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# An Experimental ASON Based on OADM Rings and a GMPLS Control Plane.

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## ABSTRACT

**This paper presents the architecture of an ASON testbed implemented in the EMPIRICO project<sup>1</sup>, focusing on design and implementation issues of real-time provisioning of bidirectional optical connections supported by a distributed GMPLS-based control plane and triggered by the Network Management System. Experimental performance is evaluated over a unidirectional and a bidirectional all-optical OADM ring in which neither wavelength converters nor optical resources discovery are employed. Performance analysis evaluates the blocking probability and the connection setup time.**

## KEYWORDS

GMPLS, ASON TESTBED, RSVP-TE, OADM RING, DWDM.

## I. INTRODUCTION

The accelerating growth of data traffic is motivating the research for next-generation intelligent optical network architectures based upon recent advances in optical networking technologies such as *Dense Wavelength Division Multiplexing* (DWDM), and more recently dynamically reconfigurable *optical cross connects* (OXC) and *optical add drop multiplexers* (OADM), capable of providing wavelength-routed WDM networks with high-bandwidth optical connections (40 Gb/s and beyond). The major benefits of intelligent optical networks are dynamic and real-time provisioning, automatic topology and resources discovery, traffic engineering for making the most optimal and efficient use of the network

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<sup>1</sup> EMPIRICO project is partially supported by the Spanish Government under contract PU-2002-56. The EMPIRICO testbed is currently being developed at CTTC laboratories.

resources, and dynamic protection and restoration capability when a failure occurs in multi-domains and multi-vendors environment. The introduction of intelligence in optical networks is achieved by means of using a distributed optical control plane, which deals with the automation of optical connection provisioning in optical networks, named *automatically switched optical network* (ASON) [1]. Basically, the optical control plane is based on three protocols: a signaling protocol for automated connection setup and teardown, a routing protocol for automated network topology and resource availability discovery, and a neighbor discovery protocol for automated neighbor discovery.

In this context, the optical control plane can be based on IP or ATM protocols. Initially, the *Internet Engineering Task Force* (IETF) proposed to adapt IP-based protocols for the control plane, particularly a MP $\lambda$ S control plane, which is essentially the *Multi-Protocol Label Switching* (MPLS) control plane with extensions for wavelength switching, allowing integration with high-speed IP/MPLS networks. More recently, *Generalized MPLS* (GMPLS) [2] has also been proposed, which extends MPLS to support multiple types of switching such as packets, time division multiplex (SDH/SONET time slots), wavelengths and fiber optics. The *Optical Internetworking Forum* (OIF) is currently specifying ASON interfaces based on GMPLS. In the last months, it has also been proposed to base the optical control plane on ATM protocols, such as the Private NNI signaling protocol (PNNI). Specifically, the basis of the GMPLS control plane takes the following protocols: *Link Management Protocol* (LMP) as neighbor discovery protocol, interior gateway protocols (IGPs) such as *Open Shortest Path First* (OSPF) or *Intermediate System - Intermediate System* (ISIS) as topology and resources discovery protocol, and *Resource Reservation Protocol Traffic Engineering* (RSVP-TE) or *Constraint-Based Routing Label Distribution Protocol* (CR-LDP) as signaling protocol to set up lightpaths.

In this paper we present the architecture of an ASON testbed currently being implemented in the EMPIRICO project, focusing on design and implementation issues of a GMPLS-based control plane for dynamic, real-time provisioning of bidirectional optical connections triggered by the optical *Network Management System* (NMS) over a unidirectional and a bidirectional OADM ring in which neither wavelength converters nor optical resource discovery are employed. This constraint means that a

lightpath must occupy the same wavelength on all the links through which it traverses. Finally we present and compare the performance evaluation of the implemented GMPLS-based control plane over a unidirectional and a bidirectional ring. Two routing schemes for performance analysis are considered; fixed and fixed-alternate.

The remainder of this paper is organized as follows. In Section II we give insight into the EMPIRICO testbed network architecture overview. In Section III we describe the architecture of the implemented *Optical Connection Controllers* (OCC), detailing the control plane modules and their functionalities. Performance evaluation obtained experimentally on the EMPIRICO testbed is presented in Section IV, and finally Section V concludes the paper.

## II. TESTBED NETWORK ARCHITECTURE OVERVIEW

As mentioned before, the EMPIRICO testbed is based on an ASON/GMPLS network constituted by a metropolitan DWDM ring with three dynamically configurable OADMs, which allows for the establishment of real-time, dynamic, end-to-end connections between Gigabit Ethernet client equipment. Figure 1 shows the logical architecture of the testbed, which can be characterized by three planes: transport, control and management.

### A. *Transport Plane*

The transport plane is responsible for the provision of uni and bidirectional optical channels, transparent to the format and payload of client signals, and for the detection of information about the state of connections and their performances, such as errors or signal quality. The transport plane is composed by an optical ring with three all-optical OADMs that can work as a unidirectional ring or as a bidirectional ring. Each link consists of one pair of unidirectional fibers, one in each direction. For the unidirectional ring one of them is used for *Optical Multiplex Section* (OMS) protection, so only a unidirectional fiber is available per link. In the testbed, each fiber is capable of handling up to 8 wavelengths (for economic reasons) spaced 100 GHz (ITU channels from 30 to 37), and each link has a distance of 35 km. This imposes a maximum optical path length of up to 70 km. All laser sources are

fully tunable. Modulating the optical channels is achieved by using 2.5 Gbit/s direct modulation or 10 Gb/s with the use of Lithium Niobate external optical modulators. The OADMs are all-optical, that is, no OEO conversions are employed within the optical network for inserting or extracting the optical channels. Moreover, no wavelength converters are contained in the OADMs.

The add/drop stage has two implementation scenarios. The first one corresponds to the structure shown in Figure 2a. An incoming signal from the fiber is first demultiplexed into separate wavelengths before entering to the 2x2 optical switches. These switches are capable of dropping the wavelength, adding a new one, or passing through the wavelength. Each wavelength has its own switch, so all the wavelengths that cross the node can be added or dropped. Finally, each output is wavelength-multiplexed before the signal is sent to the outgoing fiber.

The second implementation scenario of the OADMs, depicted in Figure 2b, uses 18x18 *Arrayed Waveguide Gratings* (AWG) components in combination with 2x2 optical switches. Each optical channel that must be added (respectively dropped) undergoes optical switching and multiplexing (respectively demultiplexing) by the AWG. On the other hand, pass-through channels go through demultiplexing, optical switching and multiplexing. The use of optical amplifiers is therefore necessary to compensate the losses introduced in the optical ring. In the bidirectional architecture, the optical signals are duplicated and sent in each direction (fiber) of the ring in order to have protection. At the reception of the signals, an optical switch selects the best fiber if one of them is failing. For this aim, the power levels of each signal and its replica are constantly monitored at reception. By use of all-optical monitoring systems, valuable information is reported to the NMS without acceding the bits carried by the payloads. To this aim, taped signals from monitoring points at the input and output of each OADM, both in unidirectional and bidirectional architectures, are continuously analyzed via measuring the power, frequency and OSNR for each DWDM channel. Processing this information allows not only the generation of alarms, but also the localization of the failure and, to some extent, its identification.

## ***B. Control Plane***

The control plane is responsible for handling dynamically and in real-time OTN's resources in order to manage the establishment and deletion of optical connections, and for disseminating and discovering network topology and resource availability through the exchange of control (signaling and routing) messages between neighbor OCCs over the *Data Communication Network* (DCN), depicted in Figure 3b. Each OCC is implemented on a Linux platform with two 1 GHz processors, acting like an IPv4 router. The DCN is implemented through full duplex Fast Ethernet links transported out-of-band on wavelengths of 1310nm (Figure 3a).

The control plane architecture (Figure 4) has been designed in line with the ITU-T Recommendation G.8080 [1]. As depicted in Figure 4, the implemented modules are the *Connection Controller* (CC), *Routing Controller* (RC), *Link Resource Manager* (LRM) and *Protocol Controller* (PC). The CC manages optical connection establishment and deletion and coordinates the rest of modules. The RC is responsible for network topology discovery and route computation. The LRM is responsible for local optical resources management and wavelength allocation. As mentioned above, no automatic optical resources discovery is implemented, so each OCC only has a representation of the local resources configured by the NMS. Finally the PC provides the function of mapping the parameters of the controller's interfaces into messages that are carried by a protocol to support interconnection via an interface. We have implemented four PCs: lightpath signaling and routing exchange (NNI) based on GMPLS extensions to RSVP-TE and OSPF-TE respectively, management (NMI) based on the *Simple Network Management Protocol* (SNMP), and optical hardware configuration (CCI) based on a proprietary protocol. A more detailed description of each module is provided in section Section III.

## ***C. Management Plane.***

Although there is an important effort to standardize ASON's architecture and functional requirements, fundamentally of the control plane [1], a considerable effort is still required for the management of this type of network and the services supported by it. In the short run, future management planes are expected

to be mainly used for provisioning of *soft-permanent connections* (SPC) within a single-operator domain [3], due to the need to protect investments currently deployed in network management systems and transport networks [4] and the immaturity of control plane technologies. This results in the primary need for exploring the interactions of management and control plane for provisioning of SPCs, taking into account the transparent nature of future transport networks.

Motivated by this fact, and since the control plane is allocated with a number of mechanisms with similar functionality to traditional management functions, such as path provisioning or route computation (Section II.B), the management plane of the EMPIRICO testbed is responsible for SPC triggering, connection status reinforcement through optical network monitoring, and control plane configuration and performance management, which takes the best of the control and management “*worlds*”: the control plane provides distributed intelligence and the information (OAM) flow is shared by the control (real-time) and management (near real-time) planes.

Figure 5 depicts the architecture of the management plane, which takes into account the functional requirements identified in [5] and applies them to the combination of GMPLS and resource information being provided through all-optical monitoring. Hence, the management plane falls within the manager-agent paradigm, being its key architectural elements the NMS, which acts as an information system manager for network control and monitoring, the management agents, located in the optical nodes of the ASON control plane (OCCs) and transport plane (OADMs), the management protocol, upon which is based the *Network Management Interface* (NMI, Figure 1) and *Management Information Bases* (MIB), which are abstractions of the optical network’s management information consisting of network resources admitting management. Due to ASON requirements, we consider MIB standards for TCP/IP-based networks and an NMI based upon SNMP in line with IETF.

For setup and teardown of SPC both over uni and bidirectional rings, the above-mentioned key elements interact with each other as described in [6] by the authors, and the following OAM flow is performed in the different phases of a SPC connection establishment:

The NMS triggers a SPC request by sending a SNMP Set message to the management part of the OCC connected to the client requesting the connection (*OCC Management Agent* in Figure 5), which has a MIB (*MIB Connection* in Figure 5) containing high-level attributes necessary for SPC establishment, such as payload, wavelength (to be assigned by the control plane) or bidirectionality, among others. The request is translated to the control plane part of the OCC (Figure 4) via an internal interface (GRAPI, further described in Section III.C). We follow this approach due to the complexity of GMPLS MIBs and to avoid both duplicating unnecessary information and creating new managed objects carrying existing control plane data, reducing network management burden and boosting network automation.

Automatic provisioning by the control plane results in the need for up-to-date information on the physical resources' availability or the status of the connections. So, the management plane is responsible for configuring a representation of local resources of the OCC (no automatic optical resources implemented in the testbed). Resource information is obtained and updated by the *OADM Management Agent*, which has direct access to physical resources' status through an all-optical monitoring block. This block sounds the analogue characteristics of optical signals and takes out valuable information about their performance. For each WDM channel, we measure the optical signal power, OSNR and optical frequency in each IP/WDM node by tapping a small part of the optical signal power to fulfill a non-intrusive optical performance monitoring. The measurements are logged, correlated and compared to convenient threshold values by the NMS in its *Alarm Manager* block (Figure 5). After the control plane has reserved an optical channel, the *OCC Management Agent* is informed and sends a SNMP Response message to the NMS. Note that the attribute corresponding to the wavelength of the established connection is filled with the value allocated by the control plane.

The control plane itself requires as well configuration, since it is made of network elements, therefore managed objects related to the control plane, such as node status, are implemented in the control plane part of the OCC, and it is the NMS that queries on their status through GRAPI to configure or update them in its *Network Inventory Management* block (Figure 5). Note that the transport part of the node needs as well managed objects for status and reconfiguration of thresholds of resources. Moreover, the

management part of the optical node is autonomous with respect of the control and transport parts; if the management agents experience an error or shut-down, they query the control plane's stored information (*Status and Control Info* in Figure 5) to get started with updated information without affecting the other parts, and the same applies for the NMS. Hence, management data modeling and interfacing is done in a distributed way (MIB Connection, GRAPI and TAPI in Figure 5) to favor fast updating, in contrast to current centralized databases, often incomplete and error prone.

### III. OPTICAL CONNECTION CONTROLLER ARCHITECTURE

#### A. Routing Controller

In the EMPIRICO testbed we have considered two routing instances each one related to its own plane (*Control Plane* and *Transport Plane*). It is clearly assumed the separation of the control and transport planes in order to avoid that control failures affect transport data channels and viceversa.

The routing at the control plane is performed by the OSPF link state routing protocol [7]. OSPF floods the state interface of each control by means of the *link state update* packets, performing a link state database at every node. From this link state database, each node constructs its routing table (*RT*) using the shortest path based on Dijkstra algorithm. This *RT* will be used for signaling issues, having IP layer rerouting after control plane link failures, which results in updating the *RT* (the signaling protocol messages are addressed using node addresses instead of the interface addresses currently used in RSVP-TE, so messages will be routed to the desired destination).

Relating to the routing problem at the transport plane, three strategies have been taken into account, as shown in Figure 6: *Fixed Routing (FR)*, *Fixed-Alternate Routing (FAR)*, and *Adaptive Routing (AR)*. In this paper we consider *FR* and *FAR* strategies, and *AR* solution will be soon implemented. In *FR* a single fixed routed is predetermined for each source-destination pair. This path is selected according with the shortest path between each source-destination pair, therefore the *RT* consists of one entry for each candidate destination node, where the entry specifies the path for every source-destination pair.

For the unidirectional ring (Table 1), a single unidirectional physical link connects each optical transport elements pair. In other words, there is only one fixed route for a given source-destination pair, and this fixed route must follow the direction of the working fiber, that is, to establish a unidirectional optical connection from node 1 to node 3, node 2 must be passed-through.. In contrast, for *bidirectional* ring (table 2.a) each source-destination pair is routed by means of a direct path. In both topologies, if the selected path for any source-destination pair is not available, the connection is blocked, so *FR* is easy to implement, but is subject to unacceptably high blocking probabilities.

*FAR* strategy attempts to address the shortcomings of *FR* by augmenting each entry in the *RT* to be a prioritized set of paths from each source-destination pair, rather than just a single one. Obviously, this routing strategy, for the EMPIRICO testbed, only takes into account the bidirectional ring topology, and the set of paths is limited to two. As shown in the in the Table 2b, we have imposed that the set of prescheduled paths for any source-destination pair be sequenced by the path metric, i.e. when a connection request arrives, the source node attempts route in this sequence from the *RT*, until an available route is found. If no available route is found from the list the request is blocked. Although in the existing *Routing and Wavelength Assignment* (RWA) literature *FAR* technique is claimed to offer lower connection blocking probabilities than *FR*, we will show in Section VI that the expected benefits of *FAR* are not achieved in bidirectional rings with wavelength continuity constraint.

*AR* attempts to select a path between a source-destination pair based on dynamically collected information concerning the network's state. This technique is currently being implemented. The approach chosen in EMPIRICO testbed considers that each link in the network has associated a specific weight function that denotes the cost of using the link, so the optical network topology can be viewed as a uni-layer graph. A way of selecting a path from a source to a destination is to determine the shortest-cost path using Dijkstra's algorithm, in which the weight functions depend on several factors, such as the hops, distance or DWDM-specific information, such as the number of available wavelengths on a given link.

The flooding of information through the network is performed using of the link state protocol OSPF with the extensions to traffic engineering (TE) [8]. OSPF-TE disseminates the optical link information by means of the *sub-tlvs* included into the *Opaque LSA type 10* (area scope). The optical link information for routing computation is the TE metric *sub-tlv*, which we have imposed to be set to the inverse of the available wavelengths over that link; hence this metric leads to compute the *RT* using the Dijkstra shortest-path algorithm. By doing so, *AR* technique is much more resilient to data link failures and allows to provide a balanced load over the whole network, thus offering lower connection blocking probability than fixed adaptive routing approaches.

### ***B. Link Resource Management***

All the information about local optical resources (wavelengths and fibers) is stored in the *Network Link Resource Table* (NLRT) and in the *Client Link Resource Table* (CLRT) of each OCC. In order to collect this information, an addressing scheme for all the optical resources of the network must be defined. The simplest option consists of assigning an IP address per wavelength, but, since this option clearly represents a great waste, the IETF proposes the use of *Unnumbered Links*. The *Unnumbered Links* addressing scheme consists of providing each OCC with only an IPv4 address acting as node identifier. The concept of logical port is used here to identify each wavelength, formed by the physical port identifier, which identifies the different fibers of the optical node, and the channel identifier, which identifies the different wavelengths inside an optical fiber. The IETF has also proposed the *Bundled Link* addressing scheme allowing to group different links that share common characteristics under the same identifier, with the aim of reducing the computational overhead. Figure 7 shows an example of the addressing scheme for OCC1 in the EMPIRICO testbed.

Note that the above-mentioned identifiers only have value locally, that is, each OCC may assign different identifiers to the same physical fiber or wavelength. Therefore, each OCC must register its local optical resources in the NLRT and CLRT, and map its identifiers with the identifiers of its neighbor OCCs (remote identifiers). On the EMPIRICO testbed, the NLRT and the CLRT are configured by the

NMS, although we also consider future automatic configuration by means of an automatic neighborhood mechanism such as the LMP, which would allow automatic detection of new fibers and wavelengths between an OCC and its neighbors, and to update NLRT and CLRT with local and remote identifiers. In the same way, this mechanism would allow to detect optical resource failures and to update the corresponding CLRT or NLRT.

In the NLRT and CLRT each wavelength is identified by its local and remote logical port, which allows to define the following attributes; switching type supported (packet, slot, lambda or fiber, taking the value of *Lambda Switch Capable*, LSC, in the EMPIRICO testbed), maximum bandwidth supported by the optical technology, type of the client signal transported (lambda in the EMPIRICO testbed), resource state (*Unequipped, Reserved, In-Service, Failed or Stand-by*), directionality (transmission or reception) and a the session that has reserved the wavelength. Apart from these attributes, the CLRT also includes the client layer and the tunable range of the laser sources.

### ***C. Connection Controller***

The CC is the main controller of the OCC. Its function is to receive and process optical connection requests and packets the NMS and the neighbor OCCs through the respective interfaces, managed by the PC. Figure 8 shows the implemented architecture of the CC and their associated PC for SPCs, which we have named *GMPLS Daemon*.

*GMPLS Daemon* is based on the RSVP protocol for optical connection signaling, and consequently a great part of RSVP operation mechanisms have been adopted. This implementation specifies a subset of RSVP messages and objects that are considered fundamentals for the I-NNI signaling from the point of view of establishing SPCs, according to GMPLS extensions introduced by [9]. A specific Application Program Interface (API) for GMPLS-RSVP, which we have named *GMPLS RSVP API* (GRAPI), has been implemented allowing local communication with *GMPLS Daemon*. The GRAPI interface is based on a client library especially designed for use by the *OCC Management Agent* (Section II.C). The *GMPLS Daemon* has three main functions: listening, processing and packet delivery. The first function

consists of a main loop that listens to all the established sockets until one of them is activated. Apart from the socket established with the GRAPI (*OCC Management Agent*), there are other types of sockets, such as those established with the I-NNI signaling interfaces, allowing the reception of NNI RSVP messages from other OCCs. So, when a socket is activated, the *daemon* identifies which socket has been activated to call the function that will process the information contained in the socket. The packet processing depends on the ring topology (unidirectional or bidirectional) and on the routing approach implemented (fixed or fixed-alternate).

In order to achieve the wavelength-continuity constraint when no global information about optical resources is employed, an aggressive downstream reservation solution must be applied, in which all wavelengths available on all of the links traversed are reserved along the downstream path to the destination on a hop-by-hop basis. A *Label Set* object is included in the Path message allowing an upstream node to restrict the set of labels that a downstream node can choose, and ensuring that a downstream node will assign a label that is acceptable to an upstream node. Note that there is no guarantee that at least one wavelength of a selected set by the source node be available along every link in the path. If no wavelength of the set is available in each link in the path, the request is blocked and the lightpath cannot be set up for fixed routing. For fixed-alternate routing, the source node attempts to establish the connection on the second route maintained in the routing table. If this connection is also blocked then the lightpath cannot be set up. If the Path Message reaches the destination OCC, it selects one of the acceptable labels based on First-Fit wavelength assignment algorithm, and releases the reservations on the remaining wavelengths. In order to show an illustrative example of GMPLS signaling working, Figure 9 shows a generic unidirectional lightpath setup with the Label Set object implemented on the EMPIRICO testbed .

When a new connection request arrives to the source OCC, the CC creates a new Path State Block (PSB) for this session (e.g. session 1) and initiates a RSVP Path Message with a new session containing a Generalized Label Request Object. Then the RC determines a strict path to the destination, recorded on an Explicit Route Object (ERO) and the LRM determines the outgoing fiber identifier associated to the

route, which is included in an IPv4\_IF\_ID\_RSVP\_HOP object (type 3). For SPCs, the last hop of the ERO specifies the destination OCC and the destination port identifier using a new subject of type 4 that specifies the client point of attachment. It then intersects the set of available labels (31, 35, 37) on its outgoing link with the set of available labels on the source laser (30, 31, 32, 33, 34, 36, 37), yielding an outgoing label set (31, 35, 37) included in the Path message, which will be forwarded to the next hop. The labels included in the new label set are reserved, so now there is no available wavelength in this fiber. Then the Path message, with other relevant objects, is sent along the selected route one hop at a time, and each intermediate node processes the Path message before forwarding it to the next node, hence creating a new Path State Block (PSB) that associates all the parameters of the session. The intermediate OCC reserves the received set of the available labels on its incoming fiber specified by the received IPv4\_IF\_ID\_RSVP\_HOP object, and intersects them on its outgoing fiber (31, 33, 35), yielding a new label set (31, 35). The outgoing link is obtained by the LRM from the ERO object. Finally, the destination OCC selects one label of the received label set using the First-Fit algorithm, and initiates a Resv message including the Generalized Label Object with the selected label that will be assigned at each hop toward the source OCC, following the same path of the associated Path messages.

#### **IV. PERFORMANCE EVALUATION**

In this section, we study the performance of two lighthousepath setup approaches over the unidirectional and bidirectional OADM rings of the experimental testbed. First we describe the main assumptions adopted and then we present the results and discuss them.

##### ***A. Assumptions***

- All the lighthousepath requests are bidirectional.
- Lighthousepath requests arrive according to a Poisson process, and the lighthousepath holding time is exponentially modeled with a mean of 1 sec.
- The traffic is uniformly distributed among all node pairs.

- Each data point is obtained over a simulation of 2000 connection requests.

Load is measured in Erlangs, which can be calculated by multiplying the connection arrival rate with the average connection holding time. To study the network's behavior under different loads, the arrival rate of connection requests is varied as a parameter in the result extraction. Note that the load refers to the average number of connections measured at any instance of time in the network if there is no blocking.

### ***B. Extracted Results and discussions for the unidirectional ring***

To the best of our knowledge, the provisioning of bidirectional optical connections using a distributed GMPLS-based control plane over a unidirectional ring has not been considered in the existing literature. In [10] the authors present and compare the performance evaluation of two novel experimental proposals of GMPLS bidirectional lightpath provisioning over an unidirectional ring, called *Whiting* and *Salmon*, designed for optimizing the blocking probability in networks with wavelength continuity constraint and no global information. The Label Set approach has the major problem that network resources are over-reserved for a short period of time during the setup delay, which may lead to the blocking of subsequent connection requests and to a decrease of network utilization.

The *Salmon* proposal (Figure 10a) is based on a parallel reservation scheme (one in line with the ring direction and another opposite with the ring direction) that tries to minimize the setup delay, that is, the time required to establish a connection in order to reduce the period of time that network resources are over-reserved due to Label Set. However contention for labels may occur between two paths traveling in opposite directions. Such contention occurs when both sides allocate the same resources at the same time. To solve this problem, label contention policies must be applied. We have applied a policy in which the session with the higher identifier wins the contention. Although network resources are over-reserved for a short period of time, the label contention problem may lead to increasing the blocking probability. The *Whiting* proposal (Figure 10b) is based on a sequential reservation scheme that avoids label contention problem but increases the setup delay. A priori, it is difficult to determine which

parameter (whether the setup delay or the label contention problem) has more impact in terms of blocking performance.

The comparison of both lightpath setup proposals (Figure 11) is mainly focused on two results: the blocking probability and the setup delay. The first one refers to the probability that a connection cannot be established due to resource contention along the path. The other refers to the time required to establish a connection once a connection request arrives. The performance analysis obtained shows that the performance evaluation of the *Salmon* approach, despite the label contention problem, is always better than the *Whiting* approach, even when no label contention policy is applied (Salmon LCP applies a label contention policy based on the higher session identifier), achieving a reduction of the blocking probability up to 50% for low rates. Finally, it is also shown that the setup delay is more important than the label contention problem, that is, is preferable to have short setup delays and label contention than large setup delays and no label contention problem.

### ***C. Extracted Results and discussions for the Bidirectional Ring***

Bidirectional lightpath setup based on GMPLS over wavelength-routed DWDM networks with bidirectional links has been extensively covered by the existing literature [2][11]. Basically, GMPLS allows both the downstream and upstream data paths to be established using a single set of signaling messages. This reduces the setup latency to essentially one source-destination round trip time plus processing time, and limits the control overhead to the same number of messages as a unidirectional lightpath setup. Bidirectional lightpath setups are indicated by the presence of an Upstream Label in the Path Message that allocates an upstream wavelength. Just like the *Salmon* proposal [10], contention for labels may occur between two bidirectional optical connection setup requests traveling in opposite directions. In this case we have applied the same label contention policy as in the *Salmon* proposal (based on the highest session identifier). Finally, note that the current GMPLS-RSVP signaling does not allow the implementation of aggressive reservation approach for the upstream label, since the Upstream Label object only specifies a single upstream wavelength and there is no guarantee that this single

wavelength chosen by the source node be available along every link in the path, so it may lead to increasing the blocking probability.

Figure 12a plots the obtained blocking probability vs. load for fixed and fixed-alternate routing schemes, from which it can be inferred that fixed-alternate routing has an upgraded behavior with respect to the fix routing approach only for lower loads. The blocking reduction is about 50% at 5 Er and 20% at 10 Er. For lower loads, in general, the second attempt of the fix-alternate routing scheme is successful and consequently the lightpath can be established. However, for higher loads, fixed routing performs better than fix-alternate. This is due to the fact that more reattempts are done, increasing the period of time that the network resources are over-reserved (Figure 12b) during the setup delay due to the Label Set, which leads to the blocking of subsequent connection requests. In general, it can be concluded that for bidirectional rings with wavelength continuity constraint and no global information about network resources, the setup delay is a parameter of first order and need to be carefully considered.

## V. CONCLUSIONS

This paper presents the architecture of the optical control plane implemented on a real ASON/GMPLS testbed for setup and teardown of soft-permanent connections and compares the performance of GMPLS bidirectional lightpath setup over unidirectional and bidirectional rings implemented on a real testbed in which neither wavelength converters nor optical resource discovery are employed. So, in order to guarantee the wavelength continuity constraint without global information, an aggressive downstream reservation scheme which over-reserves resources must be applied, such as the Label Set object in GMPLS-based networks. For the unidirectional ring, it is shown that the setup delay is more important than the label contention problem, that is, it is preferable to have shorts setup delays and label contention rather than large setup delays and no label contention problem. Regarding the bidirectional ring, the performance evaluation has shown that under wavelength continuity constraint, the fixed-alternate routing has better performance for lower loads. On the other hand, the fixed routing performs better for higher loads, due to the fact that fix-alternate routing has longer setup delays than fix

routing, increasing the period of time that the network resources are over-reserved, which leads to the blocking of subsequent connection request.

## REFERENCES

- [1] ITU-T Recommendation G.8080, *Architecture for the Automatically Switched Optical Network (ASON)*, November 2001.
- [2] E. Mannie et al, *Generalized Multi-Protocol Label Switching Architecture*, IETF draft-ietf-ccamp-gmpls-architecture (work in progress).
- [3] Manzalini, A.; *Roadmap to automatic switched optical networks for metropolitan areas*, Global Optical Communications 2001, WMRC. 2001.
- [4] Hartmer, U. Ed.; *Generic architecture for a management system of automatic switched transport networks*, Network Operations and Management Symposium, NOMS. Florence (Italy), April 15-16 2002.
- [5] Chen. L., Ed.; *Requirements for the management plane in support of NG-OTN control plane functions*, oif2003.041.00, February 2003 (work in progress).
- [6] R. Muñoz, C. Pinart, G. Junyent, *A GMPLS optical control plane for IP/Gigabit Ethernet over dynamic DWDM networks. Testbed implementation for soft-permanent connections*, 7<sup>th</sup> IFIP Working Conf. Optical Network Design and Modeling. Budapest, February 3-5 2003.
- [7] J. Moy et al, *OSPF Version 2*, IETF RFC 2328.
- [8] D. Katz et al, *Traffic Engineering Extensions to OSPF Version 2*, IETF draft-katz-yeung-ospf-traffic (work in progress).
- [9] L. Berger et al, *Generalized Multi-Protocol Label Switching (GMPLS) Signaling Resource Reservation Protocol-Traffic Engineering (RSVP-TE) Extensions*, IETF RFC 3473, January 2003.
- [10] R. Muñoz, R. Martínez, G. Junyent, C. Pinart, G. Junyent, *Performance Evaluation of two new GMPLS Lightpath Setup Proposals over an Unidirectional OADM Ring Implemented on a Testbed*, 29<sup>th</sup> European Conference on Optical Communication, Rimini, September 21-25 2003.
- [11] L. Berger et al, *Generalized Multi-protocol Label Switching (GMPLS) Signaling Functional Description*, IETF RFC 3471.

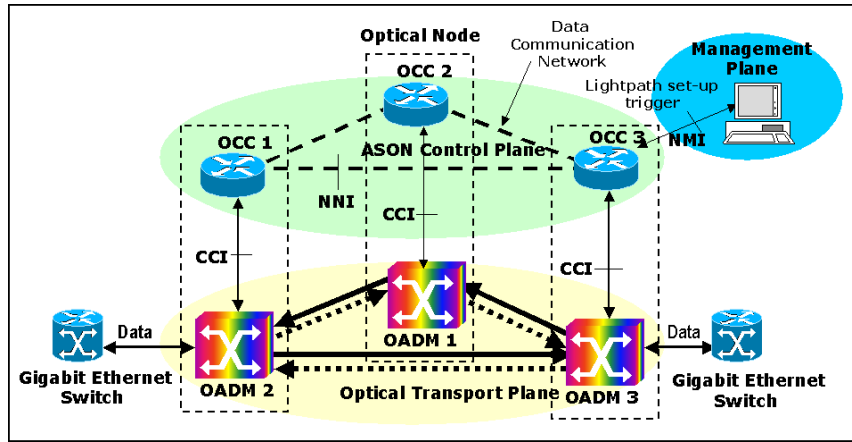


Fig. 1. Logical architecture of the implemented ASON/GMPLS testbed.

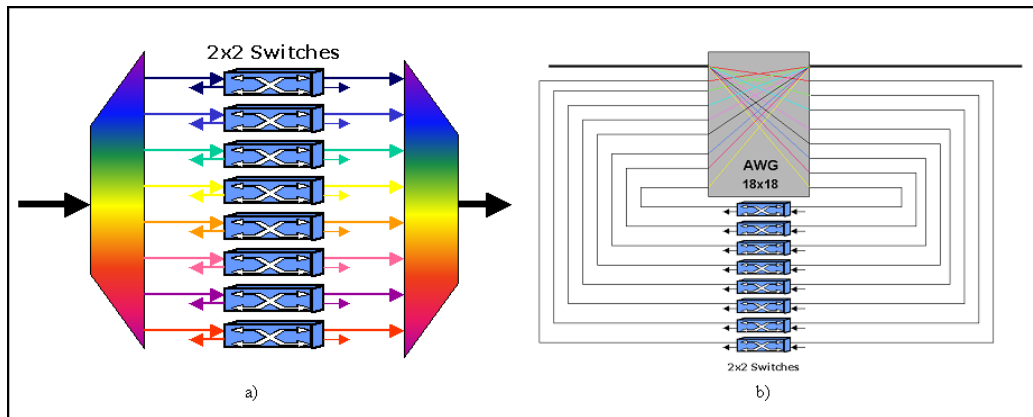


Fig. 2 Illustrative structures of the add/drop stages.

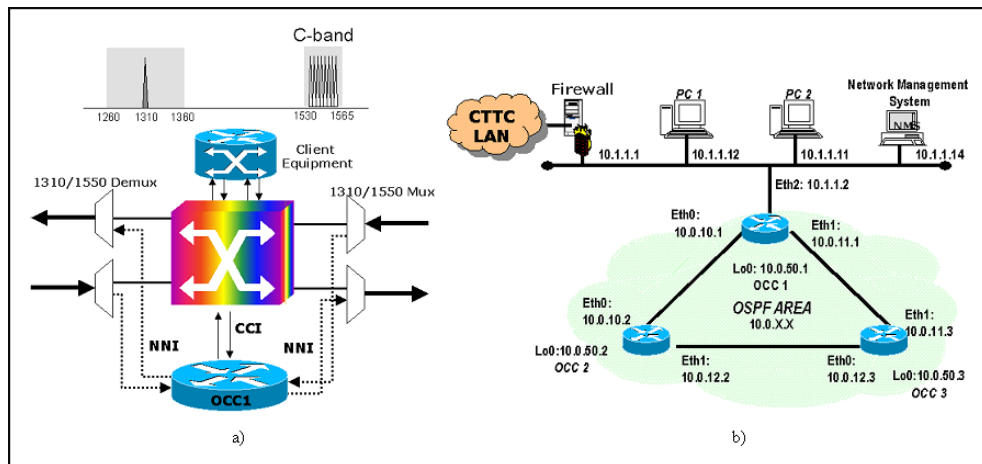


Fig. 3 Structure of the DCN.

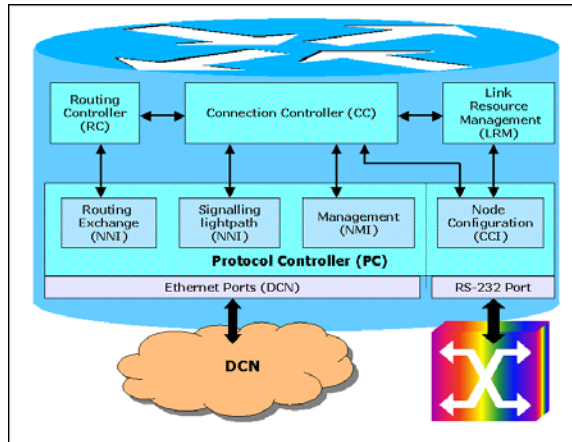


Figure 4. Optical Control Plane Architecture.

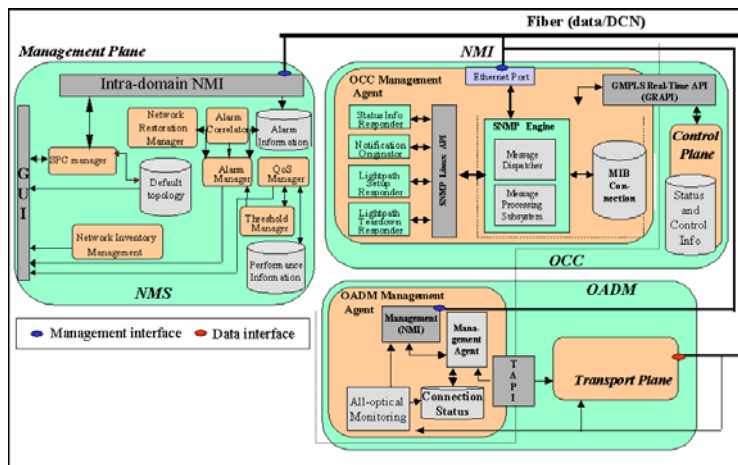


Figure 5. Architecture of the management plane.

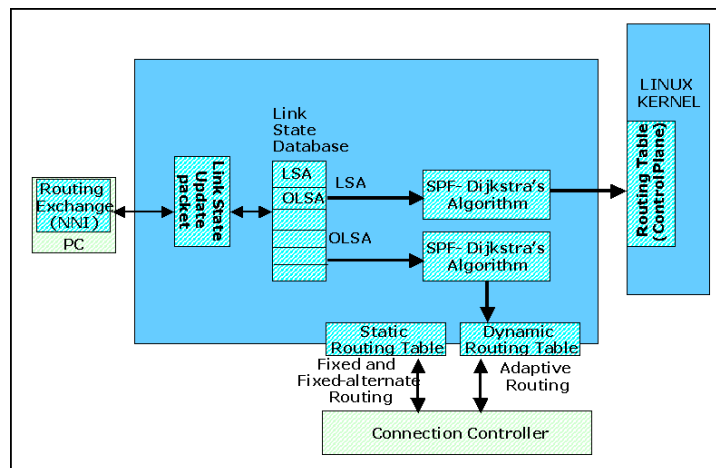


Figure 6. Routing Controller.

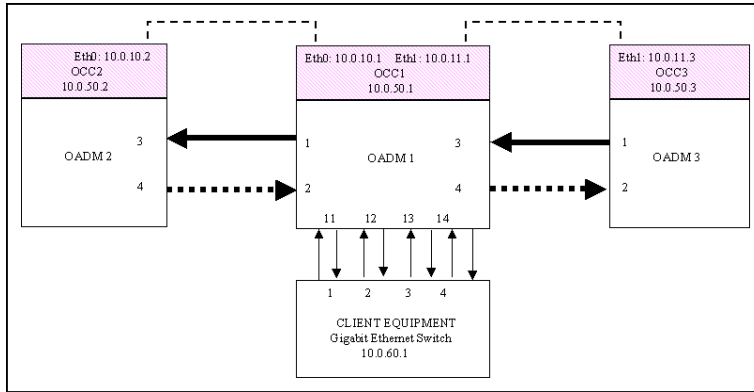


Figure 7. Addressing scheme.

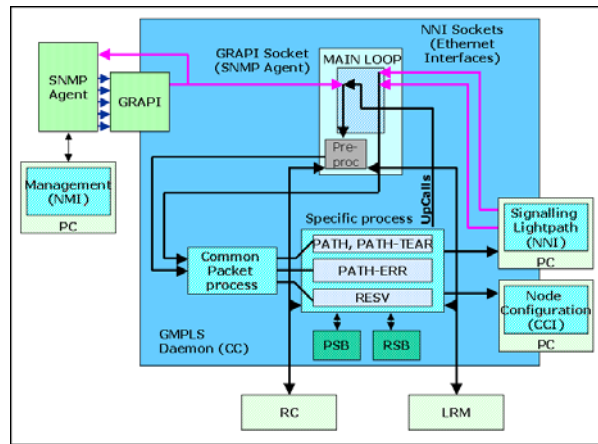


Figure 8. GMPLS Daemon

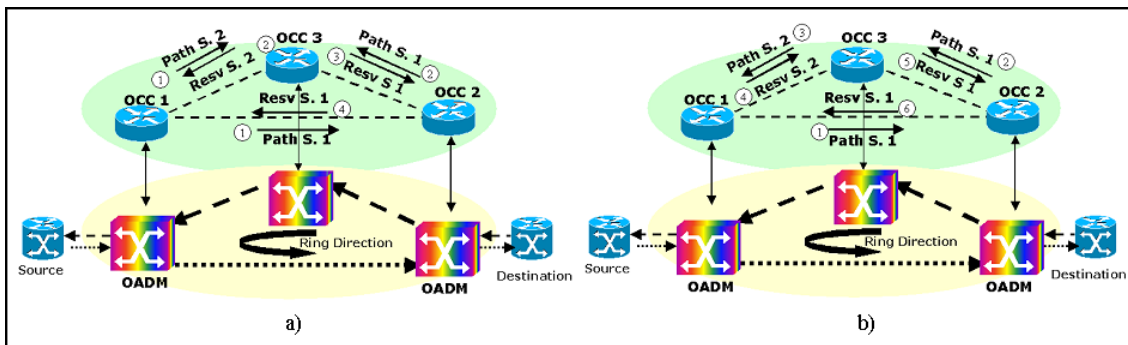


Figure 10. Bidirectional lightpath provisioning from node 1 to node 2. a) Salmon Proposal. b) Whiting proposal.

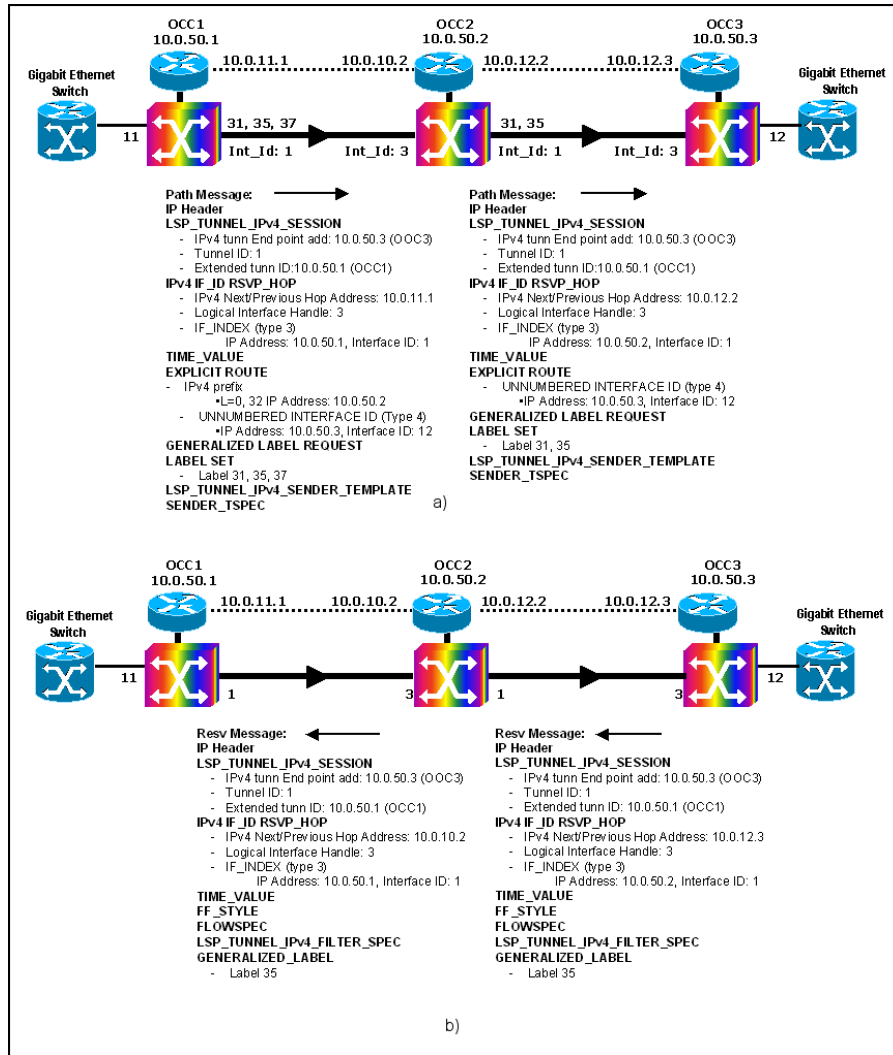


Figure 9. GMPLS lightpath setup example with Label Set object. a) Path Flow. b) Resv Flow

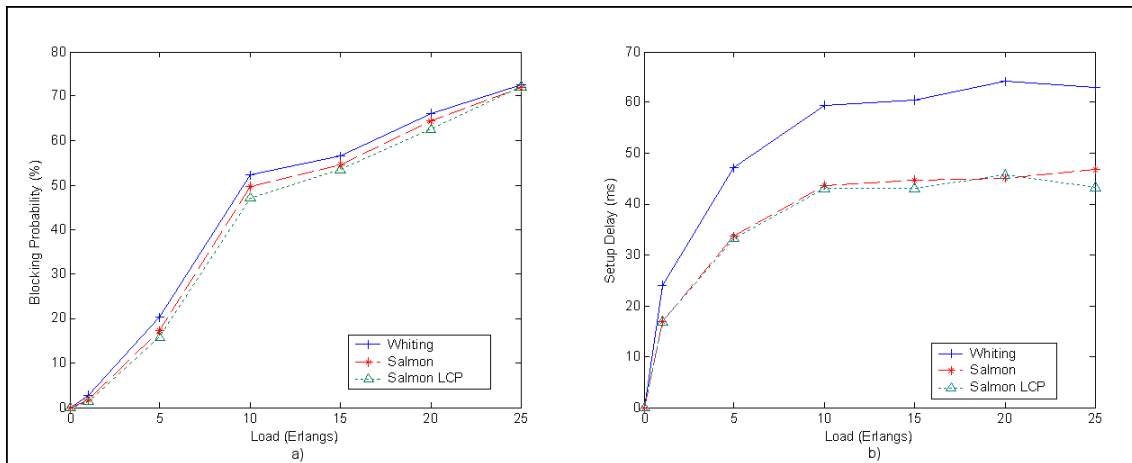


Figure 11. Blocking probability Salmon and Whiting proposals.

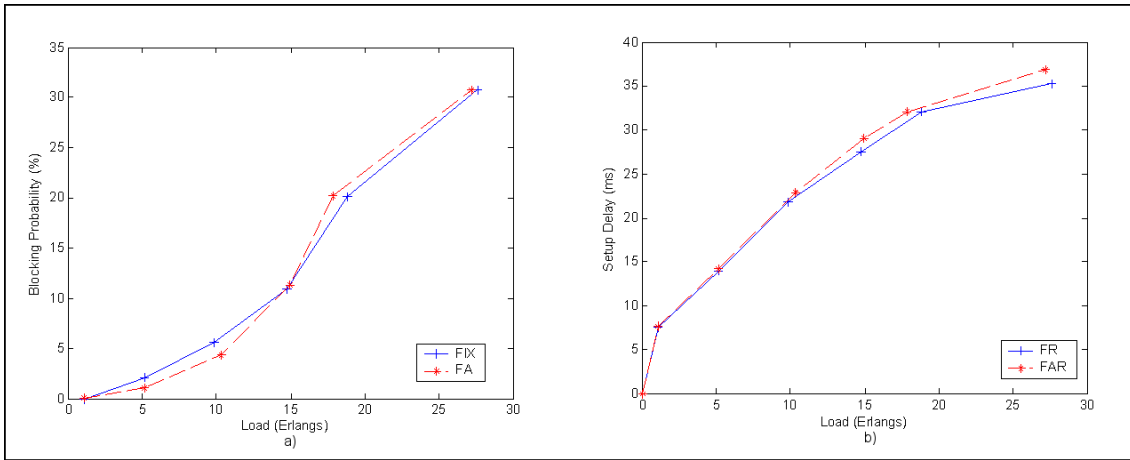


Figure 12. a) Blocking probability. b) Setup Delay

Source	Destination	Metric	Explicit Route
OADM 1	10.0.50.2	1	10.0.50.2
	10.0.50.3	2	10.0.50.2 10.0.50.3
OADM 2	10.0.50.1	2	10.0.50.3 10.0.50.1
	10.0.50.3	1	10.0.50.3
OADM 3	10.0.50.1	1	10.0.50.1
	10.0.50.2	2	10.0.50.1 10.0.50.2

Table 1. Routing tables in a unidirectional ring for FR scheme

Source	Destination	Metric	Explicit Route
OADM 1	10.0.50.2	1	10.0.50.2
	10.0.50.3	1	10.0.50.3
OADM 2	10.0.50.1	1	10.0.50.1
	10.0.50.3	1	10.0.50.3
OADM 3	10.0.50.1	1	10.0.50.1
	10.0.50.2	1	10.0.50.2

a)

Source	Destination	Metric	Explicit Route
OADM 1	10.0.50.2	1	10.0.50.2
	10.0.50.2	2	10.0.50.3 10.0.50.2
	10.0.50.3	1	10.0.50.3
	10.0.50.3	2	10.0.50.2 10.0.50.3
OADM 2	10.0.50.1	1	10.0.50.1
	10.0.50.1	2	10.0.50.3 10.0.50.1
	10.0.50.3	1	10.0.50.3
	10.0.50.3	2	10.0.50.1 10.0.50.3
OADM 3	10.0.50.1	1	10.0.50.1
	10.0.50.1	2	10.0.50.2 10.0.50.1
	10.0.50.2	1	10.0.50.2
	10.0.50.2	2	10.0.50.1 10.0.50.2

b)

Table 2. Routing tables in a bidirectional ring for a) FR scheme, b) FAR. Scheme.