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Abstract:

This deliverable describes the activity carried out during the first year of WP22. This work has been structured into Joint Activities (JA) by complementary partners.

Keyword list: MPLS, GMPLS, routing, optical networks, IP, electronic-optical convergence, BGP, PCE, path computation, protection, signaling

Clarification:

Nature of the Deliverable

R	Report
P	Prototype
D	Demonstrator
O	Other

Dissemination level of Deliverable:

PU	Public
PP	Restricted to other programme participants (including the Commission Services)
RE	Restricted to a group specified by the consortium (including the Commission Services)
CO	Confidential, only for members of the consortium (including the Commission Services)

Disclaimer

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1. Executive Summary

This document is the second deliverable of the work package 22 “Topical Project on MPLS, GMPLS and routing”. The overall purpose of WP22 is to research on key issues in the evolution of IP-MPLS multi-service networks to all-optical. Under this lemma a number of Joint Activities have been defined during the first year of BONE. These JAs mainly deal with open research topics such as path computation – both based on Path Computation Element (PCE) and on BGP extensions –, inter-domain optical networking issues, QoT-aware signalling, interoperability of MPLS and GMPLS sub-networks, multicast issues, different aspects of RWA and resilience in GMPLS, GMPLS and OPS, optimization of bidirectional signalling, etc.

As seen in this document most of the JAs have completed most of their objectives and hence minor additional result remain to be reported. Some others were started more recently and show very preliminary results.

2. Introduction

The current Joint Activities (JAs) defined under the scope of WP22 and the corresponding partners participating in them are the following (The JA responsible is shown in boldface):

1. "Scalability of Path Computation Elements (PCE)". Partners: **CTTC**, AGH, UST-IKR.
2. "BGP extensions for inter-domain TE in transport networks". Partners: **COM-DTU**, UC3M, BME, AGH.
3. "QoT-Aware GMPLS Control Plane. Partners: **SSSUP**, Orange Labs, CTTC.
4. "MPLS-ASON/GMPLS Interconnection". Partners: **UPC, UC3M**, AGH, FUB.
5. "Scalability issues in G/MPLS-based VPLS network design". Partners: **UC3M**, FUB, BME.
6. "GMPLS-based RWA algorithms for optical protection/restoration". Partners: **CTTC**, SSSUP, UPCT, FUB, RACTI, AIT, KTH, COM-DTU.
7. "Resilience Issues in the GMPLS-enabled Control Plane". Partners: **UPC**, AGH, BME
8. "Multi-domain provisioning/recovery within GMPLS all-optical networks". Partners: **CTTC**, UPC, Orange Labs, IBBT, AGH.
9. "GMPLS-based control plane for optical packet-based technologies". Partners: **UPC**, DEIS, UNIROMA3, AGH, COM
10. "Bidirectional service signaling in GMPLS networks". Partners: **SSSUP**, DTU Fotonik, UESSEX.

The following sections outline the work carried out in each of these JAs.

3. Scalability of Path Computation Elements (PCE)

The main macroscopic goal of the Joint Activity “Scalability of Path Computation Elements (PCE)” is to perform theoretical and experimental studies on the current PCE Architecture specifications, such as PCEP protocol extensions and TE efficiency. Moreover, several PCE implementation issues will be investigated, with particular focus on scalability and interoperability problems. The Joint Activity covers research on the applicability of a Path Computation Element for Wavelength Switched Optical Networks (WSON) and Ethernet-switched architectures, both from a single layer and from a multi-layer perspective. In particular, the joint activity will encompass tasks such as:

- To conceptually propose heuristics and algorithms for path computation and wavelength assignment. This could encompass RWA for more than one (independent) metric, or the combination of a objective metric plus a "bounding"-like metric e.g. optimize TE metric with the second metric (e.g. hop count) remaining below a given threshold.
- To validate the proposed algorithm(s) in simulation environments, obtaining key performance indicators.
- To validate the proposed algorithm(s) in real networks deploying a PCE as per current IETF drafts and RFCs.
- To evaluate partner’s prototypes and implementations in terms of scalability and performance.
- To propose adapted extensions addressing identified issues or drawbacks.

The JA on scalability aspects of path computation elements comprises three sub-activities. The first sub-activity includes the design and implementation of PCE entities along with related algorithmic aspects, while the second sub-activity includes the inter-operability of two different PCE implementations and the investigation of the scalability of a PCE. The third sub-activity is devoted to the design and evaluation of various routing strategies with QoS differentiation in a multilayer, single-domain network.

3.1 List of expected results

Within the context of the JA, expected results include publications on international major conferences and journals, as well as interoperability tests and validations, as well as the PCE-to-PCE gateway for interoperability. Scientific and technical dissemination activities (papers, workshops, seminars) cover the evaluation of the implemented path computation entities and algorithms, with a special focus on with respect to scalability parameters such as requests/sec, network size, etc.

3.2 Design and Implementation of a Path Computation Element

3.2.1 CTTC implementation

CTTC has implemented the Path Computation Element (PCE) within ADRENALINE testbed ® according to the IETF proposal RFC4655 and followed the according draft standards on the PCE protocol (PCEP, [JA1-1]). These standards include the definition of the PCE protocol necessary to request an optionally constraint path and depict the PCE architecture and its modules, respectively. The PCEP operates between two entities, the Path Computation Client (PCC) as well as the PCE acting as a server. The PCE may also take the role of a PCC, when requesting a path from another PCE. Especially in segmented networks or in inter-domain scenarios, this may occur. The implementation of the deployed PCE involves a single, multi-threaded and asynchronous process (Fig. JA1-1). One or more dedicated threads are responsible for updating the traffic engineering database (TE updaters), and another thread from a thread pool is responsible for the actual path computation, using a writer/readers lock. Upon acceptance of a connection, the Finite State Machine drives the PCEP protocol. Dynamic shared libraries provide pluggable algorithms, following an algorithm API (Application Programming Interface). The API allows abstracted access to the underlying TE database in form of a directed graph. Further, it allows the request for path computation to other PCE peers for cooperative path computation as in the BRPC. The PCE has been successfully used within a single domain for Shared Path Protection.

The PCE deployment model relies on a single PCE per OSPF area, co-located in an OCC. The deployed synchronization mechanism with the Traffic Engineering database (TEDB), although coupled to a Routing Controller (RC) is non-intrusive. By sniffing OSPF-TE traffic, the PCE constructs a dedicated (i.e. not shared) database by means of stateful inspection of TE Link sub-TLVs contained within OSPF-TE Link State Updates, passively reusing the OSPF-TE dissemination mechanism and not requiring the creation of an additional listener adjacency. The PCE performs ABR discovery by parsing OSPF-TE type 3 Summary-LSAs, which announce reachability information towards both the source and the destination. The implemented API allows us the introduction of different TE algorithm both for RWA in optical Networks with Shared Path Protection, and Multidomain Path Computation with BRPC (Multi-area and multi-AS).

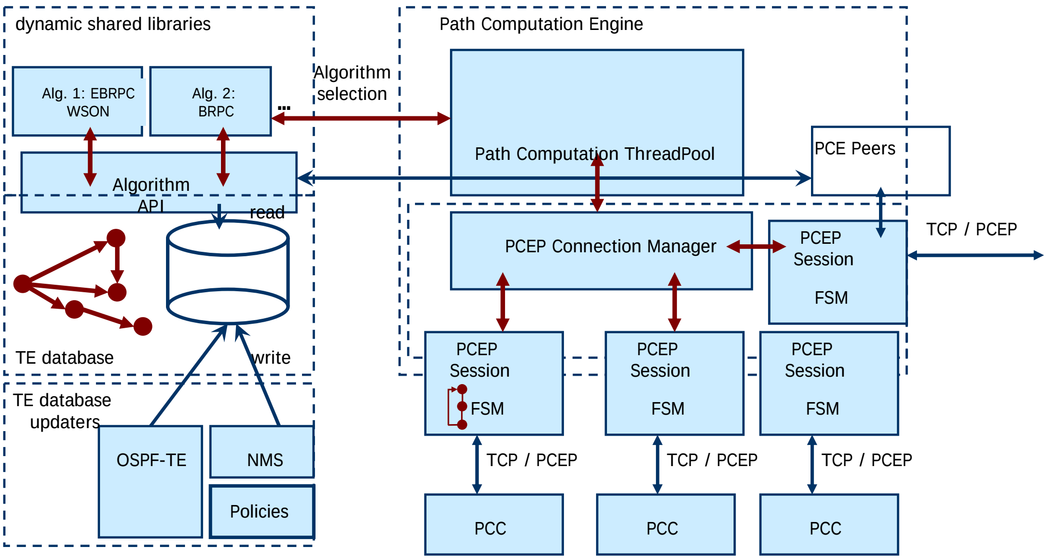


Figure JA1-1 PCE functional architecture

3.2.2 UST/IKR implementation

UST-IKR has setup the Network Aware Resource Broker (NARB) implementation of the Dragon project [JA1-2, JA1-4]. The NARB implementation includes a topology manager as well as a Resource Computation Element (RCE). Both together, offer the functionality of a PCE. A path request follows the protocol specification of the NARB API [JA1-3]. It defines the NARB Api for a client/server communication, while the NARB itself may also act as a client, if requesting a path from another NARB.

3.3 Interoperability of CTTC IETF PCE implementation and UST-IKR Dragon PCE implementation

The task of this sub-activity works out a gateway device, which enables the seamless inter-operability between the IETF PCE implementation and the implementation of the NARB. Figure JA1-2 depicts this scenario. On the left side, the IETF PCE implementation communicates with the gateway device using PCEP. On the right side, the NARB implementation uses the NARB Api to communicate with the gateway. The gateway in between handles the messages exchange between both entities in an inter-domain scenario of domain A and domain B. Within this activity, we have planned to show the following inter-operability functionality:

- Simple path computation request including a source and destination address, as well as a required capacity, switching capability and encoding
- Inter-domain path computation request originating in the NARB network destined in the PCE network
- Inter-domain path computation request originating in the PCE network destined in the NARB network

These inter-operability functions require the implementation of the following functionality in the gateway:

- PCEP functionality
    1. Session initialization phase
    2. Keep alive messages
    3. Reception of PCEP requests
    4. Translation of PCEP requests in NARB requests
    5. Translation of NARB replies in PCEP replies
    6. Sending of PCEP replies
- NARB functionality
    1. Reception of NARB requests
    2. Translation of NARB requests in PCEP requests
    3. Translation of PCEP replies in NARB replies
    4. Sending of NARB replies

The Dragon project as already implemented the NARB functionality of the sending and receiving of NARB messages. Thus, we reuse this functionality in the gateway and concentrate on the implementation of the PCEP functionality. In the current state, we finalize the implementations of this part and aim for testing our implementation

Once the implementations are over, the joint activity will proceed with the interconnection of PCE entities. For this purpose, CTTC and IKR already exchanged PCEP traces obtained from CTTC. The interconnection will allow us to run interoperability tests on a first step, and to investigate scalability using measurement data.

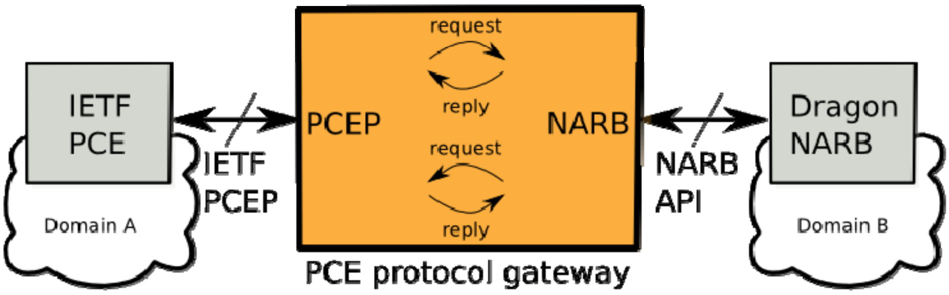


Figure JA1-2 NARB/PCE interoperation scenario

3.4 AGH-UST Evaluation of PCE architectures in a multilayer, single-domain network.

The main goal of this subactivity is to propose and evaluate several routing strategies in a multilayer, single domain network. The proposed routing strategies are based on centralized Path Computation Element (PCE). The PCE will gather information about the state of the network, process it and select a path for a given request. The arriving requests are not known in advance, i.e., the fully dynamic scenario is assumed. The PCE's task is to find a path for a request in a way, which allow to guarantee transport of data with given throughput and delay values. It is assumed that requests may be categorized into three categories: with high, medium and low required throughput. Moreover, some of them should be conveyed with minimal delay, while for others it is not a crucial parameter. As a result, the essential parameters of a request are: concatenation of throughput, delay, identification of source and destination node. It is assumed that the node is composed of the electrical and optical subcomponents. The optical part may establish a lightpath for a given request, while the electronic component ensures transport of data stream throughout the established lightpaths. The physical topology of a network is based on the Pan-European network shown in Fig. JA1-3.

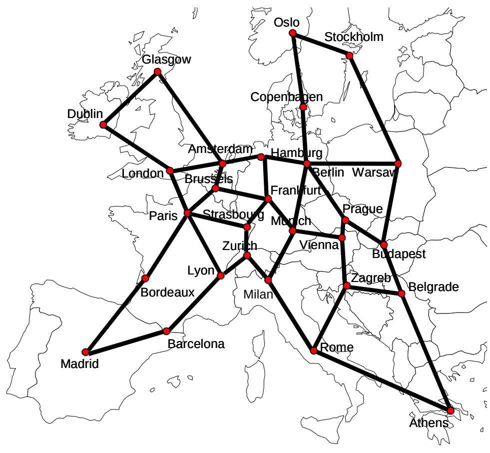


Figure JA1-3 The reference network used in the study

It is assumed that the routing strategies will be based on some heuristics and will be evaluated through simulation studies. The simulation environment is based on the OMNeT++ simulator.

3.5 Conference Calls and meetings

To date, we have had several conference calls to define the scope and participants of the Joint activity, as well as to define a preliminary set of tasks for the first year. Likewise, there have been several meetings to discuss the status and evolution of the JA, focusing on development and targeted functionalities. The meetings took place during ONDM2008 and ICTON 2008 conferences, as well as during BONE plenary meetings.

3.6 Main results and publications

3.6.1 Non-joint publications

- R. Casellas, R. Muñoz, R. Martínez, "A Path Computation Element for Shared Path Protection in GMPLS-enabled Wavelength Switched Optical Networks", in Proc. 34th European Conference on Optical Communications, ECOC2008, Brussels, (Belgium) September 20-25 2008.
- R. Casellas, R. Martínez, R. Muñoz, "Design, implementation and validation within ADRENALINE® testbed of a Path Computation Element for Wavelength Switched Optical Networks", in Proc. 4th International Conference on IP over Optical (iPOP2008), Toklyo (Japan), June 2008.

3.6.2 Joint publications

- R. Casellas, R. Martínez, R. Muñoz, S. Gunreben, "Enhanced BRPC for multi-domain PCE-based path computation in Wavelength Switched Optical Networks under Wavelength Continuity Constraint", submitted to Journal of Optical Networking (JON) special issue on Optical Networks for the future Internet, October 2008.

3.7 References

[JA1-1] Vasseur et al., Path Computation Element (PCE) Communication Protocol (PCEP), draft-ietf-pce-pcep-18.txt, November, 2008

[JA1-2] DRAGON Project, "Dynamic Resource Allocation via GMPLS Optical Networks," http://dragon.maxgigapop.net.

[JA1-3] Network Aware Resource Broker (NARB) - Design and User Manual, University of Southern California (USC), Information Sciences Institute (ISI), Version 1.1, June 2006

[JA1-4] Network Aware Resource Broker (NARB) and Resource Computation Element (RCE) Architecture, University of Southern California (USC), Information Sciences Institute (ISI), Version 1a, May 2006

4. BGP extensions for inter-domain TE in transport networks

4.1 Objective

The objective of this JA is to investigate theoretically and via simulations the efficiency of different extension of the BGP protocol in support of multi-domain Label Switched Path establishment with QoS and /or resilience provisioning. The activity focuses on identifying possible BGP extensions for support of interconnected ASON/GMPLS networks, as well as elaborates on policy-exchange mechanisms which support inter-domain TE and QoS provisioning across transport networks.

4.2 Description

The JA is divided in two main parts. The first part focuses on the modification of the BGP for achieving different TE capabilities such as increased survivability and/or QoS support. This part is related to the dynamics of the network operation and thus the efficiency of the proposed algorithms and BGP modifications are to be shown experimentally via simulations. The second part of the activity focuses on different political aspects of TE-oriented interconnections between transport networks. Different export policies as well as their effect on the QoS provisioning are to be investigated. This part of the activity focuses on algorithms facilitating the design of networks and thus the used methodology will be applying and designing mathematical models, focused on the optimization of different aspects of the design and operation of the multi-domain networks.

4.3 Current results

The following specific topics have been covered by the JA so far: 1) BGP modifications for end-to-end TE support and multi-path dissemination for survivability support (COM DTU); 2) BGP modifications for AS disjoint path dissemination for survivability support (UC3M, BME, COM DTU), and 3) Least Cost Routing (LCR) solution for inter-domain traffic distribution (AGH).

4.3.1 BGP modifications for TE support (COM DTU)

The implementation of the BGP modifications has been done in an event driven simulator (OPNET), which is flexible and can be used for evaluation of different BGP modifications in real network environments (i.e. dynamic not static environments). The BGP modeler is complemented with an RSVP-TE model which combined with the implemented BGP engine can be used for evaluation of the real effect of different modifications on the operation of a multi-domain GMPLS network and the efficiency of the routing protocol itself.

Several extensions to the BGP protocol have been suggested, implemented and tested. The main objective is automatic TE support across multiple dynamic GMPLS domains. Two main BGP enhancements have been proposed: disseminating end-to-end TE information per path and disseminating additional path attribute, specifying the border nodes of the path. Furthermore, the suggestion for using the BGP protocol only as a dissemination protocol and not as a path selection one has been evaluated. Three different strategies for TE support can be applied having implemented the stated extensions:

1. Using the end-to-end TE metric as a first decision criterion under the BGP path selection phase (***BGP TE case 1***);
2. Using the end-to-end TE metric as a first tie-breaking criterion under the BGP path selection phase (***BGP TE case 2***);
3. Using the end-to-end TE metric as the only decision criterion without implementing the traditional BGP path selection (***Enhanced BGP***).

For the last case due to scalability considerations it is important that suitable export policies are applied in the multi-domain network. Several such policies have been designed.

The results from applying the stated strategies in a dynamic network can be seen on Fig. JA2-1, which illustrates the blocking probability of LSP requests with varying load in a multi-domain mesh network. ***BGP TE case 3*** refers to the case where the Multi-Exit-Discriminator is used in the BGP path selection with the "Always compare" policy. Normalized load of 2 indicates the maximum input load per node. From the figure it can be seen that the proposed ***Enhanced BGP*** scheme, which includes all modifications, performs the best. An interesting result is that ***BGP TE case 1*** performs the worst which is due to the greediness of the approach and the inherent BGP drawback of path dependency.

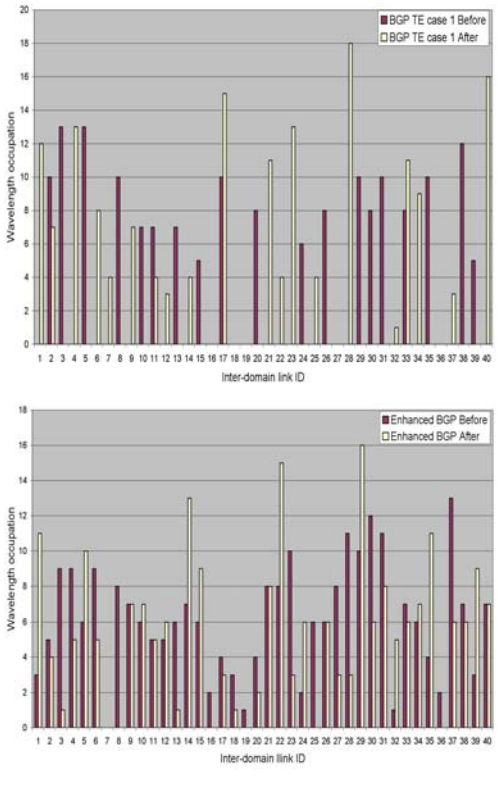


Figure JA2-3 Wavelength occupations before and after re-convergence for BGP TE case 1 and Enhanced BGP schemes

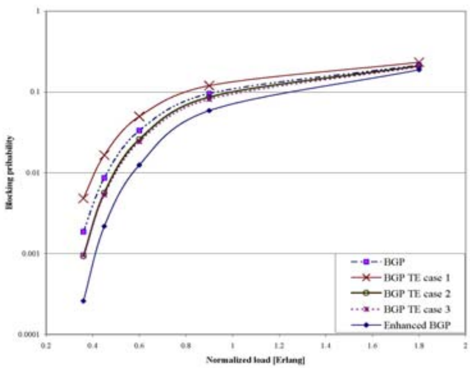
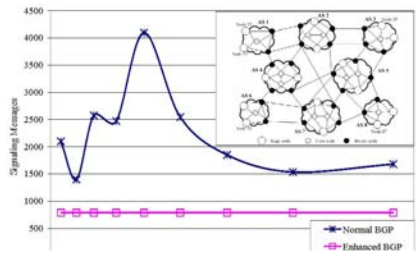


Figure JA2-1 Blocking probability vs. Normalized Load



The efficiency of the modified BGP protocol was also evaluated in terms of needed overhead for re-convergence of the protocol in order to accommodate any changes in the TE state of the disseminated paths. Fig. JA2-2 illustrates the result. The stable operation of the ***Enhanced BGP*** is evident, whereas the normal BGP operation has unpredictable overhead. Next, Fig.

JA2-3 illustrates how the ***Enhanced BGP*** copes with one of the biggest BGP drawbacks[1] – the path dependency, which leads to not using many of the inter-domain links.

Using ***BGP TE case 1*** strategy many of the inter-domain resources are used either only before or only after re-convergence, whereas the ***Enhanced BGP*** utilizes them continuously. The blocking probabilities for the illustrated simulation runs are 0.048 for ***BGP TE case 1*** and 0.014 for the ***Enhanced BGP*** respectively.

4.3.2 BGP modifications for AS disjoint path dissemination (UC3M)

During this year a mobility action between has been made. Anna Vasileva Manolova form DTU.COM visited University Carlos III of Madrid. The goal of the visit was to work on a joint paper which adapts the DTU BGP model simulator to the UC3M BGP decision process proposal for AS disjoint path dissemination. The main issue of that proposal is to obtain the normal BGP AS_PATH and a disjoint AS_PATH for all BGP speakers for every destination to improve the survivability of the network. Figure JA2-4 shows a schema of the proposed mechanism which is further explained in the 4th submitted publication (see list of submitted publications, Sec. 4.5).

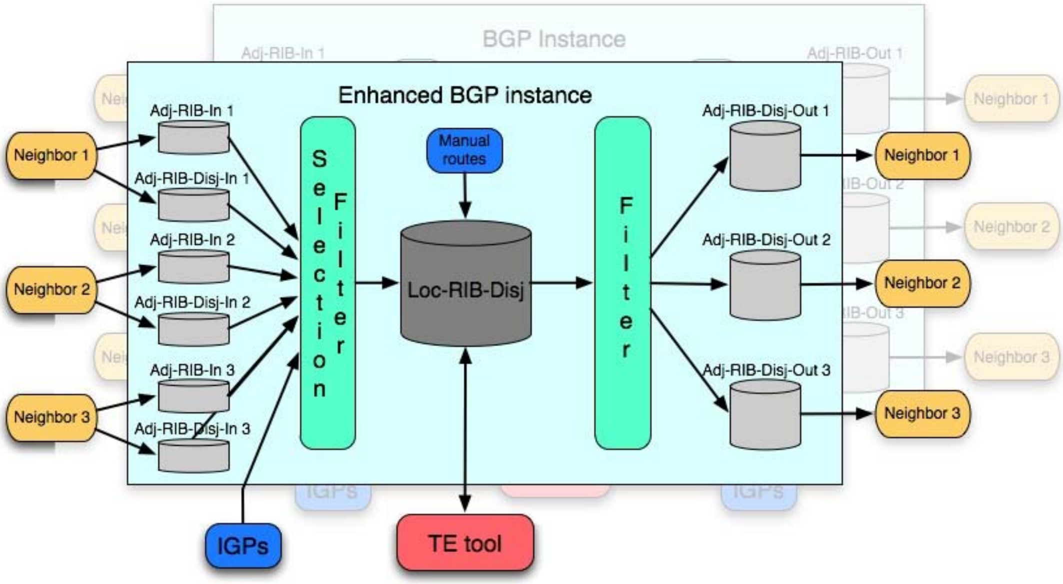


Figure JA2-4 Proposed selection mechanism scheme for disjoint AS_PATH dissemination

During the visit, the implementation of the new proposal in the simulator has been done. The simulation scenarios, covering different possible situations, have been defined as well. Several related issues, such as applying clustering for enhanced survivability and respectively cluster definition and optimisation, will be subject to future collaboration, which is planned to be done during the first half of 2009 in the form of a second mobility action between UC3M and COM DTU.

[1] Drawback when BGP is applied in optical networks. For further explanation please refer to the submitted publications and the references therein.

4.3.3 Least Cost Routing (LCR) solution for inter-domain traffic distribution (AGH)

Development of Next Generation Networks leads to a multiservice transport layer within a multi-domain environment. In such a context the interconnection of multiple network providers for offering global connectivity becomes the next important step. In this new situation network providers face many deployment options, such as interprovider traffic engineering approaches, methods for guaranteeing coherent QoS across providers' boundaries and new business models for offered services.

As the number of potential interconnection partners increases, operators face more and more routing alternatives. The applied business models are also an important part of the inter-domain issue. Network service providers often negotiate special interconnection agreements and tariffs to provide the best services to their end-customers. However, changes in tariff plans, which are complex and may use highly granular pricing models, should be considered as a characteristic feature of this market. These characteristics and the explosive growth in the voice and data traffic lead carriers to deploy new connection routing models since the business environment becomes very dynamic and routing changes are required in shorter time frames.

Therefore, the need for developing algorithms supporting the choice of optimal interconnection routes becomes crucial. To help it the concept of the Least Cost Routing (LCR) solution has been proposed (See Figure JA2-5).

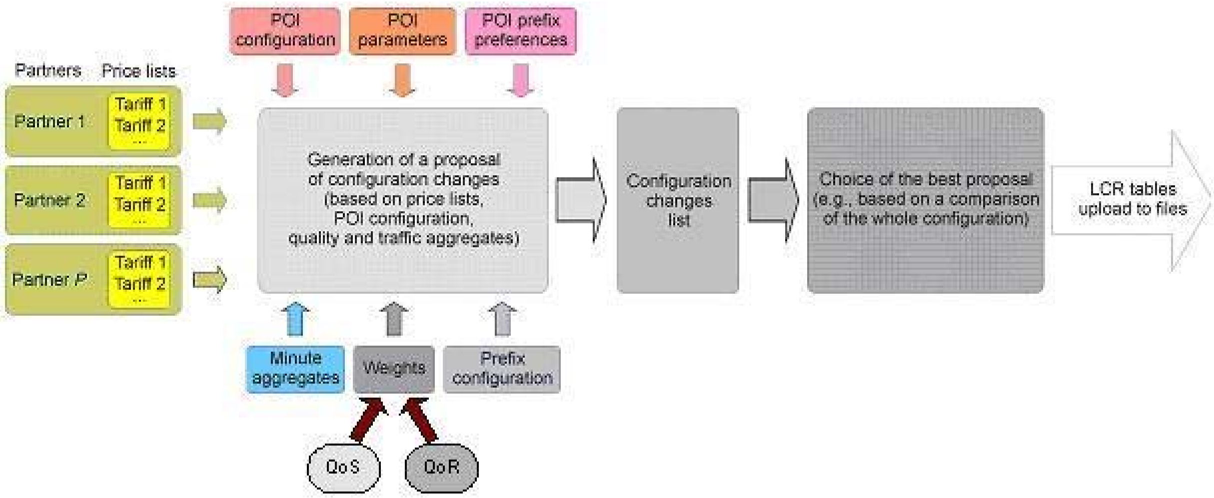


Figure JA2-5 LCR solution

To determine the optimal routes the implemented algorithms take into account multiple network-based parameters like operators' price lists, network configuration, traffic history, etc. The most important parameter for choosing the routes is the interconnection cost (given in tariffs as the price per time/volume unit). Based on a series of reference data, the heuristic algorithms implemented in LCR find automatically the optimal route configurations for all interconnect traffic, assigning the most appropriate Points of Interconnection (POI) for specific traffic directions and termination points.

The solution helps to optimize connections between telecommunication operators by minimizing costs for served demands and maximizing efficient use of the existing network infrastructure. By using the results of LCR algorithms, the routing strategy can be more efficiently executed by incorporating the knowledge of the connection cost with network conditions. The usage of the LCR solution can also shorten time needed to analyze a huge number of alternatives and help a carrier make decisions considering new agreements with other carriers within a dynamic framework. The results of the proposed solution help also a carrier to track which traffic routes generate the highest revenues.

4.4 Publications list

Accepted:

1. M. KANTOR, K. WAJDA, "Inter-domain traffic optimization in resilient Next Generation Network environment", NOC conference, July 2008, Krems, Austria.
2. M. KANTOR, P. CHOLDA, A. JAJSZCZYK, "LCR Solution for Interdomain Traffic Distribution", FITraMEn conference, December 2008, Porto, Portugal.

Submitted:

1. A. Manolova, S. Ruepp, J. Buron, L. Dittmann, "On the Efficiency of BGP-TE Extensions for GMPLS Multi-Domain Routing", submitted to ONDM 2009
2. A. Manolova, S. Ruepp, L. Dittmann, "TE-enhanced Path Selection for QoS Provisioning in Multi-Domain GMPLS Networks", submitted to OFC 2009
3. A. Manolova, S. Ruepp, L. Dittmann, "Enhanced BGP for PCE Support in Multi-Domain GMPLS Networks", submitted to ICC 2009
4. R. Romeral, D. Larrabeiti, M Uruena, T. Cincler, J Szigeti, "Enabling disjoint AS path computation in BGP-based GMPLS multi-domain optical internetworking", submitted to Journal of Optical Networking.

5. QoT-Aware GMPLS Control Plane

Novel solutions for guaranteeing quality of transmission (QoT) in GMPLS-controlled transparent optical networks have been investigated in this JA. A joint paper, "Probe-based Schemes to Guarantee Lightpath Quality of Transmission (QoT) in Transparent Optical Networks", by N. Sambo, F. Cugini, I. Cerutti, L. Valcarenghi, P. Castoldi, E. Le Rouzic and C. Pinart, has been published at ECOC 2008, Brussels. In particular, the proposed solutions are based on probe traffic measurements before actually activating a lightpath. In transparent dynamic optical networks, activation of lightpath for data transmission requires that lightpath quality of transmission (QoT) is ensured. In [JA3-1], GMPLS routing and signaling protocol extensions are proposed for estimating the lightpath QoT prior to lightpath set-up procedure. However, lightpath QoT estimation may be inaccurate.

In [JA3-2], an enhanced version of the routing-based scheme, namely Create-and-Wait (CW) scheme, is proposed. In CW, relevant QoT parameters are collected by the monitoring equipment and flooded by the routing protocol within hundreds of ms. Upon a lightpath request, an OSNR-based or Q-factor-based model estimates the expected lightpath QoT (e.g., estimated Bit Error Rate (BER)). When the estimated QoT meets the required QoT level, the lightpath set up procedure is triggered. The main feature of the CW scheme is the generation of probe traffic, to be transmitted on the lightpath prior to activation (i.e., data transmission). The QoT measurements (e.g., BER) taken on the probe traffic at the destination can validate the estimated QoT. If the measured QoT does not meet the required QoT level, the lightpath is torn down and a successive set up attempt is triggered on a different route.

When using CW scheme, acceptable QoT is always guaranteed for each activated lightpath. However, OSNR-based QoT models, that take into account multiple physical impairments, are complex and may need a large amount of QoT-related information. This may negatively impact the control plane stability and scalability. Moreover, OSNR-based model may require complex and expensive monitoring equipment. Furthermore, some physical impairments (e.g., non-linear impairments) are difficult to model and to relate to OSNR.

Two different schemes, based on probe traffic measurements, have been proposed and evaluated in this JA. The proposed probe-based schemes reduce the CW scheme implementation complexity. The advertisement of QoT information and the models for QoT estimation are either simplified (by using an equivalent-length model) or avoided.

5.1 Proposed Probe-based Schemes

The first proposed scheme is referred to as Equivalent-Length Probe Scheme (EL-PS). In EL-PS, the Equivalent Length (EL, [JA3-3]) is the only QoT parameter. The EL value for each network link is typically static and advertised by the routing protocol with EL extensions [JA3-3]. In EL-PS, lightpath QoT is estimated by linearly combining the EL values of the traversed links. If the total EL is below a predefined Maximum EL (M_{EL}) threshold, the lightpath set up is triggered and the probe traffic is transmitted over the established (not yet activated) lightpath.

The second proposed scheme is called Probe Scheme (PS). In PS, no QoT estimation is carried out, i.e., no need for routing protocol extensions. Lightpath set up procedure is triggered for each lightpath requests. Then, QoT is evaluated by means of the probe traffic measurements.

In both schemes, if the probe measurement meets the required QoT level, the lightpath is activated for data transmission. Otherwise, another set up attempt is triggered on a different route. Probe measurements are performed using the Link Management Protocol (LMP). In particular, the LMP Link Connectivity Verification procedure transmits a LMP Test message (i.e., a pre-defined sequence of bits), over the lightpath not yet activated. BER measurements taken at the destination node are reported to the source node in the LMP BER Estimate field defined in [JA3-4].

5.2 Simulation results

The performance of the proposed EL-PS and PS schemes is evaluated by means of a custom C++ event-driven simulator. A Pan-European topology with 32 links and 17 nodes is considered [JA3-5]. Lightpath requests are generated following a Poisson process and uniformly distributed among all node pairs. Lightpath routes are randomly selected between the shortest paths in terms of number of traversed hops. Lightpath wavelength selection is first fit. The considered EL value is the link length expressed in km while the EL threshold M_{EL} is selected as the length that guarantees that lightpaths with acceptable QoT are never rejected. QoT measurement values are emulated considering the OSNR-based QoT model utilized in [JA3-5], taking into account Amplifier Spontaneous Emission (ASE), Polarization Mode Dispersion (PMD), chromatic dispersion, and self-phase modulation. Among the considered physical impairments, ASE and PMD are the most stringent for QoT. When QoT is not met or not enough resources are available in the network, lightpath set up is blocked and up to 2 additional set up attempts are triggered. Two different physical networks are considered for the Pan-European topology. The first one, N_A, is a realistic worst case scenario where a percentage (P_A=79%) of shortest routes traversing a number of hops equal to the network diameter (D=5) is unable to meet QoT requirements. In the second one, N_B, the link impairments are less detrimental, i.e. P_B=24%. Two different equipment scenarios are considered, S_1 and S_2, which represent a lower and upper bound on expected equipment performance.

Table JA3-1 summarizes the main lightpath set up operations including probe traffic generation and QoT measurement, in the two considered scenarios (i.e., t_1=500 ms in S_1 and t_2=10 s in S_2).

Fig. JA3-1 and JA3-2 show the lightpath blocking probability of EL-PS and PS schemes at the n-th set up attempt ($n \leq 3$) in scenario S_2 versus the network load, for network N_A and N_B, respectively. Fig. 1 shows that the EL-PS scheme outperforms the PS scheme especially after the first set up attempt. However, also the EL-PS scheme presents relevant blocking probability contributions especially at the first set up attempt. This is due to the M_{EL} selection policy, which has the counter effect that some lightpaths with acceptable EL-estimated QoT may be rejected during the probe-based QoT measurement. Fig. JA3-2 shows that the PS scheme is outperformed by the EL-PS scheme also in N_B. However, the performance gap between the two schemes is narrower and almost negligible after the first set up attempt. Moreover, results show that, by exploiting successive set up attempts, the overall blocking probability decreases. However, when n increases from 2 to 3 only marginal reduction of blocking is achieved. This indicates that two set up attempts may be a good tradeoff between performance and set up time. Similar blocking probability is also achieved by S_2 scenario (not included for space reason).

Table JA3-1: Lightpath set up operations

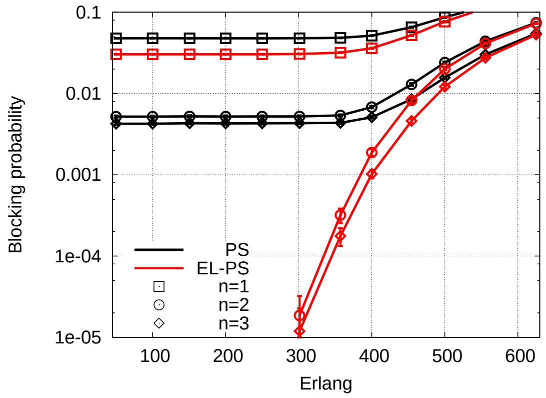


Fig JA3-1: Network NA: Blocking probability at the n-th set up attempt.

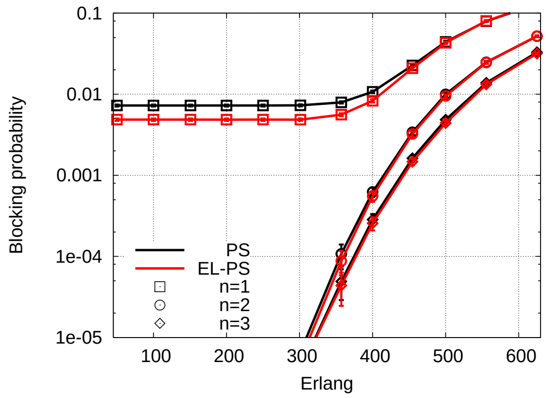


Fig JA3-2: Network NB: Blocking probability at the n-th set up attempt.

	S_1 [ms]	**S_2 [ms]**
Laser power & frequency setting at Tx	50	1000
Traversed node switching (e.g., WSS)	45	1000
Propagation time (1000 km)	5	5
Probe synchr. & acquisition at Rx	250	7000
Probe QoT measurement (e.g., BER)	150	1000
Total	**500**	**~10000**

Table JA3-2: Network N_A: Average lightpath set up time

	S_1 (t_1=500ms) [s]		**S_2 (t_2=10s) [s]**	
	All	D hops	All	D hops
EL-PS	0.53	0.54	10.3	10.3
PS	0.54	0.60	10.4	11.4

S_1 and S_2 scenarios differ in terms of the average time required to complete the lightpath set up (in Table JA3-2, for network NA). Results show that the EL-PS scheme performs better than the PS scheme in case of long lightpaths, i.e., traversing D nodes. However, the overall average set up times are similar in S_1 and S_2 scenarios**.**

5.3 *Conclusions and Future works*

In this JA, two lightpath set up schemes based on probe traffic measurements, with or without a priori QoT estimation, have been proposed and investigated, aimed at guaranteeing the required lightpath QoT in GMPLS transparent networks. Results show that the proposed PS achieves good performance without requiring protocol extensions for QoT, especially in transparent networks with few QoT impaired routes.

Currently, the study is oriented to the analysis of probe schemes accounting for multi-layer performance information (e.g., packet loss rate, bit error rate).

A joint paper, "Signaling and Multi-layer Probe-based Schemes for guaranteeing QoT in GMPLS Transparent Networks", by N. Sambo, C. Pinart, E. Le Rouzic, F. Cugini, L. Valcarenghi and P. Castoldi has been submitted to OFC 2009.

5.4 Reference

[JA3-1] R. Martinez, C. Pinart, F. Cugini, N. Andriolli, L. Valcarenghi, P. Castoldi, L. Wosinska, J. Cornelias, G. Junyent, "Challenges and requirements for introducing impairment-awareness into the management and control planes of ASON/GMPLS WDM networks", Com Mag, Vol. 44, Dec. '06.

[JA3-2] C. Pinart, E. Le Rouzic, I. Martinez, "Physical-Layer Considerations for The Realistic Deployment of Impairment-Aware Connection Provisioning", ICTON Conf., June '07.

[JA3-3] J. Strand, A. Chiu, "Impairments and Other Constraints on Optical Layer Routing" RFC 4054, May '05.

[JA3-4] A. Fredette, J. Lang, "Link Management Protocol (LMP) for Dense Wavelength Division Multiplexing (DWDM) Optical Line Systems" RFC 4209, Oct '05.

[JA3-5] F. Cugini, N. Sambo, N. Andriolli, A. Giorgetti, L. Valcarenghi, P. Castoldi, "GMPLS extensions to Encompass Shared-Regenerator in Transparent Optical Networks", ECOC Conf., Sept. '07.

6. MPLS-ASON/GMPLS Interconnection

6.1 Objectives

The main objectives of this joint activity are:

- To define and test extensions in order to extend protection mechanisms already defined for the intra-domain scenario, to the multilayer and multidomain scenario.
- To define failure notification mechanisms in multilayer and multidomain scenarios.
- To define multilayer, multidomain e2e diverse LSP signallig.

6.2 Description

In this activity, we consider a scenario with MPLS islands belonging to the same MPLS domain connected through one ASON/GMPLS domain (Figure JA4-1). We assume that different operators manage MPLS and ASON/GMPLS networks; therefore, we are in a multi-domain scenario. The exchange of topology information between client and server networks has to be restricted, due to administrative and security reasons. Hence, the overlay model, designed for a business model in which one optical core operator lease its network facilities to Internet service providers (ISPs), should be applied.

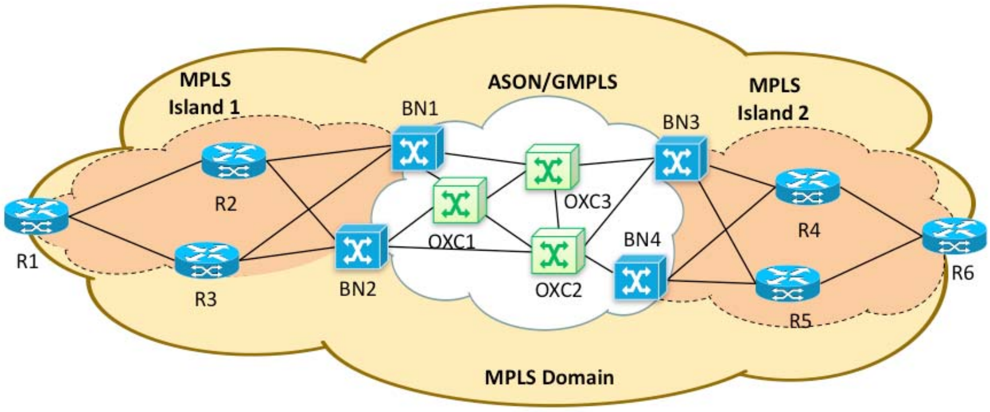


Figure JA4-1 Multi-domain MPLS ASON/GMPLS network

Both network technologies, MPLS and ASON/GMPLS, provide intra-domain recovery mechanisms able to recover LSPs from failures over resources strictly in that domain. For example, in MPLS fast reroute mechanisms can be used to recover MPLS LSPs from failures in that network; whereas a wider variety of mechanisms have been proposed to be used in ASON GMPLS networks.

However, when the resource in failure is a border node, it is not clear how the different layers have to become coordinated and which domain has to provide the recovery mechanism. This case can be extended to a more general case in which when the server layer cannot provide the needed recovery after the detection of an intra-domain failure, communicates this event to the client layer to provide recover in the client layer.

Therefore, the objectives of this activity are to define and test extensions in order to extend protection mechanisms already defined for the intra-domain scenario, to the multilayer and multi-domain scenario which has been presented. Moreover, specific analysis has to be done in the multi-domain diverse routing.

6.3 Current state of the Joint Activity

To start studying and comparing the different possible solutions to the problem and it performs a test-bed will be used. This test-bed is almost ready to be used. Emulated Cisco MPLS network is performed in an application server. In this network a standard RSVP-TE signaling is used, the same that Cisco use in them routers. This network will be connected to the ASON/GMPLS network via the Spain Research Network. ASON/GMPLS network is done with optical switches and special border nodes that allow connect a virtual-circuit switched network (MPLS/IP network) to a pure-circuit switched network (optical ASON/GMPLS network). The scheme of these nodes is presented in figure JA4-2.

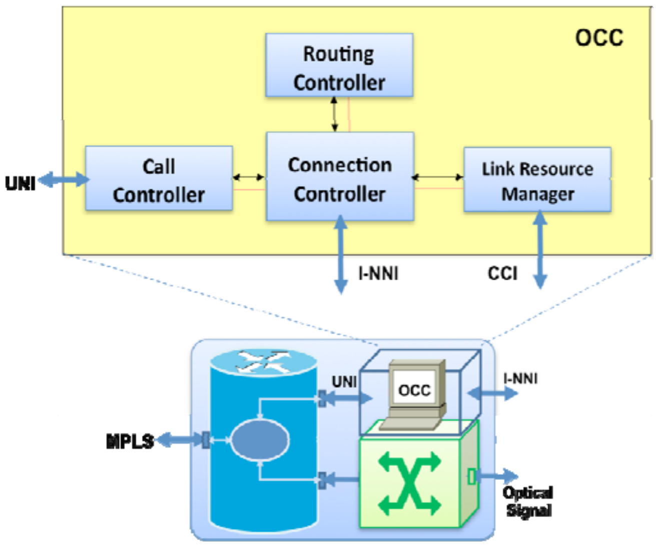


Figure JA4-2 Modules of the border nodes

A Quagga implementation of different aspects of RSVP-TE is used in the ASON/GMPLS network to make the LSPs. RSVP-TE interoperation issues will be studied between the two used versions too.

7. Scalability issues in G/MPLS-based VPLS network design

7.1 Motivation and goals

A major current challenge for the evolution of the VPLS (Virtual Private LAN Service) from a MPLS-based implementation to an eventual all optical GMPLS one is solving the scalability problem that derives from the connection-oriented nature of this technology. One of the open questions is how to provide the LAN's broadcast emulation in an efficient way given the fact that in principle there must be a different delivery tree per VPLS, which implicitly means that there must be LAN-specific forwarding information inside the core of the VPLS Service Provider network. This is a major design target of VPLS provisioning over connection-oriented networks: all VPN-specific information must remain in the edge nodes. Otherwise the state in core routers explodes. If this is a concern in MPLS, the problem is more complex in the optical case. The amount of lightpath switching entries is much more limited than in the electronic domain and so is the number of available optical multipoint units. Therefore, traffic engineering and grooming methods are necessary to take full advantage of optical technology in a cost-effective way.

On the other hand, if several optical service provider networks are involved, VPLS interconnection across multiple domains may require optical processing of stacked labels which is another open research issue. This JA addresses all these issues and will study the alternatives, and will propose practical solutions to these questions.

7.2 Status of development and summary of results

The joint activity in this JA started with a certain delay and thus the results in terms of publications are also suffering some delay, but the completion of objectives is expected in due date.

7.2.1 Intelligent aggregation of VPLS.

MPLS-based VPN services are gaining momentum, and also the trend to use corporative high-quality IP multipoint videoconferencing, streaming, multimedia news or bulk file/disk replication over the companies PCs. The challenge is much more complex in the VPN context for two main reasons: the multipoint-to-multipoint requirement and the hard trade-off between network state and bandwidth utilization, stressed by the fact that the backbone must support an overlay of isolated virtually private multicast trees. Moreover, even if the IP Multicast service is not required, the ethernet multicast and broadcast emulation is still needed in the case of the multi-site layer-2 VPN. This is the context where P2MP LSPs may save a lot of bandwidth for the SP; and the saving must be justified against the increase of forwarding entries in core routers. As we shall review, experts have surrendered to the evidence that only intelligent aggregation of multiple VPNs into the same multicast/broadcast tree can yield important bandwidth savings at a reasonable cost. How this partition and allocation of VPNs to trees should be made is an open research issue, given the diversity of topologies, traffic and sites of different VPNs. On the other hand, highrate flows may justify the set up of group membership-aware multicast trees to eliminate traffic in nodes not leading to group receivers.

In this joint activity we have continued the work started in e-photon/one+, with the inclusion of a study of the impact of intelligent aggregation of VPNs in bandwidth and forwarding state efficiency. This study is not limited to reference topologies but also tries to assess the results in real backbone topologies.

The following figures show several examples of the type of simulations being carried out. Figure JA5-1 illustrates the gain due to intelligent aggregation for different aggregation degrees (0% means no tree aggregation, 100% means a single shared tree) and also the effect of reconfiguration (dynamic re-organisation of trees), for a density of 25% (the probability of a PE belonging to a given VPLS is 0.25).

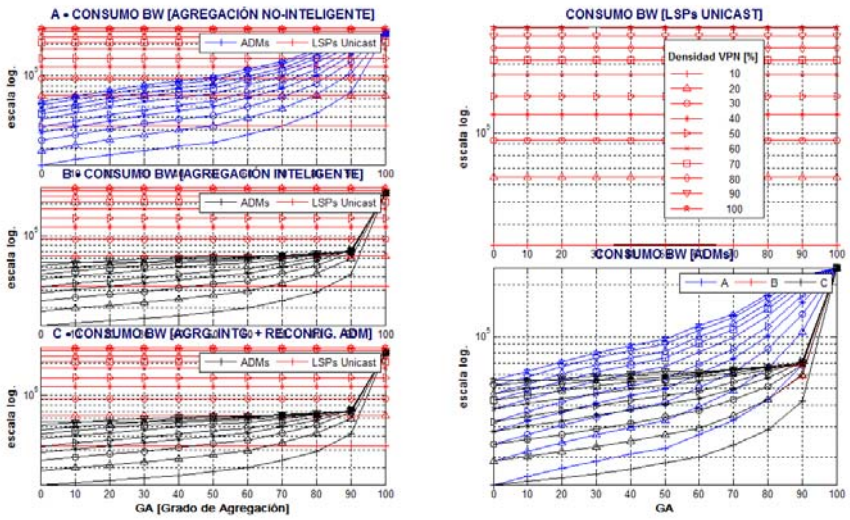


Fig JA5-1. Bandwidth consumption in Tiscali network for 25% of VPLS member density

Figure JA5-2 shows the same parameters for a 75% VPLS density.

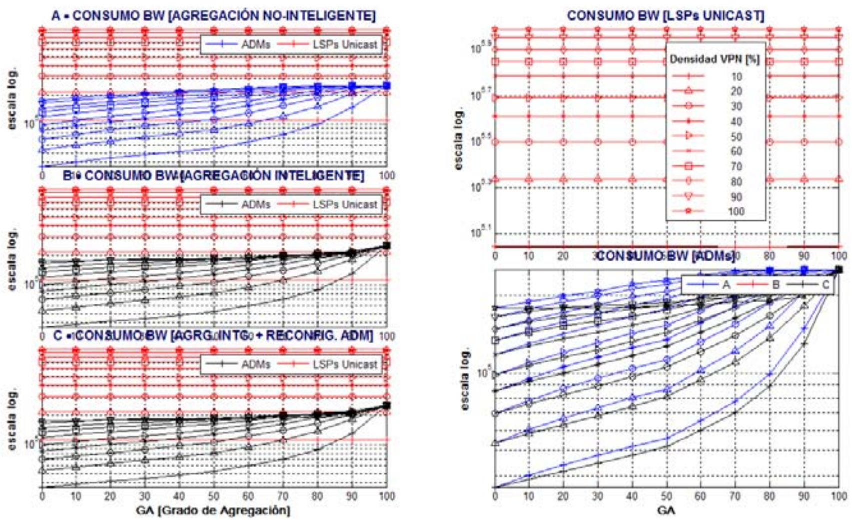


Fig JA5-2 Bandwidth consumption in Tiscali network for 75% of VPLS member density

The results show that intelligent aggregation is very effective for high aggregation degrees and that dynamic reconfiguration adds very little value in this setting.

A paper describing the algorithm and methodology for aggregation is under preparation.

7.3 Meetings

A preliminary meeting for the JA took place in the Athens joint workshop in June 2008 and a second technical meeting was held in the BONE plenary at Rome in October 2008.

7.4 Main results and publications

No publication has been submitted yet. A submission to a magazine and to a conference is expected by the end of WP22 life.

8. GMPLS-based RWA algorithms for optical protection/restoration

8.1 Reference scenario and objectives

One of main challenges of wavelength routed Networks is how to manage differentiated survivability mechanisms under network failure leading to achieve efficient network performance (e.g., resource usage, recovery time, availability). In this Joint Activity, we specifically focus on protection and restoration recovery schemes in Wavelength-Routed Networks (WRN) subject to the Wavelength Continuity Constraint (WCC).

In GMPLS networks, upon reception of a connection request, the source node executes a constraint shortest path first (CSPF) algorithm to find two feasible end-to-end link-disjoint working and backup paths, considering as input the topology and network resource state collected in the traffic engineering database (TED). Indeed, GMPLS routing protocols (e.g., Open Shortest Path First - Traffic Engineering, OSPF-TE (IETF RFC 4203) flood any change occurring in that network state, which permits nodes to maintain a detailed view of current network topology and resource availability. Standard GMPLS routing protocols flood TE link attributes at bandwidth granularity (unreserved bandwidth and maximum supported bandwidth) in bytes/sec. Apart from that, in order to ensure link-disjointness between working and backup paths, the shared risk link group (SRLG) concept is disseminated as a TE link attribute.

The lack of per-wavelength channel granularity dissemination restricts the CSPF computation when facing up the wavelength assignment (especially under the WCC restriction) which is addressed by the signaling protocol (i.e., Resource Reservation Protocol - Traffic Engineering, RSVP-TE (IETF RFC 3473). In particular, through the Label Set object which aims at collecting available wavelengths contiguous from source to destination nodes along the computed path. Next, the selected channel from the received Label Set (e.g., through a random heuristic) is notified to the rest of nodes through the Generalized Label object carried into the RSVP-TE Resv message traveling back to the source node along the same route.

In this context, neither standard GMPLS OSPF-TE nor RSVP-TE protocols convey the required routing and signaling information to deal with efficient distributed RWA algorithms and reservation protocols. This joint activity aims at:

- Proposing RWA algorithms and reservation protocols along with the required extensions to the current GMPLS RSVP-TE and OSPF-TE protocols addressing identified drawbacks.
- Validating the proposed GMPLS-based RWA mechanisms in simulation and real experimental environments.

8.2 Status of development and summary of results

This JA on GMPLS-based RWA algorithms for optical protection/restoration is organized in joint sub-activities, and individual sub-activities aiming at becoming joint collaborations in the near term. Currently, it has been set up one joint sub-activity devoted to Shared Path

Protection (SPP) in GMPLS networks with limited wavelength conversion between the CTTC, SSSUP and DTU, and four individual sub-activities carried out by the CTTC, SSSUP, UPCT and RACTI. The five sub-activities are:

8.2.1 Shared Path Protection (SPP) in GMPLS networks with limited wavelength conversion (CTTC, SSSUP, DTU).

A8.2.1.1 Objectives

The main objective of this joint sub-activity is to investigate novel GMPLS-enabled Shared-path protection (SPP) mechanisms (algorithms and protocol extensions) for wavelength-routed optical networks with limited wavelength conversion, that is, with scarce wavelength converters (WC). In this context, the Shared Path Protection (SPP) scheme is widely accepted as the most capacity-efficient recovery scheme achieving an acceptable recovery time. Such benefits are accomplished through the so-called backup sharing, i.e., the sharing of resources among the existing backup lightpaths (Label Switched Path - LSP in GMPLS context). Specifically, resources along backup LSPs are pre-reserved, but not cross-connected. Therefore, to ensure 100% survivability of the LSPs affected by a single-link failure, the same pre-reserved resources can be shared by multiple backup LSPs as long as their respective working LSPs do not share any link (i.e., no sharing violation).

In all-optical networks without WCs, GMPLS RSVP-TE signalling protocol manages the wavelengths in an inefficient way, when wavelength continuity constraint and backup sharing in SPP schemes needs to be encompassed. The reason is that all the wavelengths into the Label Set Object are treated in the same way. Therefore, the destination node must be provided with intelligent wavelength assignment schemes to enhance not only the probability of setting up connections, but also the network capacity efficiency through backup sharing. To overcome the limitations of GMPLS Label Set, the CTTC [JA6-1] proposed novel wavelength assignment schemes that consider channel state not only of the last TE link, but of all the links. For this purpose, standard GMPLS Label Set (named Shared Label Set) was enhanced to carry specific backup sharing information per wavelength channel.

On the other hand, all-optical WCs are technologically mature, but still an expensive resource. Consequently, transparent networks are provided with a limited number of WCs. The GMPLS RSVP-TE signalling protocol neither manages the wavelengths in a very inefficient way to minimize the number of WC. Therefore, RSVP-TE must be provided with mechanisms for minimizing WC usage, while ensuring the required wavelength continuity constraint between consecutive WCs (and the source and destination nodes). In other words, mechanisms that try to allocate the same wavelength on the maximum number of consecutive links along the computed LSP route, while avoiding unnecessary wavelength conversions are necessary. For this purpose, the SSSUP [JA6-2] introduced an enhanced signalling object called Suggested Vector (SV), which enables wavelength ranking aiming at WC usage reduction.

Most of the studies on SPP recovery consider either 3R regenerators or full WCs embedded at each node. Thus, their main objective is to optimize backup sharing. In wavelength-routed with limited conversion, both the wavelengths and WCs can be shared between backup LSPs. Therefore, backup sharing and the WC sharing must be optimized to achieve low connection blocking and high network capacity efficiency. This study aims at encompassing jointly backup sharing, WC sharing and limited wavelength conversion in Shared Path Protection mechanisms for GMPLS-enabled wavelength-routed networks, by combining and enhancing the already proposed Shared Label Set and the Suggested Vector extensions.

A8.2.1.2 Activities

After the definition of the problem and scenario, new extensions for the current GMPLS RSVP-TE signalling protocol have been studied. Based on the Shared Label Set and Suggested Vector extensions, the following objects are proposed to allow the sharing of wavelengths and WC, while guaranteeing the wavelength continuity among WCs and ensuring 100% survivability against single link failure:

1) shared wavelength vector (SW) whose elements indicate the number of links on which the corresponding wavelengths are in shared-reserved status;

2) protected wavelength vector (PW) whose elements indicate the number of SRLGs protected by the corresponding wavelengths;

3) SRLG list vector (SLV) whose elements indicate the list of SRLGs protected by each wavelength;

4) suggested WC vector (SV) whose elements indicate the minimum number of WCs that are required in order to use the corresponding wavelengths from the source;

5) shared WC vector (SHV) whose elements indicate minimum number of shared WCs that are required in order to use the corresponding wavelengths from the source.

Different strategies to be applied to new vector objects have also been proposed for updating object weights and for performing wavelength assignment. Wavelength assignment strategies apply at both the destination node and any intermediate node that should perform wavelength conversion. The main selection criteria that can be devised are:

- random (R): a wavelength in the label sets (SW, PW, SV, SHV) is randomly selected;
- first fit (FF): the first wavelength in the vector objects (SW, PW, SV, SHV) is selected;
- last fit (LF): the last wavelength in the vector objects (SW, PW, SV, SHV) is selected;
- maximum-protecting (P): the wavelength with the highest SW weight is selected;
- maximum-wavelength-sharing (WS): the wavelength with the highest PW weight is selected;
- minimum-conversion (C): the wavelength with the lowest SV weight is selected;
- maximum-WC-sharing (WCS): the wavelength with the highest SHV weight is selected.

The future step will be the validation of the proposed GMPLS-based RWA mechanisms in a simulation environment.

A8.2.1.3 Meetings

- June 8th 2008 : Conference call. Participants: CTTC, SSSUP and DTU.
- July 18th 2008: Joint meeting at CTTC premises. Participants: CTTC and SSSUP.

8.2.2 Experimental evaluation of GMPLS enhanced routing and signaling for differentiated survivability in GMPLS-enabled all-optical networks (CTTC)

A8.2.2.1 Objectives

Future Intelligent Optical Networks (ION) are devised to support a wide variety of clients each having their own reliability requirements such as availability. The aim of these networks is thus to support differentiated recovery schemes leading to guarantee those requirements along with achieving efficient network performance (e.g., resource usage). In this activity, we specifically focus on Dedicated Path Protection (DPP) and Shared Path Protection (SPP) recovery within GMPLS all-optical networks. In this context, neither standard GMPLS OSPF-TE protocol nor RSVP-TE protocol convey the required routing and signalling information respectively to deal with such an efficient network performance. Thus, the novelty of this work is twofold: first, presenting enhanced GMPLS signalling and routing approaches for both recovery schemes that besides maximizing resource usage address connection blocking mostly due to the Wavelength Continuity Constraint (WCC), and second, evaluating these implemented schemes in a real experimental ION network named ADRENALINE testbed.

A8.2.2.2 Activities

Taking this into account, for the DPP schemes, we present two algorithms: the standard GMPLS bandwidth routing (DPP Bw) operating with aggregated link bandwidth information to compute a pair of link-disjoint paths, and the WCC is satisfied by the signaling; and the enhanced GMPLS channel (DPP Ch) approach, whose path computation uses full link details comprising wavelength channel availability, and thus enabling link-disjoint routes that satisfy the WCC. Likewise, three SPP recovery schemes are proposed and evaluated, namely, standard (Std) GMPLS SPP, GMPLS SPP with shared Label Set, SPP Bw, SPP Bw with Shared Label Set, and SPP Ch routing approaches. In the Std GMPLS SPP scheme, the path computation operates with network information flooded by current GMPLS routing protocols. This consists on detailing the TE link resource availability (i.e., occupied or free) in terms of bandwidth. As a consequence, there is not distinction regarding the amount of bandwidth which is allocated for either working or (shared) backup purposes. This restricts the path computation to only obtain link-disjoint routes without favouring the backup sharing among existing backup LSPs, performing poorly on the whole network resource usage. To take full advantage of backup sharing in SPP schemes and thus outperforming the capacity efficiency, the authors presented the SPP Bw and SPP Ch routing approaches.

These strategies led to jointly increase the backup sharing while minimizing the connection blocking due to the WCC. The difference between the two approaches relies on the level of granularity of the required and disseminated network state information. In particular, SPP Bw routing approach uses aggregated link information at bandwidth (link) level. In SPP Ch, however, its path computation operates on a wavelength channel basis. Since current GMPLS Open Shortest Path First – Traffic Engineering (OSPF-TE) protocol does not disseminate link sharing information, extensions for each routing approach were proposed and implemented in [JA6-3]. In both strategies, upon receiving a connection request, the source node executes a Constraint Shortest Path First (CSPF) algorithm to compute two link-disjoint paths (using the SRLG concept), the working and the backup LSPs (wl and bl). The used CSPF algorithm follows a link-cost method in which the shortest path cost is computed. For the wl path, the cost of any usable link (i.e., having unused resources) is set to 1. This in turn leads to compute the shortest path in terms of number of hops. Likewise, for the bl path the cost of any usable link is also set to 1. However, if the link has allocated resources for SPP purposes without causing sharing violation, and for the bl path computation only, the link cost is reduced by the so-called backup sharing ρ factor (wherein ρ < 1). By doing so, network links in which backup sharing is feasible are prioritized by the CSPF to enhance the efficiency of the network resource usage. In previous work, the selected ρ factor was arbitrarily set to 0.5, and the performance evaluation consisted on comparing these two schemes with regard to two metrics: the blocking probability and the restoration overbuild. The results showed that SPP Ch approach lowers the connection blocking probability performed by the SPP Bw method, because the former is optimized to achieve minimal blocking due to the WCC. In addition, SPP Ch scheme also presents appreciable savings in the restoration resources compared to SPP Bw approach. Taking this into account, this work quantitatively investigates the impact over these figures of merit when the ρ factor is varied. In other words, when the backup sharing aggressiveness is either strengthen or weaken. The results are exclusively obtained for the SPP Ch scheme, wherein besides the above metrics, the average setup delay is also used for performance discussion purposes.

We also proposed novel wavelength assignment algorithms along with the required extensions to the current GMPLS RSVP-TE Label Set to efficiently encompass the Wavelength Continuity Constraint (WCC) and the Backup Sharing in GMPLS-enabled Wavelength-Routed Networks (WRN) with Shared Path Protection (SPP) recovery schemes. The focus of this paper is to experimentally validate in ADRENALINE testbed the proposed signalling-based solution for WCC in SPP recovery when GMPLS OSPF-TE routing protocol disseminates only aggregated link information at bandwidth level based on two approaches: Unreserved Bandwidth (UBw), as proposed in standard GMPLS, and Sharable Bandwidth (SRBw) through an extended GMPLS OSPF-TE protocol proposed by the authors.

A8.2.2.3 Publications

- R. Martínez, R. Muñoz, R. Casellas, Experimental evaluation of the backup sharing aggressiveness for dynamic shared path protection in GMPLS transparent optical networks, ICTON 2008. Athens (Greece). June 22-26, 2008.
- R. Muñoz, R. Casellas, R. Martinez, An Experimental Signalling Enhancement to Efficiently Encompass WCC and Backup Sharing in GMPLS-enabled Wavelength-Routed Networks, in Proc. IEEE ICC 2008. Beijing, China, May 19-23 2008.
- R. Martínez, R. Casellas, R. Muñoz, Experimental evaluation of GMPLS enhanced routing for differentiated survivability in all-optical networks, OSA Journal of Optical Networking. vol. 7, no.5, pp. 496-512, May 2008.

8.2.3 Restoration Schemes in GMPLS-controlled Translucent Networks (SSSUP)

A8.2.3.1 Objectives

A translucent WDM network (i.e., network with limited and sparse regeneration capabilities) with a GMPLS control plane is considered. Regenerator (3R regenerators) information is carried by GMPLS protocols (RSVP-TE signaling and OSPF-TE routing protocols). To meet QoT requirements, lightpaths may undergo 3R regeneration to compensate for the accumulated physical impairments. The resource reservation protocol with traffic engineering extensions (RSVP-TE) is used for restoring lightpaths affected by a link failure. The aim of the study is evaluation of the GMPLS ability to restore failed lightpaths, while guaranteeing the required Quality of Transmission (QoT).

A8.2.3.2 Activity

The performances of two different restoration schemes are compared: a path-restoration scheme and a segment-restoration scheme. In the path-restoration scheme, restoration takes place between the end nodes of the failed lightpath. Two protocols for disseminating regenerator information are considered: the signaling protocol RSVP-TE and the routing protocol OSPF-TE. In the segment restoration scheme, restoration takes place on the failed lightpath segments included between two regenerators. This allows to exploit the regenerators already in-use by working lightpaths and to avoid the need for the disseminating regenerator information. The two schemes were compared and evaluated in terms of restoration blocking probability (i.e., probability that a failed lightpath cannot be restored), control plane load (i.e., number of control plane messages), and expected restoration latency (i.e., expected time to restore a failed lightpath).

A8.2.3.3 Results

Restoration blocking probability in restoration schemes is decomposed in forward blocking (due to resource unavailability), backward blocking (due to resource contentions), and QoT blocking (due to inability to meet QoT requirements). When applying both the restoration schemes, the backward blocking is higher than the forward blocking, due to the large number of restoration instances that attempt to concurrently reserve the available resources. When the the number of 3R regenerators installed in the network is limited, QoT blocking can be even higher than the backward blocking.

The path-restoration scheme based on signaling and routing protocols for disseminating regenerator information were compared. Simulation results show that, by using the signaling protocol, the restoration blocking probability is as high as the one achieved using the routing protocol, but the control plane load is reduced. When comparing the segment-restoration scheme against the path-restoration scheme (based on signaling protocol for regenerator information dissemination), segment-restoration scheme can achieve a lower QoT blocking, and a lower overall restoration blocking probability with respect to the path restoration scheme. At the same time, the expected restoration latency is reduced.

A8.2.3.4 Publications

- N. Sambo, I. Cerutti, F. Cugini, A. Giorgetti, L. Valcarenghi, P. Castoldi, Segment "Restoration Scheme with QoT-guarantees in GMPLS-controlled Translucent Networks," ECOC 2008, Belgium, September 2008.
- N. Sambo, F. Cugini, N. Andriolli (SSSUP), A. Giorgetti, L. Valcarenghi, P. Castoldi, "Path Restoration Schemes in GMPLS-controlled Translucent Networks," Photonics in Switching (PS) 2008, Japan, August 2008.

8.2.4 Implementation of an extension of MatPlanWDM tool to cope with the evaluation of the merits of protection/restoration schemes (UPCT)

MatPlanWDM tool is a planning tool for optical networks developed by UPCT research group. There is a publicly available version of the tool in www.matlabcentral.com. It has received about 900 downloads before November 2008. Some previous extensions of the tool have been published in [JA6-4] [JA6-5] [JA6-6]. Current activity within this JA is the development of an extension of the MatPlanWDM tool for automating the testing of protection and restoration algorithms. A further activity is the design and comparison of protection/restoration schemes in the MatPlanWDM tool, proposed by UPCT and/or other partners.

8.2.5 Genetic algorithms to jointly solve the impairment aware RWA (IA-RWA) problem (RACTI)

We have examined the use of multi-objective optimization algorithms and particular genetic algorithms to jointly solve the impairment aware RWA (IA-RWA) problem. We have used the number of common hops and end-to-end path length as the objective functions to be minimized. It has been shown that when these functions are used, impairments are indirectly but satisfactory considered, significantly improving blocking ratio. Work will continue to evaluate the proposed IA-RWA algorithms employing 1+1 protection

8.2.6 Publications

- Demetris Monoyios and Kyriakos Vlachios, “On the use of genetic algorithms for solving the RWA problem employing the maximum quantity of edge disjoint paths”, in Proceed. of ICTON 2008. Athens (Greece). June 22-26, 2008.

8.2.7 REFERENCES

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[JA6-2] N. Andriolli, J. Buron, S. Ruepp, F. Cugini, L. Valcarenghi, and P. Castoldi, “Label preference schemes in GMPLS controlled networks,” IEEE Communications Letters, vol. 10, no. 12, December 2006.

[JA6-3] R. Martínez, R. Muñoz, R. Casellas, J. Comellas, G. Junyent, Experimental Shared Path Protection Algorithms in Distributed All-Optical GMPLS-based Networks, 6th International Workshop on the Design of Reliable Communication Networks (DRCN2007), La Rochelle (France). October 8-10 2007.

[JA6-4] P. Pavon-Mariño, R. Aparicio-Pardo, G. Moreno-Muñoz, J. Garcia-Haro, J. Veiga-Gontan, "MatPlanWDM: An educational tool for network planning in wavelength-routing networks", Lecture Notes in Computer Science (Springer-Verlag GmbH, ISSN 0302-9743), VOL. 4534, pp. 58-67. Proceedings of the 11th International Conference on Optical Networking Design and Modeling - ONDM 2007, Athens (Greece), May 2007.

[JA6-5] P. Pavon-Mariño, R. Aparicio-Pardo, B. García-Manrubia, J. García-Haro, "WDM networks planning under multi-hour traffic demand with the MatPlanWDM tool", SimulationWorks 2008: Industry Track to The First International Conference on Simulation Tools and Techniques for Communications, Networks and Systems (SIMUtools 2008), Marseille (France), March 2008.

[JA6-6] P. Pavon-Mariño, R. Aparicio-Pardo, B. García-Manrubia, J. García-Haro, "WDM networks planning under multi-hour traffic demand with the MatPlanWDM tool", SimulationWorks 2008: Industry Track to The First International Conference on Simulation Tools and Techniques for Communications, Networks and Systems (SIMUtools 2008), Marseille (France), March 2008.

9. Resilience Issues in the GMPLS-enabled Control Plane

9.1 Motivation and goals

The Generalized Multi-Protocol Label Switching (GMPLS) paradigm introduces the freedom of the Control Plane (CP) to be physically separated from the Transport Plane (TP). Therefore, the control plane might fail independently from the transport plane and vice versa, as control and transport plane forwarding states become no more linked. Failure detection and recovery mechanisms in the control plane are no more associated with the ones of the transport plane. Hence, new mechanisms must be provided, which meet control plane fault recovery requirements.

Because message delivery in the GMPLS control plane is IP-based, IP layer rerouting is the natural fault recovery mechanism. With such purposes, Open Shortest Path First (OSPF) is extensively used in IP networks to provide shortest path packet routing, as well as automatic IP routing convergence upon topology changes (e.g., link failures). Nonetheless, the long convergence time needed by OSPF, due to the long failure detection time (around 40 s), makes its applicability inappropriate for control failure recovery in the next-generation optical networks control plane.

The main aim of this joint activity is to design and validate suitable failure detection and recovery mechanisms for the GMPLS-enabled control plane, achieving the resilience required for next-generation optical transport networks performance.

We firstly identified major disruptions (both in the control and transport planes) due to control link failures in GMPLS-controlled networks. This allows quantifying the impact of control link failures on whole network performance. Generally speaking, because the control plane in GMPLS does not have to follow the same topology as the transport plane, several topologies for the control plane can be deployed. Specifically, simulation of various failure cases for various CP over DP mappings will be carried out. The suitable cooperation between Control Plane and Transport Plane must be analysed, especially focused on possible difficulties in cooperation. The solution needs to be studied from the viewpoint of the way of mapping the functionalities of GMPLS messages (i.e. transferred through CP) by TP (e.g. via SNMP (Simple Network Management Protocol)). Each element from the TP can be seen as an agent for managing station in CP which understands GMPLS protocol messages and translates them into appropriate device specific protocols.

Within the joint activity, not only simulation studies but also experimental activities are performed.

9.2 Implementation of GMPLS-like Control Plane

Within current task we have focused on solution using DRAGON software (version April 2008). We adapted the software to support Catalyst 3560 series switch and created own GMPLS network named *KT-GMPLS*. Two scenarios with different topologies and amount of elements in CP and TP, supporting L2SC type of switching are presented in the following part of this description.

DRAGON (Dynamic Resource Allocation via GMPLS Optical Networks) is an American project where the main aim is to create dynamic, deterministic, and manageable end-to-end network transport services for high-end e-Science applications (data bases, VoD, HDTV).

DRAGON is simultaneously an open source software that is mainly composed of: VLSR (Virtual Label Switching Router) which is responsible for participation in GMPLS protocols' exchanges and provision for supervised ("covered" by DRAGON's nomenclature) switch according to protocol events (PATH setup, PATH tear down, etc.). NARB&RCE server (Network Aware Resource Broker with Resource Computation Element) is equivalent to PCE (Path Computation Element). NARB is responsible for path computation, inter-domain routing and intra-domain listening. CSA (Client System Agent) is the end system or client software responsible for signaling into network (UNI or peer mode) and participate in path computation. These elements were installed and compiled on previously prepared linux machines.

Each scenario described below uses Ethernet wired-link with capacity 100 Mb/s. However, the VLSR has also been adapted to control TDM switching and Optical switches.

The first scenario was created to check basic functionality of the DRAGON environment. It was assumed to use two CSA and one VLSR modules supervising single Catalyst 3560 which is presented in Fig. JA7-1.

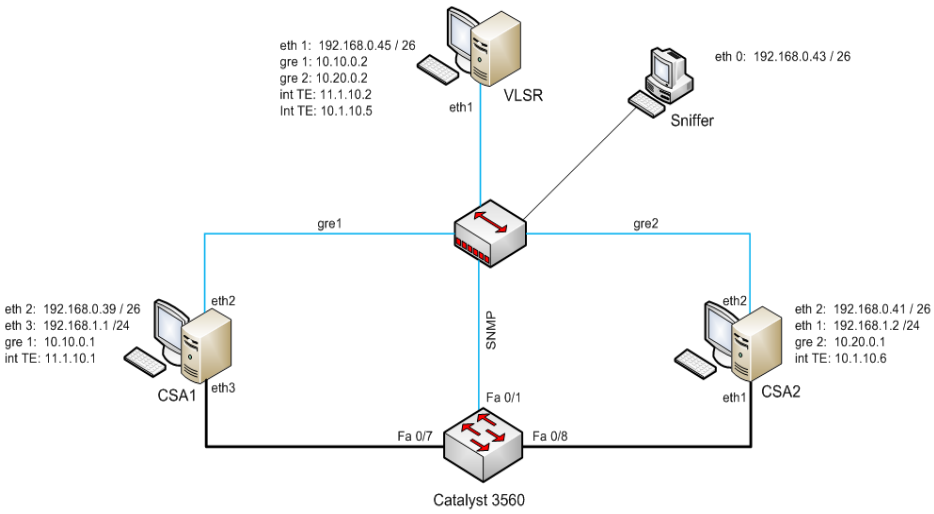


Fig. JA7-1. First scenario: The basic topology of KT-GMPLS

CP links are marked on blue and TP links on black. Each device was connected to 10/100 Mb/s hub. Using Wireshark and tcpdump we were able to sniff whole network. After OSPF-TE adjacency was established the unidirectional and bi-directional LSP were computed using RSVP-TE signaling in CP between CSA1 and CSA2 through Catalyst 3560 which was managed by VLSR. VLSR passes RSVP-TE Path message from CSA1 to CSA2 and after reception of RSVP-TE Resv message with ERO (Explicit Route Object) it assigns in SNMP session first free VLAN for requested LSP.

To test connectivity the ping function was used. The parameters of the computed LSP are following: bandwidth 100 Mb/s, type of switching L2SC, encoding Ethernet, GPID (Generalized Payload ID) Ethernet.

The disadvantage of this scenario is a possibility to create only one LSP assigned to one switch port. This problem vanishes after adding NARB which was presented in second scenario.

In next presented scenario (see Fig. JA7-2) *KT-GMPLS* topology was extended to more advanced architecture. We have added the VLSR2 managing additional Catalyst switch and NARB server connected logically to VLSR1 by virtual link. CP links constituted star topology.

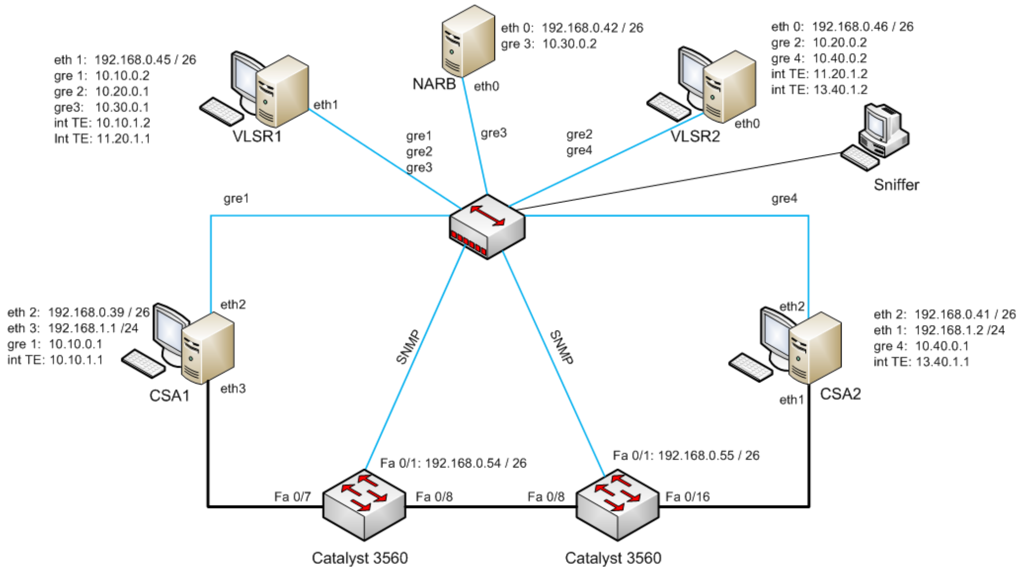


Fig. JA7-2 Second scenario: The extended topology of KT-GMPLS network using NARB in intra-domain environment

In this case LSPs were established between CSA1 and CSA2 through two Catalyst 3560 switches which were managed by VLSRs. When CSA1 wanted to set LSP first sent in TCP session a query about possibilities of this end-to-end connection to NARB. Then NARB which was aware of intra-domain topology set requested LSP if parameters were suitable with available resources. Otherwise NARB returned PathErr message.

The significant advantage of this topology is the fact that user himself can define which VLAN ID he wants to use for new LSP. Another advantage is the possibility to set several LSPs between switches. Then link is treated as a VLAN trunk carried LSPs in various VLANs e.g. from different users.

This scenario may be easily extended for multi-domain architecture.

Considering the DRAGON implementation we are aiming to various scenarios escalating the different levels of complexity and cooperation between network elements. In our opinion DRAGON supports resilience features thanks to:

- OSPF-TE (RFC 4203 with additional enhancements for DRAGON software)
- RSVP-TE (RFC 3473 with additional enhancements for DRAGON software)
- NARB in single domain (awareness of topology, TE-links, any node failure is identified
  and omitted in path computation)
- NARB in multi-domain environment (awareness of intra- and inter-domain topology, TE-links, thanks to NARBs internal communication in CP)

We are going to enhance our testbed into multi-domain environment and provide different routes in CP and TP form CSA1 to CSA2 to study protection mechanisms for created topology.

9.3 Preliminary simulation studies

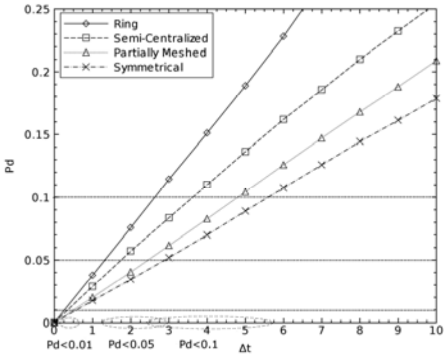
The freedom introduced by GMPLS in the deployment of the control plane opens a wide range of possible control plane topologies. Generally speaking, the control plane can follow symmetrical or asymmetrical topologies, depending on whether it follows the same topology of the transport plane or not. The symmetrical topology is typical from an in-fiber control plane configuration (in-band or out-of-band), where control channels are constrained to use the same physical links as the transport plane. Conversely, the flexibility introduced with the out-of-fiber control plane configuration fosters the deployment of asymmetrical topologies, supported on an alternative physical network.

Here, four different topologies have been investigated, pointing out benefits and drawbacks of each one. To allow comparison amongst them, the transport plane follows the same topology in all situations. First, the symmetrical topology follows exactly the same topology as the transport plane, where all control channels are deployed in an associated mode over the link connecting both nodes. Second, the ring topology tries to save control plane resources by interconnecting all nodes in the network forming a ring. To alleviate such problematic and to reduce communication delays but still requiring fewer resources than the symmetrical topology, the partially meshed one appears as a hybrid between the symmetrical and the ring topologies. Specifically, in the partially meshed topology, communication in the control plane is covered by concatenating sub-rings so that shorter paths between node pairs can be found and the burden per control link can be lighten. Finally, a semi-centralized topology was also considered. The idea behind this solution is to let a control plane node the management of several transport plane nodes in a centralized way (e.g., by a Path Computation Element).

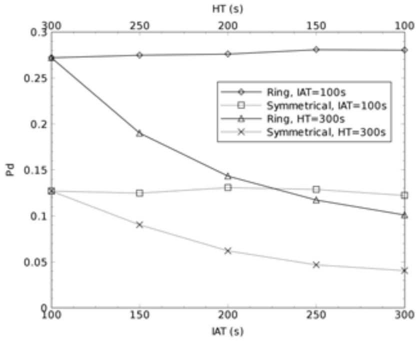
9.3.1 Preliminary simulation results

For the simulations, we assume that each TP link carries 8 bidirectional wavelengths and end-to-end routes accomplish the wavelength continuity constraint. For the traffic characteristics, we assume that uniformly distributed unidirectional connection requests arrive at the controller of each node following a Poisson process, and connection holding times are exponentially distributed. Connection Inter-Arrival Time (IAT) and connection Holding Time (HT) of 150 s and 300 s respectively were considered, thus offering 18 Erlangs to the network. Specifically, we evaluated the parameter P_d, which identifies the probability that at least one connection request or one connection teardown becomes affected by a control link failure (i.e., it is forwarded onto the failed link) during the total failure recovery time, denoted by Δt. It is worth to mention, that IP convergence time is also included in Δt.

As seen in Fig. JA7-3, the symmetrical topology provides the best results. In fact, each control link supports only one control channel. This is not the case, however, of the ring topology. In this case, since the control plane topology is quite sparse, several control channels are supported on each control link. Therefore, much more communications become disrupted due to a control link failure, thus leading to significant Pd for a given Δt. Note, however, that a partially meshed topology obtains notoriously better results, almost reaching the same performance as the symmetrical one but, at the same time, reducing the number of physical control links. Hence, it appears as an interesting candidate to implement the control plane of next-generation transport networks. Finally, the semi-centralized approach also suffers from control link failures. In fact, as in the ring topology, each control link carries several control channels.



(a)



(b)

Fig. JA7-3 (a) Comparison of Pd for each topology under study, (b) Pd with constant IAT and HT for ring and symmetrical topologies

Looking at Fig. JA7-3, note that whether $P_d < 0.1$ has to be assured, Δt range from 3 to 6 s, depending on the topology. Contrarily, for Pd < 0.01 requires Δt = 500 ms. Finally, $P_d < 0.05$ would require Δt values between 1 s in the ring topology and 3 s in the symmetrical one. Hence, the ring topology would likely require dedicated backup link protection, whereas in the symmetrical and even in the partially meshed topologies IP rerouting could be sufficient due to the 2 s allowed IP convergence time. In fact, starting from the obtained requirements, the proper resilience mechanisms have to be adopted.

9.4 Future plans

The future plans for this activity include experimental results obtained through the implementation of the GMPLS Control Plane from DRAGON as well as further simulation results considering different topologies not just for the control plane but also for the transport plane, aiming at identify the most efficient topologies from the resilience point of view.

On the other hand, considering a hybrid network scenario composed by a GMPLS control plane able to control not just circuit-oriented optical networks (OCS) but also Optical Burst Switching (OBS), the joint activity will investigate the overall impact of the failures occurred at OBS control plane.

9.5 Publications

- K. Monist, K. Wajda, Implementation of GMPLS network and future enhancements towards recovery mechanisms, BONE Summer School 2008, Mons (Belgium), October 13-17, 2008.

10. Multi-domain provisioning/recovery within GMPLS all-optical networks

An optical carrier may subdivide its network topology into different domains, where a domain is defined as any collection of network elements within a common sphere of management or path computation responsibility such as IGP areas, Autonomous Systems (ASs) and multiple ASs within a Service Provider network.

Reasons for such a division are protocol scalability purposes, administrative or strategic objectives, vendor or equipment separation, geographic reasons, etc. As a result of this segmentation, several reference points and control interfaces are defined among the control plane entities: UNI, I-NNI and E-NNI. These reference points determine the amount and the type of information concerning the topology and the network resource details being exchanged through them in order to achieve the necessary protocol scalability as well as to preserve the security and confidentiality. By doing so, at the time of provisioning paths spanning several domains, the path computation may rely on per-domain computation operating with limited network information. This may yield suboptimal routing decisions. In addition, such a lack of domain visibility is a source of problems when a diverse path computation is required to satisfy recovery requirements.

To deal with the above problem the JA will encompass the following objectives:

- To study potential enhancements to two of the GMPLS protocols, namely OSPF routing and RSVP-TE signaling, in order to exchange TE information related to inter-domain TE links such as switching capability, protection attributes, SRLG, etc.
- To devise intelligent on-line path computation algorithms leading to attain improvements in the performance of provisioning and recovery of multi-domain connections in terms of connection blocking, network resource usage, etc.
- These improvements may be achieved at the expense of increasing the control, routing and signaling overhead. Therefore, the third objective relies on quantifying this overhead along with assessing potential scalability problems. As a consequence, a trade-off between performance and protocol scalability may be established.
- To perform and validate interoperability tests between partners having experimental network infrastructure.

10.1 List of expected results

The JA expected results include publications on international major conferences and journals, as well as interoperability tests and validations within the interconnection of experimental network infrastructures available in the JA. Scientific and technical dissemination activities (papers, workshops, seminars) cover the evaluation of the implemented and devised multi-domain provisioning/recovery mechanisms, along with proposed GMPLS protocol extensions in terms of key performance indicators (e.g., blocking probability, recovery time, etc.) and scalability aspects.

10.2 Design and implementation set up of a GMPLS experimental infrastructure.

One of the main goals of this JA is the set up of an experimental infrastructure in which the proposed GMPLS protocol extensions, and the devised provisioning/recovery schemes can be thoroughly validated and evaluated. To this end, this JA addresses the interoperability between the UPC CARISMA and the CTTC ADRENALINE testbeds. Specifically, this interconnection focuses on at the control plane level. In other words, only control messages (i.e., routing and signaling) will be exchanged, since no transport layer connectivity is provided.

The design and implementation for the interconnection/interoperability between both demonstrators are conveyed from a threefold perspective:

- From the physical IP connectivity to allow the IP message forwarding.
- From a control plane interconnection, that is the Data Communication Network (DCN) for the control protocol message exchange.
- From the emulated data (TE) links connectivity to establish emulated optical connections (lightpaths).

10.2.1 Physical IP connectivity and DCN between UPC CARISMA and CTTC ADRENALINE tetsbeds

The premises having both UPC CARISMA and CTTC ADRENALINE testbeds are physically located at Barcelona, but separated 20 Km. Due to this the IP connectivity between both infrastructures needs to be carefully studied. The selected solution relies on using the public Internet through IPSec tunnels as depicted in Fig. JA8-1. By doing this, the DCN interconnection is feasible allowing the exchange of signaling and routing messages.

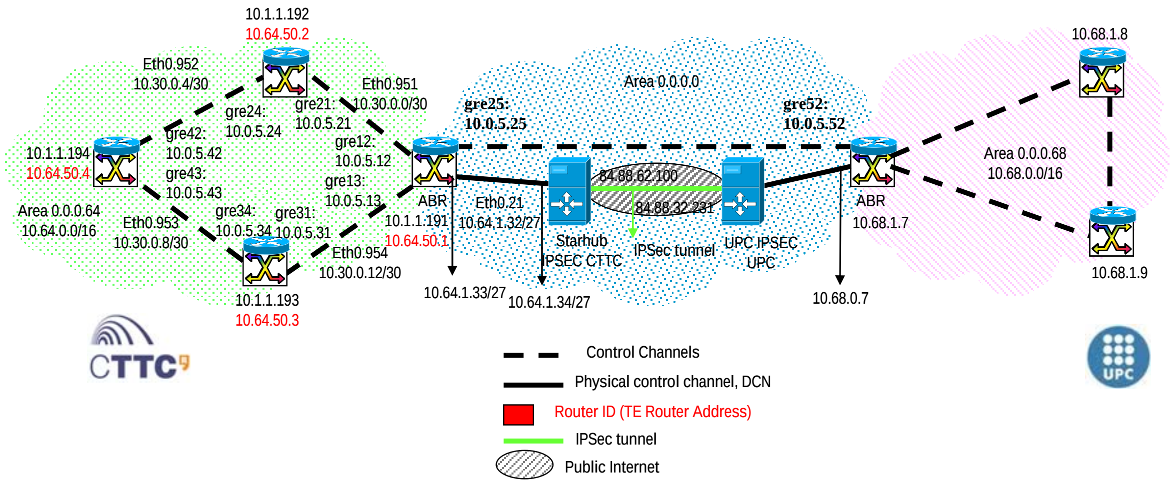


Figure JA8-1 IP connectivity and DCN design between UPC CARISMA and CTTC ADRENALINE testbeds

With regard to the DCN, it is needed to detail the specific network topology for the multi-domain GMPLS-enabled provisioning/recovery tests. The considered reference network scenario is shown in Fig. JA8-1. This network is constituted by a single AS (network provider) formed by three IGP areas: Area 0 (backbone), Area 64 (CTTC) and Area 68 (UPC). The control channels are configured over point-to-point IP (gre) tunnels. The number of internal area nodes as well as the number of area border routers (ABRs) may vary according to better accommodate the necessities of the specific experimentation.

In addition to the DCN configuration, it is also essential to define the main control protocols running between these domains, namely the signaling and the routing: The former follows the

GMPLS RSVP-TE protocol, and is used to in a distributed way to yield automatic connection establishment as well as connection recovery once a network failure actually occurs. The second, on the other hand, follows the OSPFv2 and the GMPLS OSPF-TE protocol. This creates the required routing adjacencies to exchange topology and network resource information required for path computation purposes.

10.2.2 Emulated TE link interconnection between UPC CARISMA and CTTC ADRENALINE testbeds.

Fig. JA8-2 depicts the network topology of the transport plane, that is, the TE links connectivity for an all-optical network infrastructure. It is considered that both the control and the transport planes follow the same topology. In other words, each network element (optical switch) has its own control plane instance.

Besides the transport topology, Fig. JA8-2 describes the used link identifiers and the IP node addresses required for the transport addressing. Furthermore, required TE attributes are defined for each TE link such as the number of multiplexed wavelength channels (i.e., 8), the aggregated unreserved bandwidth (i.e., 12.5 GB/s), the interface switching capability (Lambda Switch Capable with Lambda encoding), the TE metric, etc.

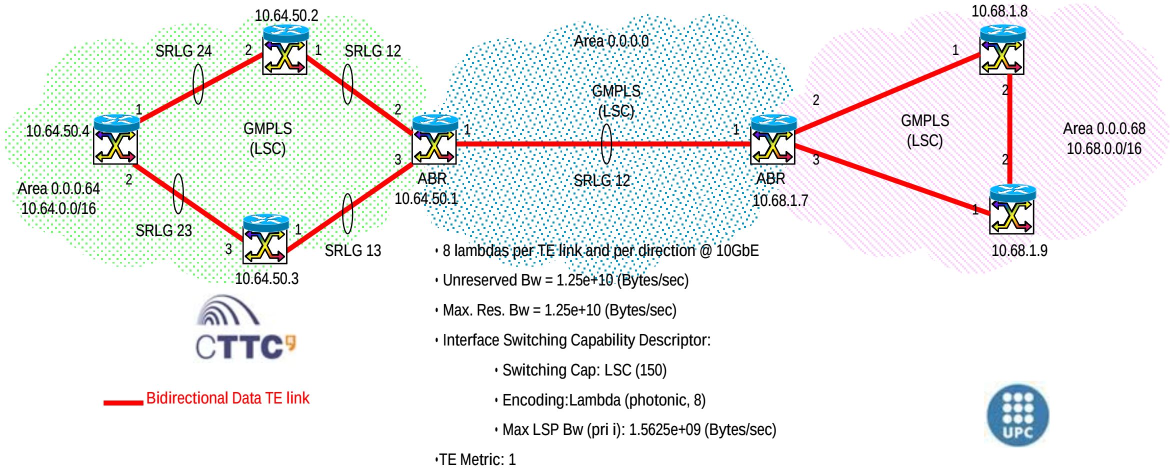


Figure JA8-2 Emulated TE link connectivity between UPC CARISMA and CTTC ADRENALINE testbeds

10.3 Proposal and implementation of provisioning/recovery schemes for multi-domain networks

Once the interoperability at the GMPLS control plane between both testbeds is over, the JA will proceed on devising efficient provisioning/recovery algorithm for multi-domain GMPLS all-optical network. The main goal is to implement such an algorithm in the experimental framework, and conduct performance and validation tests in terms of different figures of merit: connection blocking probability, average setup delay, restoration time for recovery schemes, control overhead measurement and scalability assessment, etc. Closely aligned to the definition of such algorithms, it will be studied potential enhancements to the standard GMPLS protocols (routing and signaling) to better address the shortcomings derived from the all-optical technologies within multi-domain network scenarios.

10.4 Meetings

To date, we have had several meetings to define the experimental tasks conducted in the Joint activity, as well as to define a preliminary set of tasks for the first year. The meetings took place during ICTON 2008 conferences, at CTTC premises in July, as well as during BONE plenary meetings.

10.5 Main results and publications

10.5.1 Non-joint publications

- Staessens et. al., Enabling high availability over multiple optical networks, IEEE Communications Magazine, vol. 46, issue 6, pp. 120-126, June 2008.
- D. Staessens et. al., Survivability over multiple GMPLS domains, ICTON 2008 (RONEXT, Mo. C3.3).

11. GMPLS-based control plane for optical packet-based technologies

11.1 Introduction and motivations

Optical Burst Switching (OBS) and Optical Packet Switching (OPS) networks need to be capable to be rapidly reconfigured with the aim of achieving an efficient use of bandwidth, low latency and high degree of transparency. However, the bufferless architecture and the one way (on the fly) reservation scheme intrinsic of the OBS/OPS networks bring several challenges to its development. Several mechanisms have been proposed to improve the OBS/OPS performance: there are generally based on including more intelligence in the switching layer (prediction of links congestion [JA9-1], [JA9-2], wavelength selection considering the streamline effect [JA9-3], feedback mechanisms to control the congestion and the connection admission [JA9-4] [JA9-5], QoS-aware deflection routing [JA9-6], etc.).

Nonetheless, these complex control processes together with the highly dynamics of OBS/OPS networks make impossible the objective of achieving fast per-burst decisions.

In our proposal, the idea is to move the intelligence to the control plane keeping the switching layer only responsible of local decisions with limited choices. Our challenge is therefore the definition of a Control Plane, which must be able to respond to the just mentioned highly dynamic and complex control requirements. In line with this, although its features fit with wavelength switched networks, GMPLS could be considered as a reference to design such OBS/OPS-capable control plane. The adaptation/interoperation of GMPLS and OBS/OPS is catching the research community attention. Several recent research relevant papers [JA9-7], [JA9-8] and [JA9-9] deal with the design of a multi-layer network architecture for interworking GMPLS and OBS networks.

This fact, together with our convincement that the deployment of OBS/OPS will necessarily take place from the migration of OCS networks, and for this reason they will need to coexist in the transition, this activity is addressing the problem of designing a GMPLS-controlled OBS/OPS network.

In this first year, the following tasks have been addressed: 1) define a functional architecture of an interoperable GMPLS and OBS Control Plane as a match between what GMPLS can offer and what the OBS Control Plane needs, 2) propose QoS-aware path establishment processes and perform simulation analysis.

11.2 GMPLS-controlled OBS architecture

The proposed interoperable GMPLS/OBS Control Plane can seamlessly enable the coexistence and easy migration between optical circuit-switched and packet/burst-switched networks as well as speed up the OBS development and standardization.

Figure JA9-1 depicts an OBS Network supported by the Interoperable GMPLS/OBS Control Plane architecture we propose in this paper [JA9-10]. It consists of a transparent all-optical data plane and an interoperable two layers control plane, one is based on the current GMPLS standard set of protocols with some extensions that will be detailed below, and the other provides the OBS specific control functions.

The GMPLS control layer works as an overlay control network (uses out-of-band, either out-of-fibre or in-fibre signalling), which is in charge of configuring a virtual topology for the OBS network. Its purpose is setting up and tearing down Traffic Engineering tunnels (TE-tunnels) –in our context, a TE-tunnel is a group of wavelengths, representing one or multiple parallel LSPs established in a single signalling session, and the whole set of established TE-tunnels can be seen as a virtual overlay network where to route the data bursts–. The GMPLS control layer is also in charge of uploading/updating the forwarding tables stored in the control units of the OBS nodes. The GMPLS standard RSVP-TE and OSPF-TE protocols have to be extended in order that they can handle this structure of TE-tunnels, and update the network state databases in the OBS nodes [JA9-11].

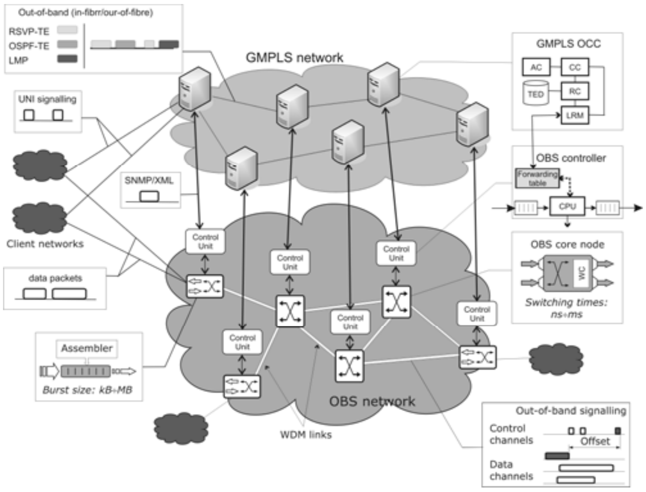


Figure JA9-1 The OBS Network Architecture with an Interoperable GMPLS/OBS Control Plane. Legend: LRM: Link Resource Manager, AC: Admission Controller, RC: Routing Controller, CC: Connection Controller, TED: Traffic Engineering Database.

The layer for the OBS specific control functions interact directly with the data plane; meaning that if a TE-tunnel has W wavelengths available, one wavelength is reserved for transmitting the Burst Control Packets (BCPs), while the rest (W-1 wavelengths) can be allocated (by the BCPs) for transmitting the data bursts. It is worth to mention that BCPs and data bursts must have a strict time relationship (the so called offset time) while the GMPLS messages can freely travel through the network (with no restrictions in time). Also the time scales in both layers are different, substantially larger in the GMPLS layer than in the OBS control layer.

According Figure JA9-2a, our network architecture works as follows: Whenever a client network has data to transport through the OBS network, it set up a request through the UNI signalling interface to its GMPLS edge node, which checks the availability of TE-tunnels that match with the potential source/s-destination/s of the client data: if so, the traffic of that client network is assigned to that/those existing TE-tunnel/s (of single or multiple wavelengths); if not, the edge node triggers a RSVP-TE Path-message to setup (in the RSVP ordinary two-way soft reservation process, and according to the information available in the TED database) new TE-tunnel/s that can satisfies the client demand/s.

Consequently, under such an architecture, the OBS network approximates the connection oriented behaviour, i.e., the source-destination path is determined by the OBS source node among the available preset TE-tunnels reaching the desired destination (see Figure JA9-2b); but the wavelength to send the bursts are chosen by the BCPs at each transit node along the selected path (TE-tunnel, meaning that a burst can be switched from one wavelength to another (always within the same TE-tunnel) according to contention avoidance policies or occupancy ratio. In this way, we achieve the idea of keeping the switching layer as fast as possible since only simple, local and limited decisions are required (select a wavelength among a set of pre-selected ones). Routing decisions, congestion notifications, protection/restoration, etc. are not implemented in the switching layer but moved to the control plane.

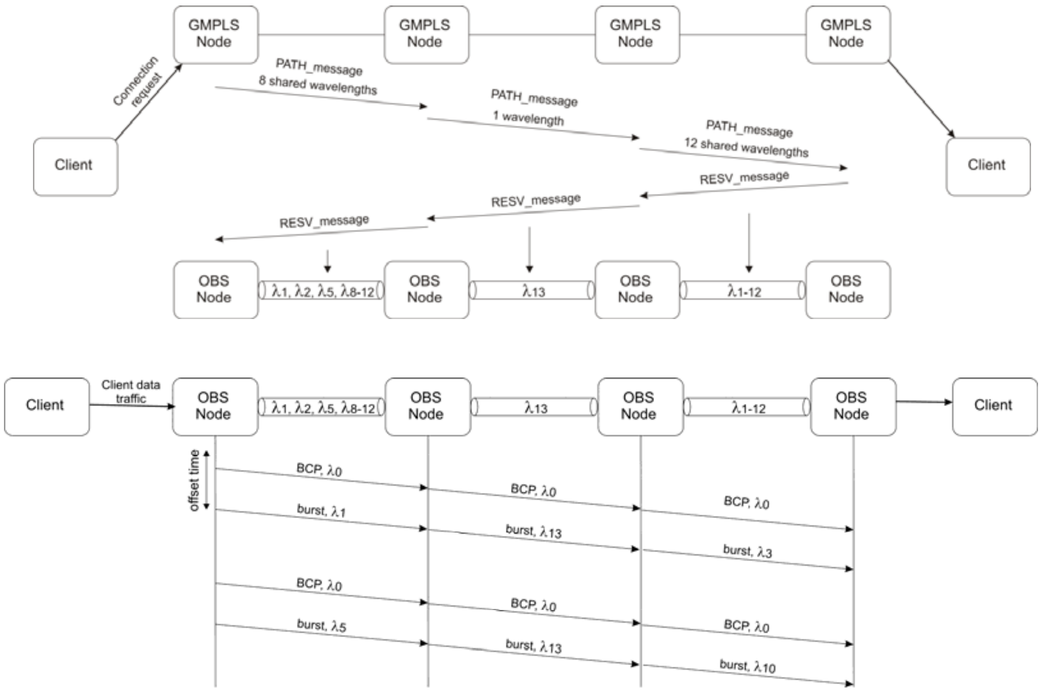


Figure JA9-2 Example of the GMPLS-controlled overlay logical network consisting of a) TE tunnels between sources and destinations, and b) wavelength selection at each OBS node.

11.3 QoS-aware path establishment processes

This section analyses the problem of Quality of Service (QoS) provisioning in GMPLS/OBS networks. The lack of optical memories result in quite complicated operation of OBS networks, especially, in case when one wants to guarantees a certain level of service quality. Indeed, quality demanding applications like for instance real-time voice or video transmissions need for additional QoS differentiation mechanisms in probability metric is perhaps of the highest importance in OBS networks.

In literature there are many papers that deal with several techniques to improve and ensure a certain QoS level. But all techniques were designed to be deployed in the OBS layer. This means that OBS should be responsible for all operations like paths setup, burst scheduling, burst switching, resources availability dissemination, connection admission control, etc. Although the combination of these mechanisms could provide better performance, OBS becomes extremely complex and not easy to manage.

In this section we propose two mechanisms to setup TE-tunnels able to provide average QoS guarantees to the OBS layer while keeping its decisions simple.

11.3.1 Algorithms

The Minimum Wavelength Load (MWL) algorithm is proposed. The algorithm performs a control action over the incoming bursts in order to support the connection requests with the specified QoS requirement. The operations of the algorithm are the following:

- We assume that each connection request, i, has an associated traffic load, ρ_i, and a QoS level, Q_i.
- At each node, the algorithm seeks for a minimum group of wavelengths, m_i, that guarantees the QoS. Starting with the four wavelengths of lowest load, m_i is incremented a unit whether QoS requirements are not met and up to a maximum equal to W: $m_i \in [4,W]$.
    - o If $m_i > W$, the connection request is rejected.
    - o If the connection request is accepted, it is forwarded to the following node.
- At the end of the process, a group of wavelengths per link j, m_{ij}, is assigned to a proper TE-tunnel for burst transmission. It is clear that the size of this group of wavelengths may change from link to link along the path according to each link load.

This process must be performed at the GMPLS layer by means of the path/resv messages of the proper extended RSVP-TE protocol.

An upgrade of this algorithm is the MWL with preemption capability (MWL/P). The purpose and premises of both algorithms are quite similar. The main difference is that MWL/P allows to releasing some of the wavelengths in the link assigned to other Te-tunnels till being able to insert the new connection request. The applicability of this algorithm is restricted to connection requests of HP traffic, whilst the released connection is of BE traffic.

A further upgrade of the MWL and MWL/P algorithms is to consider multiple paths. It means that, while MWP and MWL/P only consider the shortest path, MWL-kSP and MWL/P-kSP also take into account other paths if they fail to establish the TE-tunnel. A maximum of k-shortest paths is assumed.

In the simulation scenario, a reference algorithm is also considered in order to have a benchmarking. The reference simple accepts all requests and the bursts can use any wavelengths.

11.3.2 Simulation results

In our simulation scenario, we consider the EON (European Optical Network) topology (see Figure JA1-3) with 28 nodes and 39 links.

Network links are dimensioned with the same number of wavelength W = 32. The transmission bitrate is 10Gbps.

We assume each node is both an edge and a core bufferless node. We assume that a one-way signalling protocol, JET resources reservation, and LAUC-VF scheduling are applied. The switching and processing times are considered negligible.

The traffic is uniformly distributed between nodes and each node offers the same amount of total traffic to the network; this offered traffic is normalized to the transmission bitrate as in [JA9-12]. We assume that each node generates connection requests of the same capacity (10 Mbps): 50% of the connection requests are for HP bursts (clearly the remaining 50% for LP bursts). The acceptable QoS level for HP requests is set to 10^{-7}.

It is worth to mention that all simulation results have 99% level of confidence. It is achieved by means of at least 10 repetition of the same simulation.

Two performance parameters are considered: the burst loss probability (BLP) and the request blocking probability (RBP).

Figure JA9-3 shows the HP BLP as a function of the normalized offered load comparing the proposed algorithms with the reference one. We can observe that any MWL version is able to provide the required QoS level (QoS req. line in the figure). Between the different version, MWL and MWL/P with single path obtains lower BLP than the ones with multiple paths choices.

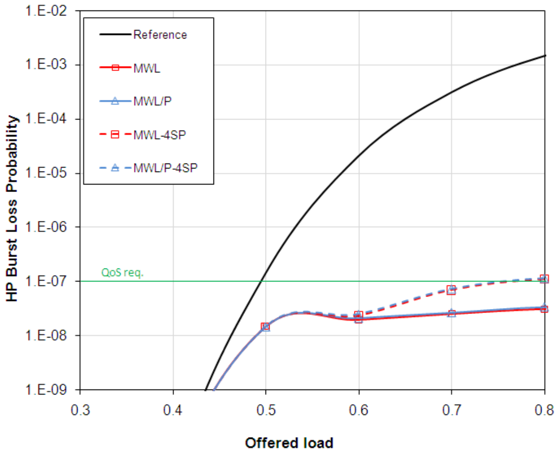
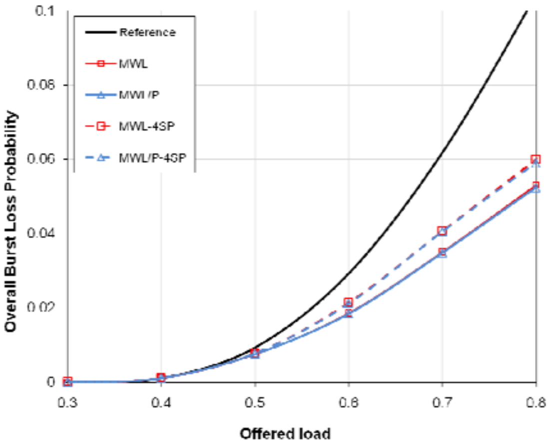
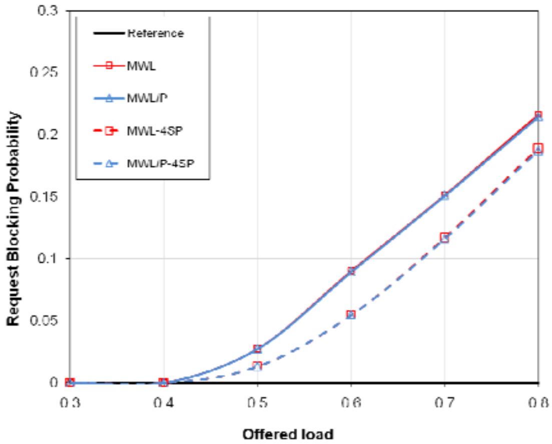


Figure JA9-3 HP burst loss probability as a function of the normalized offered load comparing the reference algorithm with the proposed MWL and MWL/P algorithms.

Figure JA9-4 shows the overall BLP (both HP and LP losses) and the RBP as a function of the normalized offered load. In Figure JA9-4a, we can see that the proposed algorithm obtain better overall performance than the reference. Comparing the proposals, MWL and MWL/P perform similarly (being the latter slightly better) and better than the ones with multiple paths. Nonetheless, these performances are achieved at the expense of having blocked path requests (see Figure JA9-4). As expected, the RBP increases accordingly to the offered load. The MWL and MWL/P with multiple paths choice obtain lower request blocking.



a)



b)

Figure JA9-4 a) overall burst loss probability and b) request blocking probability as a function of the normalised offered load comparing the reference algorithm with the proposed MWL and MWL/P algorithms.

11.4 Conclusions

This section discusses how to interoperate GMPLS and OBS to provide a proper Control Plane for OBS networks, which at the same time can be compatible with OCS networks. The outcome of this work can be summarised in two main contributions, namely a functional architecture for this interoperable GMPLS/OBS Control Plane, and four path establishment processes able to guarantee an average QoS level.

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12. Bidirectional service signaling in GMPLS networks

In the first year the joint activity focused on the definition of control plane strategies for the efficient set up of bidirectional connections in Generalized Multi-Protocol Label Switching (GMPLS) networks, as detailed in the following. A custom built event driven simulator has been developed to analyse and compare various bidirectional connection establishment schemes: the results of this work lead to the publication of the joint paper entitled "Bidirectional Lightpath Provisioning in GMPLS-Controlled Optical Networks" by N. Andriolli, A. Giorgetti, S. Ruepp, J. Buron, L. Valcarenghi, and P. Castoldi, in the Proc. of PS2008.

The GMPLS protocol suite builds on and extends MPLS techniques and protocols to provide a distributed control plane for transport networks with heterogeneous technologies and switching granularities (e.g., TDM timeslots, wavelengths, fibers). In GMPLS networks, a unidirectional connection (called Label Switched Path, LSP) is established with a downstream on demand label distribution [JA10-1]. After finding a route, typically by using the information gathered by the routing protocol [JA10-2] (e.g., OSPF-TE), a signaling session [JA10-3] is initiated exploiting the RSVP-TE protocol. A Path message is created at the source node and sent towards the destination node. It may include optional objects, such as the Label Set, used to constrain the label selection. When the Path message reaches the destination node, a Resv message is sent back indicating the label to be reserved for the incoming request. When the Resv message reaches the source node, the LSP is established.

The application of the GMPLS protocol suite to WDM optical transport networks enables the creation of dynamic Wavelength Routed Optical Networks (WRON), offering connection services directly at the optical layer in a flexible and cost-effective way. However connections in transport networks are typically bidirectional, with the same data transfer capabilities in each direction [JA10-1]. Another common requirement is that both connection directions share the same links to provide fate sharing. Moreover in WRON without wavelength conversion capability, both connection directions have typically to be routed on the same wavelength since (i) some optical devices, such as reconfigurable add/drop multiplexers and transponders, are constrained to handle the same wavelength in both directions, and (ii) the operation of flexible optical devices, such as optical cross connects, is simplified if the same wavelength is used on both directions [JA10-4]. These requirements can be satisfied by the trivial approach of establishing a pair of unidirectional lightpaths with two separate signaling sessions.

A smarter solution requiring a single signaling session to set up both directions of a bidirectional LSP has been standardized in the GMPLS signaling [JA10-3], [JA10-9]. This scheme reduces the setup latency, the number of exchanged control plane messages, and the memory requirements in the traversed nodes, since only one control plane state has to be stored. To setup a bidirectional LSP, the ingress node adds an Upstream Label into the Path message, used to perform a forward reservation of the resources belonging to the reverse path, while the forward path is reserved with the Resv message as usual.

However, the forward reservation in WRON without wavelength conversion capability may lead to poor network performance. If the status (i.e., reserved or available) of the wavelengths on the traversed links is not known in detail, the source node may reserve a wavelength not available on the whole path, causing the blocking of the setup attempt. To simplify the bidirectional LSP setup, a solution requiring a Label Set object dedicated to the reverse path, namely the Upstream Label Set, is proposed in [JA10-5]. This scheme however can run into problems when the Upstream Label Set conflicts with the Upstream Label, and additional signaling messages are required to confirm the reservation. Moreover this solution is not specifically tailored at establishing both lightpath directions on the same wavelength.

Recently an alternative scheme based on the Label Set object has been proposed, where both lightpath directions are established on the same wavelength with the usual backward reservation after collecting information on the wavelength utilization of both directions [JA10-4]. This scheme has also the advantage of not requiring any additional signaling object, but only a modification of Label Set processing within traversed nodes. For this reason the Upstream Label and the Label Set schemes are compared by means of simulations in three typical routing scenarios, where the routing protocol advertises more or less detailed network status information [JA10-6].

12.1 GMPLS Lightpath Setup

In this section the mechanism for LSP setup in a GMPLS-controlled WRON is described. After an LSP setup request, a route from source to destination is computed using the information advertised by the routing protocol. The three considered routing scenarios are detailed in Sec. 12.2.1. After the path computation, a signaling session is triggered to establish the lightpath: the two signaling schemes, namely the Upstream Label scheme and the Label Set scheme, are detailed in Sec. 12.2.2.

12.1.1 Routing scenarios and path computation

Three routing scenarios have been envisioned, where an increasing amount of network status information is advertised. In the *No Information (NI*) scenario, OSPF-TE is used to advertise only the network topology. In the *Aggregated Information (AI)* scenario, OSPF-TE is exploited to flood the number of wavelength channels available on each link. In the *Detailed Information (DI)* scenario, an extended version of OSPF-TE [JA10-7] is implemented to advertise the status of each wavelength on every link.

Path computation is performed at the source node by exploiting the advertised network status information. In all routing scenarios, the path between each node pair *(s,d*) is selected within a set of candidate paths called $P_{s,d}$. In the NI scenario, a path within $P_{s,d}$ is randomly selected. In the AI scenario, the path with the largest number of available wavelength channels on its most congested link is selected, using a link-state database containing the number of available wavelength channels on every link. Finally, in the DI scenario, the path that can accommodate the largest number of wavelength-continuous lightpaths is selected, using a link-state database containing the status of each wavelengths on every link. In AI and DI scenarios, if more than one path satisfies the condition, one of them is randomly selected. Note that in AI and DI scenarios a lightpath request may be blocked during path selection (i.e., Routing blocking) if the source node is unable to find a path with available wavelength channels.

In all routing scenarios the information is flooded through link-state advertisements (LSAs). To limit LSA generation in the AI and DI scenarios, where up-to-date network status information is distributed, an LSA update timeout is used. Once an LSA has been generated for a given link, all link-state changes detected on the link before the timeout are not immediately advertised, but delayed after the timeout expiration. OSPF-TE minimum LSA update timeout is 5 s.

12.1.2 Bidirectional wavelength assignment

After path selection the signaling session is triggered. If it fails during Path (Resv) message propagation Forward (Backward) blocking occurs in the downstream (upstream) direction. The two signaling schemes under consideration are detailed in the following.

A12.1.2.1 Upstream Label (UL) scheme

This scheme, depicted in Fig. JA10-1, adheres to [JA10-3]. A Path message is sent from source to destination. It contains a Generalized Label Request object and an Upstream Label, which reserves a wavelength in the reverse direction (λ_1 in Fig. JA10-1) and contextually indicates that the LSP is bidirectional. It may include optional objects, such as the Label Set. However, since both LSP directions must be routed on the same wavelength, the usefulness of the Label Set is severely limited as the only acceptable label is the one indicated in the Upstream Label object. In this case, the Label Set just serves to fill out the Acceptable Label Set object carried in the PathErr message. This situation is shown in Fig. JA10-1, where λ_1 is found busy on the second hop.

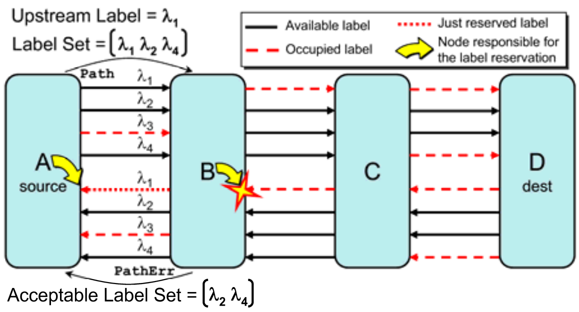

Fig. JA10-1 Upstream Label scheme.

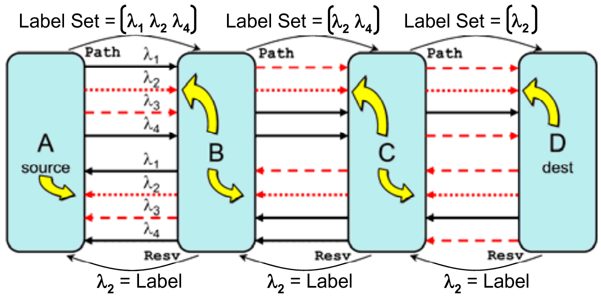

Fig. JA10-2 Label Set scheme.

Assuming that no error occurs, the reverse path is completely set up when the Path message reaches the destination. A Resv message is sent in the upstream direction to reserve the forward path, carrying a Generalized Label identical to the one used on the reverse path. When the Resv message finally reaches the source node, the LSP is established. If a reservation failure occurs due to a resource contention, the LSP is blocked and PathErr and ResvErr messages are sent to free the occupied resources

A12.1.2.2 Label Set (LS) scheme

This scheme, depicted in Fig. JA10-2, has been proposed in [JA10-4] to avoid the drawbacks of the forward reservation performed with the Upstream Label. The request for a bidirectional LSP is indicated with a flag in the LSP_ATTRIBUTES object [JA10-8] carried by the Path message. In this scheme the Label Set is mandatory and is updated at each intermediate node by checking the availability in both directions jointly. When the LSP setup request arrives at the destination node, it selects an available wavelength within the received Label Set (λ_2 in Fig. JA10-2) and starts the backward reservation of both LSP directions on the chosen wavelength.

12.2 Simulation study

The UL and the LS scheme performance are compared by means of a custom-built C++ event-driven simulator. A Pan-European network topology with 27 nodes and 55 bidirectional

WDM links is considered. Each link carries 32 wavelength channels per direction. Lightpath requests are dynamically generated according to a Poisson process and uniformly distributed among the source-destination pairs. Both inter-arrival and holding times are exponentially distributed with an average inter-arrival time of $1/\lambda = 1$s and an average holding time of $1\backslash\mu$ s. The load offered to the network is therefore expressed as λ/μ Erlang. The set $P_{s,d}$ includes all the paths whose hop length is within one hop from the shortest path. Random wavelength assignment is used in both schemes. In the UL scheme it is performed at source to select the Upstream Label, while in the LS scheme it is performed at destination to select a label within the received Label Set. Two LSA update timeouts are considered: 5 s and 30 s.

Simulation results are presented in Fig. JA10-3 in terms of blocking probability vs. offered network load for the three routing information scenarios. Each simulation point is plotted with the confidence interval at 95% confidence level. Links lengths are equal to their geographical distances. Processing time of the packets are considered negligible compared to the transmission and the propagation times.

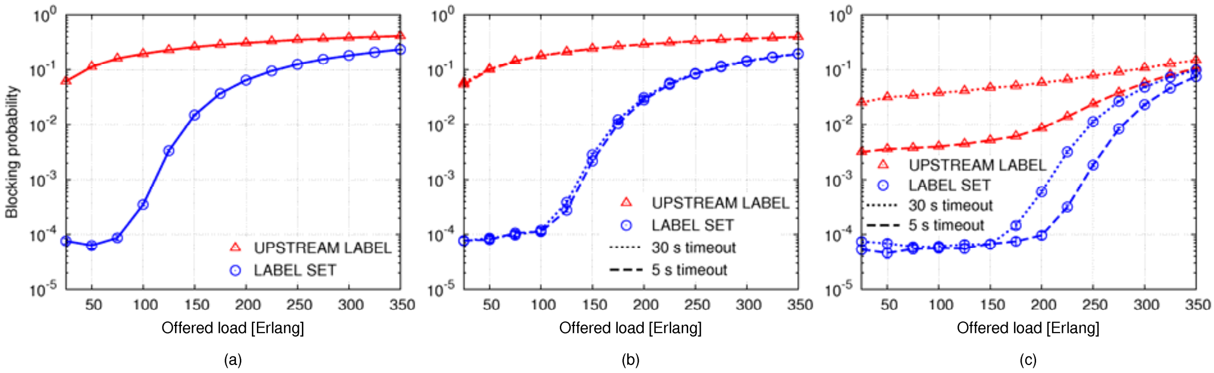

Fig. JA10-3 Blocking probability comparison between the Upstream Label scheme and the Label Set scheme in the (a) NI, (b) AI, and (c) DI scenarios.

Fig. JA10-3 shows that the LS scheme outperforms the UL scheme in all considered scenarios. The UL scheme experiences very high blocking probability particularly in the NI and in the AI scenarios. The forward blocking dominates, showing that the selection of the Upstream Label made at source node is not effective especially when only partial network status information is advertised. In the DI scenario the UL scheme performs slightly better thanks to a more precise knowledge of the network status. In particular, if the timeout is 5s the blocking is significantly reduced compared to 30s, which highlights the importance of exploiting up-to-date information when performing a forward reservation.

On the contrary the LS scheme, by leveraging the backward reservation to optimize the wavelength assignment, significantly lowers the blocking probability. Forward and backward blocking are the main blocking probability contributions. Backward blocking is a flat contribution dominating at low loads: since it is caused by resource contention between concurrent lightpath setup requests, it is not affected by the routing information scenario. Forward blocking is a contribution which grows with increasing offered load and depends on the resource availability. Using more detailed routing information, a higher load can be tolerated before forward blocking becomes dominant. As in the UL scheme, a shorter LSA update timeout is especially useful in the DI scenario, when detailed and up-to-date wavelength availability information allows a smarter path and label selection.

12.3 Conclusion and future work

In this study we compared the standard Upstream Label (UL) scheme and the proposed Label Set (LS) scheme for bidirectional lightpath provisioning in GMPLS WRONs. In the LS scheme, the only signaling process modification is that the Label Set object is updated by considering the wavelength availability also on the reverse path. Simulation results show that the UL scheme performs poorly unless detailed routing information is frequently advertised. The LS scheme outperforms the UL scheme in all the considered routing scenarios, especially at low and medium loads.

As a further work, we aim at studying the benefits of introducing a Path Computation Element (PCE) to set up bidirectional LSPs without the need of signalling extensions (i.e., using the standard UL signalling scheme). The network status information and the centralized location of the PCE can be effectively exploited for avoiding resource contentions during the forward and the backward signalling phase, respectively. The simulation scenario will also introduce the use of crankback functionalities, and both blocking probability and set up delays will be investigated.

12.4 References

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13. Conclusions

The activity being carried out in the first year of WP22 shows that the topic on convergence of IP, MPLS and GMPLS networks is quite active and the WP is expected to complete its objectives with the planned scheduled. The results in terms publications includes over 5 joint conference papers, plus 7 non-joint, two published journal paper (1 joint, 1 non-joint) plus some others submitted. In this period, 3 mobility actions were committed (one already done), and several testbed interconnection activities for joint experimentation are underway (CTTC-UPC, CTTC-IKR, UC3M-UPC).