol, Light-tree, Light hierarchy.

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 [16]. 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 [?]. A survey of the possible and actual solutions for multicasting in optical access networks can be founded in [?]. This year, we have explored more deeply the same issues, for instance with the introduction of light-hierarchy and production of bounds or approximation ratios for some route computation algorithms.

Light Hierarchy Multicast routing in all-optical WDM networks where the light splitting capacity of some optical switches is limited is an important problem. The computation problem of the minimum cost multicast routes under optical constraints is NP-difficult. To solve the optimal multicast routing problem under physical constraints, we propose a new routing structure called light-hierarchy. In a light-hierarchy, the multicast route can traverse the same optical switch several times using the same wavelength. This new routing structure may improve both the cost of the optical structures and the throughput on WDM multicast networks [15].

For instance based on the false assumption that multicast incapable (MI) nodes could not be traversed twice on the same wavelength, the light-tree structure was always thought to be optimal for multicast routing in sparse splitting Wavelength Division Multiplexing (WDM) networks. In fact, for establishing a multicast session, an MI node could be crosswise visited more than once to switch a light signal towards several destinations with only one wavelength through different input and output pairs. This is called Cross Pair Switching (CPS). Thus, a new multicast routing structure light-hierarchy is proposed for all-optical multicast routing, which permits the cycles introduced by the CPS capability of MI nodes. We proved in [28] 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 are developed to search the optimal light-hierarchies. Numerical results verified that the light-hierarchy structure could save more cost than the light-tree structure.

Multicast Routing Algorithms for Sparse Splitting Optical networks The construction of light-trees is one principal subproblem for 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 optimal multicast light-trees is NP-hard. In this work [27], we study the wavelength channel cost (i.e., total cost) of the light-trees built for a multicast session. An equal cost of one unit cost is assumed over all the fiber links in the network. We prove that the total cost of a multicast session is tightly lower limited to K and upper bounded to K(N-K) when $K < N/2$ or $(N^2) - 1)/4$ when $K =< N/2$, where K is the number of destinations in the multicast session and N is the number of nodes in the network. Classical sparse splitting multicast routing algorithms such as Reroute-to-Source and Member-Only [ZWQ00] also follow these bounds. And particularly in WDM rings, the optimal multicast light-tree has a cost inferior to $N - N/(K + 1)$.

Approximation Ratios of Multicast Light-trees in WDM Networks All-optical multicast routing (AOMR) is implemented by the concept of light-tree in WDM networks. The cost-optimal multicast light-tree is NP-hard to compute, especially when taking sparse splitting into account. Thus many heuristic algorithms have been proposed. In this study [26], the approximation ratios of two classical heuristic AOMR algorithms for sparse splitting WDM network are studied. Let K be the number of destinations in a multicast session, it is proved

[ZWQ00] X. Zhang, J. Y. Wei, C. Qiao, "Constrained Multicast Routing in WDM Networks with Sparse Light Splitting", *Journal Lightware Technology 18*, 12, 2000, p. 1917 –1927.

that Reroute-to-Source (R2S) algorithm achieves a tight approximation ratio equal to K in the non-equally-weighted WDM network while Member-Only (MO) algorithm approaches the optimal solution with a ratio inferior to $(K^2+3*K)/4$ for any WDM network. It is also found that if the WDM network G is unweighted, both the approximation ratios of R2S and MO are no bigger than the diameter of the network Diam(G). Simulation results illustrate that both R2S and MO obtain good performances in candidate WDM backbone NSF network, which are far from the worst cases.

All-optical Multipoint-to-point Routing in WDM mesh networks In [9], the routing and wavelength assignment (RWA) problem for supporting multipoint-to-point communications in all-optical WDM mesh networks is investigated. Two effcient algorithms, namely Reverse Shortest Path Tree routing (RSPT) and k-Bounded Edge Disjoint Path routing (EDPR), are proposed. We proved that the problem of minimizing the total cost while establishing a multipoint-to-point session can be solved in polynomial time of $O(|V|.log|V| + |V| + |E|)$ by the RSPT algorithm, where |V| and |E| denote the number of nodes and the number of edges in the network respectively. Nevertheless, the solution provided by the EDPR algorithm produces a significant reduction in the maximum number of wavelengths required per link (i.e., the link stress) for a multipoint-to-point session compared to RSPT algorithm. EDPR algorithm can also approximate to the optimal total cost with a ratio of k. Simulations are done to assess these two algorithms. Numerical results demonstrate their efficiencies in supporting multipoint-to-point communications in all-optical WDM networks.

Multicast Tree Computation Heuristics In sparse light splitting all-optical WDM networks, the more destinations a light-tree can accommodate, the fewer light-trees and wavelengths a multicast session will require. In [10], a Hypo-Steiner light-tree algorithm (HSLT) is proposed to construct a HSLT light-tree to include as many destinations as possible. The upper bound cost of the light-trees built by HSLT is given as $N(N-1)/2$, where N is the number of nodes in the network. The analytical model proves that, under the same condition, more destinations could be held in a HSLT than a Member-Only light-tree. Extensive simulations not only validate the proof but also show that the proposed heuristic outperforms the existing multicast routing algorithms by a large margin in terms of link stress, throughput, and efficiency of wavelength usage.

PhD on Multicast in All-Optical Networks Most of the above works and results have been gathered in Fen Zhou's PhD document [2].

Location of Splitters in Optical Network Design When multicasting is implemented within the switching control plane of optical networks, it combines the efficiency of multicast tree along with high speed and low delay of optical communications. Multicast nodes must be equipped with light splitters. Light splitters are expensive equipment. Therefore, a limited number of optical nodes will have this splitting capability. A good placement of optical splitters can increase the efficiency of the multicast signaling and routing techniques on one hand, and reduce the number of those splitters on the other hand. This leads to faster multicast trees setting up, lower data transmission delays, and less traffic on the network links; thus saving of optical links capacity for other multicast and unicast transmissions. In order to achieve efficient multicasting in optical network, we propose in [18] to take into account network characteristics (link capacity and node degree) when placing the optical splitters. The benefits of the smart placement of light splitters will be clearly shown in heterogeneous optical networks, where multicast traffic is not uniformly distributed over the network, and optical links connecting different nodes in the network have different characteristics.

Splliter-aware Multicast Routing Protocol For an all-optical switch to play the role of a branching router, it must be equipped with a light splitter. Light splitters are expensive equipments and therefore it is very expensive to put splitters on all optical switches. Limited availability of light splitters raises a problem when we want to implement multicasting in optical network (because usual multicast protocols make the assumption that all nodes have branching capabilities). Another issue is the knowledge of the locations of light splitters in the optical network. Nodes in the network should be able to identify the locations of light splitters scattered in the optical network. This means that any node must be able to identify if other nodes in the network are multicast capable optical cross-connect MC-OXC or multicast incapable optical cross-connect OXC. These problems are resolved in [19] by a multicast routing protocol that takes into consideration the nodes which can be branching node. As a result, a new signaling process has been implemented so that light paths can be created, spanning all the group members from the source.

6.2 Multiconstrained QoS Routing

Participants: Ahmed Frikha, Alia Bellabas, Miklos Molnar, Samer Lahoud.

Keywords: Networking, Routing, Multicast Routing, QoS Routing, Multi-domain, Multi-constrained 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: this is especially the case when service delivery requires crossing heterogeneous domains under the responsibility of different operators, or when the applications necessitate a multicast communication between different entities.

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. We study 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.

QoS routing and management in backbone networks, Intelligent quality of service technologies and network management: models for enhancing communication

The Internet relies on the cooperation of competitive network operators that typically administrate their networks unilaterally and autonomously to interconnect people and companies in different locations. Recent work calls for extending this organizational model with augmented interactions between network operators, to provide a higher level of end-to-end quality of servi ce and to ease certain aspects of traffic management in backbone networks. The work in [4] presents the emerging collaborative network management models as well as related technologies. In particular, it describes recent techniques for inter-domain traffic engineering and for quality-of-service aware routing. The detailed methods are of great interest for network operators and permit the development of new types of commercial relationships between them, ranging from simple interconnection agreements to collaborative traffic management and automated provisioning.

Inter-domain path computation with multiple QoS constraints, Recent advances in providing QoS and reliability in the future Internet backbone It is important to provide efficient solutions to the fundamental inter-domain QoS routing problem, which consists in computing paths subject to QoS constraints. Due to the important applications of this problem, many solutions have been proposed. However, most of these solutions do not consider the specific issues introduced by the division of a network into domains. Therefore, they cannot realistically be applied for computing inter-domain multi-constrained paths. In [3], a synthesis of recent advances in multi-constrained inter-domain routing is provided. In particular, two innovative path computation approaches are presented. These approaches can be applied in the Path Computation Element (PCE) framework, as well as in novel architectures based on extended IP routing protocols. The proposed solutions allow the computation of inter-domain paths with a reasonable complexity and without degrading the QoS level. Therefore, the results described in this work open interesting perspectives for enhancing the performance of QoS routing and for engineering inter-domain traffic.

Pre-computation Based Heuristic for Inter-Domain QoS Routing In [17], a fast heuristic for inter-domain QoS routing, named ID-PPPA, is proposed. ID-PPPA is based on a pre-computation scheme. The pre-computation scheme attempts to solve the QoS routing problem while keeping a low response time by computing in advance a set of QoS paths. The proposed solution preserves domain confidentiality and solves the scaling problem related to inter-domain routing by distributing computations over the domains. Theoretical analysis proves that the ID-PPPA algorithm has a low computational complexity, which is very necessary for a pre-computation algorithm to deal with dynamic changes of the network link state information. Moreover, extensive simulations confirm the efficiency of the algorithm in terms of success rate and quality of the computed path.

Fast Heuristics for the QoS Multicast Routing Problem In [13], the QoS Multicast Routing (QoSMR) is investigated, as well as its different existing formulations. The limitations of these formulations are analyzed and a novel formulation is proposed. The main advantage of the proposed formulation is that it considers not only the quality of the multicast subgraph formed by computed paths, but also takes into account the end-to-end quality of each of these paths. Moreover, the state-of-the-art proposal for solving the QoSMR problem is studied which reveals that the well-known MAMCRA algorithm can be very expensive in computation time. Therefore, two efficient heuristics based on the computation of shortest paths are proposed. Extensive simulations are performed, and obtained results prove that these fast heuristics have bounded response time and find satisfying solutions for the QoS requirements.

6.3 Network Survivability

Participants: Bernard Cousin, Hamza Drid, Miklos Molnar, Samer Lahoud.

Keywords: Networking, Routing, All-optical Networks, WDM, Network Survivability, Multi-domain Network, Network Partitioning, Network aggregation.

Survivability is becoming an important issue in optical networks due to the huge bandwidth offered by optical technology. Many works have studied network survivability.

For instance, in optical backbone networks, the p-cycles based protection technique is a very interesting solution to protect predicted traffics. In [7] this technique is analyzed and new computation methods are proposed. An overview of the survivability in inter-domain optical networks using the p-cycle protection techniques was presented in [8]. In order to diminish the computational complexity of the inter-domain p-cycles, the aggregation of the topology information can be applied as it is proposed in [DLCM09]. The protection of routes in MPLS based domains was the subject of a common research project with France Telecom R & D. In the frame of this common work, the analysis of the failure risk becomes of interest The risk analysis can be the base of the backup route classification as it is demonstrated in [SCR09]. Some other results in this domain illustrate that the utilization of shared risk link groups (SLRGs) enhances the performance of the protection schemes [12] and that the backup paths can be classified efficiently based on the analysis of risks [?]. A PLR-based efficient backup path computation algorithm was proposed in [11].

However the majority of these works are destined to single-domain networks. In our most current works, we address the survivability of multi-domain optical networks.

Survey of Multi-domain WDM Network Survivability Network survivability is becoming an important issue in networks in general, and particularly in optical mesh networks because optical mesh networks make most of the Internet backbone. However, few works have focused on survivability in multi-domain optical networks. In [5] we review the literature on survivability against failures in multi-domain optical networks. The main objective of this study is to evaluate and analyze existing solutions and to compare their performance in terms of different criteria: resource utilization, ratio of rejected connections and recovery time.

[DLCM09] H. Drid, S. Lahoud, B. Cousin, M. Molnar, “A Topology Aggregation Model for Survivability in Multi-Domain Optical Networks Using p-Cycles”, *in: 6th IFIP International Conference on Network and Parallel Computing (NPC 2009)*, p. 211–218, Gold Coast, Australia, October 2009.

[SCR09] M. Y. Saidi, B. Cousin, J.-L. L. Roux, “Backup Path Classification based on Failure Risks for Efficient Backup Path Computation”, *in: 8th International Conference on Networking (Networking 2009)*, Aachen, Germany, May 2009.

Partitioning of Multi-domain Optical Networks for 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. To address this concern, various solutions have already been proposed based upon topology aggregation schemes. However, these mechanisms do not scale well with increasing domain counts and further investigation is required to develop more scalable alternatives. Along these lines, in [16] and [6] we propose to use graph partitioning techniques to solve the scalability problem in multi-domain optical networks. To demonstrate the efficiency of our method, we also extend the p-cycle concept to multi-domain settings. Overall simulation results show the efficiency of our proposed solution in terms of resource utilization and the number of p-cycle structures

Aggregation Model for Survivability of Multi-domain Optical Networks In this study[7] we provides a classification of the existing protection solutions proposed for multi-domain networks and analyses their advantages and limitations. We propose a new solution for multi-domain optical networks based on p-cycles (pre-configured cycles). For scalability and security reasons, we also propose a topology aggregation model adapted to p-cycle computations. This aggregation model allows our proposed solution to find a trade-off between two competing goals: efficient use of backup resources and short running time. Simulation results show that the proposed solution is a good trade-off between resource utilization and running time compared to existing solutions.

PhD on Survivability of Multi-domain Optical Networks Most of the above works and results have been presented in Hamza DRID's PhD document [1].

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.

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, the anomaly detection and monitor location problem.

Multi-domain Monitoring In [11, 31], 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, [30]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. In [29], 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 /citeBelghith 2010c through extensive simulations that the proactive collaboration scheme provides a more flexible multi-domain monitoring and reduces the delay and the overload of the monitoring establishment.

Anomaly Detection and Monitor Location Problem Achieving cost-effective systems for network performance monitoring has been the subject of many research works over the last few years. Most of them adopt a two-step approach. The first step assigns optimal locations to monitoring devices, whereas the second step selects a minimal set of paths to be monitored. However, such an approach does not consider the trade-off between the optimization objectives of each step, and hence may lead to sub-optimal usage of network resources and biased measurements. In [22], we propose to evaluate and reduce this trade-off. Toward this end, we come up with two ILP formulations for a novel monitoring cost model. The aim is to jointly minimize the monitor location cost and the anomaly detection cost, thereby obtaining a monitoring solution that minimizes the total monitoring cost. Our formulations apply for both active and passive monitoring architectures. We show that the problem is NP-hard by mapping it to the uncapacitated facility location problem. Simulation results illustrate the interplay between the optimization objectives and evaluate the quality of the obtained monitoring solution.

Anomaly Detection and Monitor Location Heuristics To reduce monitoring cost, the number of monitors to be deployed have to be minimized and the overhead of monitoring flows on the underlying network have to be reduced. The problem is NP-complete, hence ILPs could not deliver solutions for large networks. In [23, 32], we address the scalability issues. We propose two greedy algorithms that optimize monitor location cost and anomaly detection cost jointly. 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 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 of hundred of billions 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.

6.5 Advanced Management for New Generation Networks

Participants: Ayman Belghith, Bernard Cousin, Samer Lahoud, Thomas Legrand, Miklos Molnar.

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. Our team has studied the following.

Individual versus Global Radio Resource Management in a Hybrid Broadband Network Nowadays, with the abundance of diverse air interfaces in the same operating area, advanced Radio Resource Management (RRM) is vital to take advantage of the available system resources. In such a scenario, a mobile user will be able to connect concurrently to different wireless access networks. In [20], we consider the down-link of a hybrid network with two broadband Radio Access Technologies (RAT): WiMAX and WiFi. Two approaches are proposed to load-balance the traffic of every user between the two available RATs: an individual approach where mobile users selfishly strive to improve their performance and a global approach where resource allocation is made in a way to satisfy all mobile users. We devise for the individual approach a fully distributed resource management scheme portrayed as a non-cooperative game. We characterize the Nash equilibriums of the proposed RRM game and put forward a decentralized algorithm based on replicator dynamics to achieve those equilibriums. In the global approach, resources are assigned by the system in order to enhance global performances. For the two approaches, we show that after convergence, each user is connected to a single RAT which avoids costly traffic splitting between available RATs.

Spectrum Efficiency of WiMAX Scheduling Algorithms Scheduling algorithms are very important in WiMAX allowing an efficient radio resources distribution to the uplink and downlink connections. However, the IEEE 802.16 standard does not specify which scheduling algorithm(s) should be used. In [12], we propose a review of scheduling algorithms proposed for WiMAX / IEEE 802.16 system. We also propose some considerations for the spectrum efficiency computations of scheduling algorithms in WiMAX. Then, we calculate the satisfaction percentage and spectrum efficiency for three scheduling approaches. Figures are given for three scenarios (pessimistic, optimistic and realistic) allowing interesting observations about WiMAX radio efficiency. These results can be used as an order of magnitude for more sophisticated studies on this important topic.

Labelled OBS Architecture The evolution of optical transport networks is driven by continuously increasing traffic demand and Internet applications. Optical Burst Switching (OBS) architectures are considered to be promising solutions for coping with these trends. A comparison of three different OBS architectures is made, in terms of performance criteria, control and hardware complexity, fairness, resource utilization, and burst loss probability. Regarding burst losses, we distinguish the losses due to burst contentions from those due to contentions of Burst Control Packets (BCP). The simulation results in [21] show that as a counterpart of an its additional hardware complexity, the labelled OBS (L-OBS) is an efficient OBS architecture compared to a Conventional OBS (C-OBS) as well as in comparison with Offset Time-Emulated OBS (E-OBS).

Scheduling Algorithm for Sensor Networks In Wireless Sensor Networks, a tradeoff between the network lifetime (limited by energy power of sensors) and redundancy of actively sensing and communicating sensors (implicated by coverage requirements for the measured area) has to be established, typically in an over-deployed environment. This is achieved by scheduling algorithms which periodically alternate the state of sensors between "asleep" and "awake". Obviously, the period length of the periodical synchronized scheduling affects the network performance and lifetime. Controlled Greedy Sleep algorithm is a quasi-optimal synchronized sensor scheduling algorithm which increases network lifetime while maintaining correct functionality, based on local decisions of sensors. In [14] we investigate the optimization of the period length of this algorithm and highlights best practices with simulations. Studies have been performed within a ring topology and in random square topology.

Fast Packet Recovery for PULL-Based P2P Live Streaming Systems Peer-to-Peer (P2P) networks play an essential role in large scale live video transmission. Though many algorithms have been proposed to deal with packet loss in P2P networks, there is still a lack of mechanisms dealing with the delay and loss constraints of live video streaming. In [25, 24], we propose a new loss recovery mechanism allowing the quality optimization of live video transmitted on P2P networks. Its principal feature consists in request retransmission of lost packets from a peer different of the original packet sender. This mechanism increases the probability of choosing the best available peer to make the retransmission and hence, improves the received video quality before its display time. We show by simulations that the proposed solution is efficient in comparison with the current retransmission mechanisms. This solution is independent from the sender peer selection used algorithm.

6.6 Assessment of achievements

Participants: All participants.

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: multicasting, multi-constrained routing, multi-domain network, survivability, etc.

7 Contracts and Grants with Industry

7.1 Rapido

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 December 2011. The goals of this project are an efficient management of network resource when the 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 tierce party (network service broker), the lack of global information and the exponential combinatory 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.

7.2 NextTV4All

We are an active member of the NextTV4All project. This is a project co-financed by the French Government and Bretagne Region. The project has started in March 2008 and has ended in June 2010. The project partners are made of 10 organizations (Alcatel-Lucent, Orange, Thomson, Telecom Bretagne, NexCom, Neotilus, etc.). NextTV4all enriches the combination of services by taking into account the interactions between interpersonal and conversational audiovisual services and IPTV services. NextTV4all specifies and develops an enriched audiovisual content distribution system based on the IMS (IP Multimedia Subsystem). It supports Fixe Mobile Convergence both on network and services layers, ensuring the content is available anywhere anytime. The AtNet team is a main contributor, in this project, for the QoS guarantee of the unicast and multicast traffic generated by the IPTV services.

7.3 Orange R&D

We are supported by two Orange R&D grants: one on P2P video streaming and the second on flexible wavelength management in optical networks.

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.). We have participated to several 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.)

- 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 September2010. 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.
- Since the 2000s, we have very good and long-lasting ties with some international universities, namely Tunisia (Manouba University), Lebanon (Lebanese University), Ivoiry Coast (Cocody University) 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.

8.2 National Collaborations

We have 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 obvioulsy the Institut National des Sciences Appliquees (INSA) in Rennes.
- Most of our research projects have been labellized 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

Bernard Cousin has served in the program committees of :

- High Performance Switching and Routing Workshop (HPSR) Richardson, USA, 2010.

- Future Trend in Ad Hoc and Sensor Networks (FT-ASN), Hammamet, Tunisia, in May 2010.
- European Dependable Computing Conference (EDCC), Valencia, Spain, in 2010.
- Sécurité des Applications et des Réseaux et Sécurité des Systèmes dÍnformations (SAR-SSI) in 2010.
- Journées des Doctorants en Informatique et Réseaux (JDIR), Sophia-Antipolis, 2010.
- International Conference on Wireless and Ubiquitous Systems (ICWUS), Sousse, Tunisia, in 2010.

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

In 2010, Bernard Cousin has been a member in ten PhD committees (Four as reviewer):

- Hamza Drid, "Tolérance aux pannes dans les réseaux optiques de type WDM"
- Fen Zhou, "All-optical multicast routing in WDM networks"
- Aymen Khalil, "Cross Layer resource allocation for future high rate multicarrier UWB systems"
- Ahmad Ahmad, "Sécuritlé orientée utilisateur pour les réseaux personnels sans fil"
- Bogdan Uscumlic, "Optical architecture and traffic engineering in optical metropolitan networks"
- Nabil Ajam, "Privacy Protection for Location-based Services"
- Pierre Abu-Char, "A Dynamic Trust-based Context-aware Secure Authentication Framework for Pervasive Computing Environments"
- Thomas Guillet, "Sécuritlé de la téléphonie sur IP"
- Sahar Ghazal, "Quality of Service Management Model for Point to Multi-point Architecture in IEEE 802.16"
- Yiping Chen, "Locality-aware Peer-to-Peer Applications: Towards the Network-Friendly Content Distribution"

In 2010, Bernard Cousin has been a member in one HDR committee:

- Jean-Louis Rougier, "Routing and Traffic Engineeing in Networks"

Bernard Cousin also serves as FP7 expert in the committees of European Economic Community.

9.2 Conferences, seminars, and abroad invitations

- B. Cousin have been invited speakers at Global Photonics Conference en December 2010.
- M. Molnar has been invited to give three seminars at the University BME, Budapest in May 2009. He has been invited to give a talk about "Spanning Hierarchies" at the Departement of Computer Science and Information Theory, a seminar about "Recent Algorithms for Multicasting" at the Departement of Telecommunications and a seminar entitled "Combinatorial Optimization Problems in Next generation Networks" at the Department of Measurement and Information Systems.
- Hamza Drid has been invited to spend some weeks at the Department of Measurement and Information Systems of BME from July 2009 to August 2009.

9.3 Teaching

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

- Bernard Cousin teaches high speed networking, network security, network survivability, and multicasting at the Master level in the University of Rennes 1. He teaches an introduction to networking at the Licence level.
- Miklos Molnar is responsible of courses entitled "Object Oriented Modeling" and "Networks for Data Treatments and Multimedia" at the Department of Computer Science and the master lecture entitled "Software Quality" at the Department of Electrical Engineering and Computer Science of INSA.
- 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. He was also invited to write a scientific document on local networks [8] in the scientific review for engineers Techniques de l'ingénieur.
- M. Molnar is an elected member of the Council of the Computer Science Department at INSA.
- Bernard Cousin is also an elected member of the board ("Conseil d'administration") of the Computing Science department at University of Rennes 1.

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