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# Experimental demonstration of two new GMPLS lightpath setup proposals for soft-permanent connections over a unidirectional OADM ring

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**Abstract.- An experimental demonstration<sup>1</sup> of two new GMPLS lightpath setup schemes over a real ASON-GMPLS-based control plane in EMPIRICO testbed is presented. Currently GMPLS is being developed as a standard in order to introduce intelligence for next-generation ASON by means of a distributed optical control plane, allowing, among other functionalities, dynamic and real-time provisioning of high-bandwidth optical connections. The provisioning of bidirectional optical connections over unidirectional OADM rings using a distributed GMPLS-based control plane has not yet been considered in the existing literature. We present two new proposals of GMPLS RSVP-TE bidirectional lightpath setup over a unidirectional ring, called *Salmon Reservation Protocol (SRP)* and *Whiting Reservation Protocol (WRP)*. WRP has long setup delays, instead SRP minimizes the setup delay but introduces label contention, that may occur if two contemporary connection requests are initiated over a particular link from both directions simultaneously. This paper also presents and compares new strategies of label contention policies for wavelength sets, providing a significant improvement in performance. Finally, management and control planes' (NC&M) interworking issues for soft-permanent connections are considered.**

## 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)*s and *Optical Add Drop Multiplexers (OADM)*, capable of providing wavelength-routed WDM networks with high-bandwidth optical connections (40 Gb/s and beyond). 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]. The major benefits of intelligent optical networks are considerable, such as dynamic and real-time provisioning, automatic topology and resources discovery, traffic engineering for making the most optimal and efficient use of the network resources, and dynamic protection and restoration capability when a failure occurs.

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 in a MPLS 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)* 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 optical fibers.

The provisioning of bidirectional optical connections over unidirectional OADM rings using a distributed GMPLS-based control plane has not been considered in the existing literature. In the basic GMPLS architecture [2], bidirectional optical connections (downstream and upstream data paths) are established using a single set of Path/Request and Resv/Mapping messages using the Upstream Label Object. This reduces the setup latency to essentially one source-destination round-trip time, and limits the control overhead to the same number of messages as a unidirectional optical connection, but this mechanism does not work over unidirectional OADM rings, due to the fact that GMPLS only considers bidirectional links, that is, one fiber in each direction. In the basic MPLS architecture [3], LSPs are unidirectional, so in order to establish a bidirectional optical connection, two unidirectional LSPs in opposite directions must be established independently. This approach has many disadvantages, but the main problem is that it does not work neither for switched connections, in which high-speed IP/GMPLS routers request unidirectional or bidirectional optical connections to the optical network through the *User Network Interface (UNI)*, nor for soft-permanent connections (SPC), in which the optical connections are triggered by the *Management System* of the network (NMS).

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In the latter, the NMS could trigger two independent unidirectional optical connections in opposite directions, but clearly it is not a good solution for intelligent networks in the sense that it is the NMS that has to synchronize the provisioning of the optical connections, having significant repercussions on the setup delay.

In this paper we present and compare the performance of two new experimental proposals of GMPLS RSVP-TE bidirectional lightpath provisioning over a unidirectional OADM ring implemented on the EMPIRICO testbed, called *Whiting Reservation Protocol* (WRP) and *Salmon Reservation Protocol* (SRP) [4]. WRP avoids the label contention but increases appreciably the setup delay. Performance evaluation has shown that SRP always performs better than WRP, both in terms of blocking probability and setup delay, even when no *Label Contention Policy* (LCP) is applied to SRP. We also present three strategies of LCP for wavelength sets that improve significantly the performance of SRP with respect to WRP [10]. Finally, we summarize the approach for modeling the interactions between control and management planes for providing services in WDM metro networks presented in [11], detail the GMPLS oriented MIB module implemented in EMPIRICO testbed and extend preliminary experimental results for provisioning of soft-permanent connections.

The remainder of this paper is organized as follows. In section II the common features of SRP and WRP are presented. In section III we give insights of SRP and describe the LCP strategies proposed. WRP is explained in section IV. A general overview of the EMPIRICO control plane where performance evaluation has been performed is described in V. Section VI presents a performance analysis in terms of blocking probability and setup delay, whereas section VII raises network control and management (NC&M) issues for soft-permanent provisioning, focusing on GMPLS. Finally, section VIII concludes the paper.

## II. SRP and WRP common features

In order to set up a lightpath, a signaling protocol is required to exchange control information among nodes and to reserve resources along the path. Both SRP and WRP employ GMPLS RSVP-TE as a signaling protocol. Signaling and reservation protocols are categorized based on whether the resources are reserved on each link in parallel, reserved on a hop-by-hop basis along the forward path (*Forward Reservation Protocol*, FRP), or reserved on a hop-by-hop basis along the reverse path (*Backward Reservation Protocol*, BRP). In this paper we employ the FRP approach [5], in which the source node decides a route to the destination node and initiates the reservation. For the case of local network state information, the source node may utilize a conservative reservation approach choosing a single wavelength and attempting to reserve this wavelength along the entire path; however, there is no guarantee that the selected wavelength will be available along every link in the path. If the wavelength is blocked, the source node may select a different wavelength and reattempt the connection. The limitation of this approach is that it may result in high setup times, since it may take several attempts before a node can establish a lightpath.

An alternate approach to maximizing the likelihood when establishing a lightpath in a forward reservation scheme is to use an aggressive reservation scheme [6] which over-reserves resources. Multiple wavelengths may be reserved on each link in the path, with the expectation that at least one wavelength will be available on all the links in the path. In GMPLS RSVP-TE this is accomplished by the Label Set Object 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. In all the hops in the selected path, only those wavelengths which are already reserved in the previous hop are reserved. It could be possible to fix an upper limit on the number of wavelengths in the Label Set Object. In this paper no limit is considered, so the Label Set created by the source node is formed by the 100% of the available wavelengths. Note that there is neither no guarantee that at least one wavelength of set of wavelength selected by the source node be available along every link in the path; if any wavelength of the set is available in each link in the path, the request is blocked and the wavelengths reserved on the partially established path are immediately released. This scheme is known as *dropping policy* [7]. An alternative scheme, known as *holding policy* can be adopted; the wavelengths on the partial path are kept reserved for a some period of time, hoping that during this period, the reservation will progress. If the reservation does not progress at the end of the period, then the request is dropped, and locked wavelengths are released. In this paper the dropping policy will be applied.

Finally, if the Path message reaches the destination node, it selects one of the acceptable labels based on the first-fit wavelength assignment algorithm and releases the reservations on the remaining wavelengths sending a message to the source node. Instead of choosing the wavelength according to first-fit, one may apply other assignment rules such as random, best-fit worst-fit, etc. The first-fit algorithm selects the first available wavelength. This approach has the major problem that network resources are over-reserved during the setup delay, which may lead to the blocking of subsequent connection requests and to lower network utilization. The reserved resources cannot be utilized by other users, even if these resources will never be used by the connection.

## III. Salmon Reservation Protocol (SRP)

SRP tries to minimize the setup delay, that is, the time required to establish a bidirectional connection in order to reduce the period of time that network resources are over-reserved due to Label Set Object. We will use Figure 1 as an example to illustrate the how SRP works for soft-permanent connections.

In Figure 1, the network is composed by a unidirectional OADM ring, in which each link is made up of one pair of unidirectional fibers, one in each direction. One of them is used for DWDM transport and the other one for *Optical Multiplex Section* (OMS) protection. Each OADM is capable of dropping, adding or passing through the wavelengths transported in the working fiber. Therefore there is only a single fixed transport route for a given

source-destination pair, and this fixed route must follow the same direction of the working fiber, that is, to establish a bidirectional optical connection from node 1 to node 3, the downstream data path goes from node 1 to node 3, passing-through node 2. The upstream data path goes from node 3 to node 1, passing-through node 4.

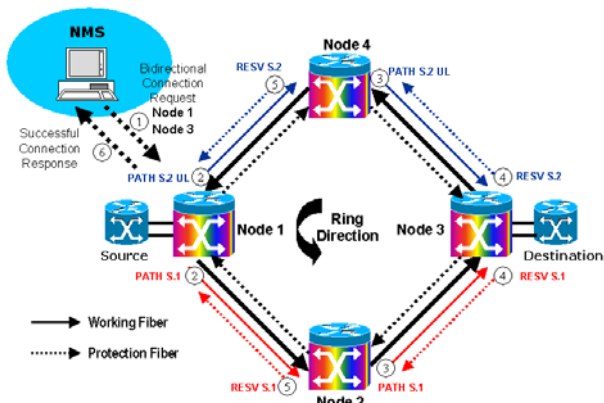


Figure 1. SRP bidirectional lightpath signaling.

In SRP proposal (Figure 1), when a new connection request arrives to the source node (node 1), it creates a new *Path State Block* (PSB) for this session (e.g. session 1) and initiates an RSVP Path message containing a Generalized Label Request Object and other relevant objects, such as the Label Set Object. Then the source node determines a strict path to the destination node (node 3) in the same direction of ring transmission, recorded on an Explicit Route Object (ERO). The RSVP Path message of session 1 is sent along the explicit route one hop at a time.

If the requested connection is bidirectional, the source node creates a new PSB with a new session (e.g. session 2) and generates automatically a new RSVP Path message including all the relevant objects such as the ERO and the Label Set Object, and a void Upstream Label Object. In this case, the strict path to the destination node follows the opposite direction to the ring transmission, so the node has a routing table in which each destination has two possible routes, one in the same direction of the ring transmission, and other one in the opposite direction of the ring transmission. The Upstream Label Object is ignored in all the intermediate nodes. In order to maintain a synchronism for handling RSVP messages, the source node must relate the PSB with session 1 and the PSB with session 2 in such a way that for example when a Path-Error message with session 2 is received, a Path-Tear message with session 1 is automatically propagated, and the same mechanism applies for the rest of RSVP messages. A node receiving a Path message knows if the wavelength resources are reserved in the opposite direction depending on whether the message includes the Upstream Label Object.

#### A. Label Contention Strategies

Contention for labels may occur between two paths messages (or more) traveling in opposite directions. The

contention occurs when both sides allocate the same resources at exactly the same time.

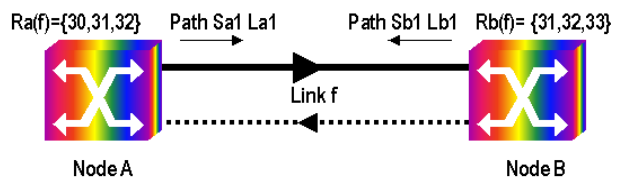


Figure 2. Label contention scenario.

For example (Figure 2), let's consider two nodes,  $A$  and  $B$ , linked by a single unidirectional fiber,  $f$ , being  $R_{A(f)}$  and  $R_{B(f)}$  the set of wavelengths reserved at the side of node  $A$  and  $B$  respectively. Let's suppose that node  $A$  generates an RSVP Path message with session  $S_{A1}$  and a Label Set Object  $L_{A1} = \{30, 31, 32\}$  and sends it to node  $B$ . These wavelengths on link  $f$  are locked at the side of node  $A$ , and  $R_{A(f)}$  is updated. At the same time, node  $B$  generates a RSVP Path message with session  $S_{B1}$  and a Label Set Object  $L_{B1} = \{31, 32, 33\}$  and sends it to node  $A$ . These wavelengths are also locked at the side of node  $B$ , and  $R_{B(f)}$  is updated. When the node  $B$  receives the Path message with the session  $S_{A1}$  and Label Set Object  $L_{A1}$ , the set of wavelengths with contention are  $C_B = L_{A1} \cap R_{B(f)} = \{31, 32\}$ . Not all wavelengths reserved in  $C_B$  must belong to the same session. In this example all the wavelengths belong to  $S_{B1}$ , but in a general case several sessions may reserve the set of wavelengths, e.g.  $[S_{B1}, \dots, S_{BT}]$ , where the maximum value of  $T$  is the number of wavelengths in  $C_B$ . If  $C_B$  is different from  $\emptyset$ , label contention policies must be applied in order to solve the contention over the wavelengths of  $C_B$  between sessions  $S_{A1}$  and  $S_{B1}$ . At the same time node  $A$  receives the Path message with the session  $S_{B1}$  and Label Set Object  $L_{B1}$ , being the set of wavelengths with contention  $C_A = L_{B1} \cap R_{A(f)} = \{31, 32\}$ . Consequently there is also a label contention between sessions  $S_{B1}$  and  $S_{A1}$ , so a single label contention policy must be applied at both sides of the link  $f$  in order to establish which session wins the contention for the labels. We consider the following strategies:

- **No policy (NP):** The incoming session (e.g.  $S_{B1}$  at node  $A$  and  $S_{A1}$  at node  $B$ ) loses always the contention over the set of wavelengths with contention (e.g.  $C_A$  at node  $A$  and  $C_B$  at node  $B$ ). This means that no label contention policy is applied, so both requests could be blocked if all the labels of the Label Set Object are in contention ( $C_A = L_{B1}$  and  $C_B = L_{A1}$ ) and a Path-Error message must be generated. If there is any label of the label set without contention the connection request continues its journey.
- **Node Identifier Policy (NIDP):** This strategy has been proposed by the IETF in [8]. To resolve the contention, the node with the higher identifier wins the contention and it must issue a Path-Error message. Returning to the example, session  $S_{A1}$  at node  $B$  would win the contention (supposing that  $A > B$ ), so session  $S_{B1}$  at node  $A$  would lose the contention. The IETF has proposed this strategy for bidirectional links, in which bidirectional LSPs requests allocate an upstream label.

So this strategy has not been optimized neither for unidirectional links nor for sets of wavelengths in contention.

Now we propose new label contention policies based on the session identifier optimized for wavelength sets. Following the example, the node A (the sample applies for node B) must classify the labels with contention,  $C_A$ , into sets  $[P_1 \dots P_T]$  in function of the session that has reserved each wavelength, that is,  $[S_{A1}, \dots S_{AT}]$ . The number of sets,  $T$ , can range from 1 (all labels in  $C_A$  are reserved by the same session) to the number of labels into  $C_A$  (each label in  $C_A$  is reserved by a different session). Obviously, each set  $P_T$  can have different lengths (number of labels inside the set that has been reserved by the same session). Three approaches have been proposed:

- **Session Identifier Policy (SIDP):** For each  $P_T$  set, if the session identifier of the received Path message, (e.g  $S_{A1}$  at node B), is compared with the session identifier of the wavelengths in  $P_T$  (e.g  $S_{BT}$ ). Then the session with the higher identifier wins the contention (e.g,  $S_{BT} > S_{A1}$ , so  $S_{A1}$  would lose the contention at node B and  $S_{BT}$  will win the contention at node A). If  $S_{A1}$  loses the contention over all the  $P_T$  set, a Path-Error message with session  $S_{A1}$  will be sent to the source node and the connection will be blocked.
- **Shared Label Policy (SLP):** In this strategy, for each  $P_T$  set, if the length is higher than 1, it must be divided into two equal sets,  $P_{T1}$  and  $P_{T2}$  respectively. If the session identifier of the received Path message (e.g  $S_{A1}$  at node B), is higher than the session identifier of the reserved labels in  $P_T$  (e.g  $S_{BT}$ ), then,  $S_{A1}$  would win the contention for the set of labels of  $P_{T1}$ . Instead if the session identifier of  $S_{A1}$  is lower the  $S_{BT}$ , then  $S_{A1}$  wins the contention for  $P_{T2}$ . Therefore basically there is a sharing of resources between both sessions. If the length of  $P_T$  is equal to 1, then the session identifier of the received Path message, (e.g  $S_{A1}$  at node B), wins the contention for this label if its identifier is higher than the session identifier of the reserved labels in  $P_T$  (e.g,  $S_{BT}$ ). Finally, after doing the same process for all  $P_T$  sets, all the labels that  $S_{A1}$  has won will be put on a Label Set Object and the Path message of session  $S_{A1}$  will continue to the destination node. If session  $S_{A1}$  has not won any label (it only can happen when all  $P_T$  sets have a length of 1), a Path-Error message with session  $S_{A1}$  will be sent to the source node and the connection will be blocked.
- **Shared Unlocking Policy (SUP):** One major disadvantage of the label contention is that when one or a set of wavelengths, which has been reserved in the previous hops, are lost in the next hop due to label contention policies, they are not immediately freed in the previous links although they can never be selected at the destination. Rather, it is released afterwards when the Resv or Path-Error message come back to the source. Therefore this set of wavelength resources remains unutilized for quite interval of time. The proposed modification removes this disadvantage doing the following modification: according with the example, if  $S_{A1}$  at node B wins the contention of the set  $P_{T1}$ , in order to reduce the amount of time that an unused

wavelength is reserved on a link, an intermediate Path-Error message with session  $S_{BT}$  is sent back immediately to the source to release only the set of wavelengths  $P_{T1}$  that  $S_{BT}$  have lost in the contention. This certainly consumes bandwidth of the control channel but it increases the probability of success for session  $S_{A1}$ , due to on optical rings, is very likely that  $S_{A1}$  share the next links with the previous links of  $S_{BT}$ .

#### IV. WHITING RESERVATION PROTOCOL (WRP)

WRP is based on avoiding label contention problem increasing the setup delay (Figure 3).

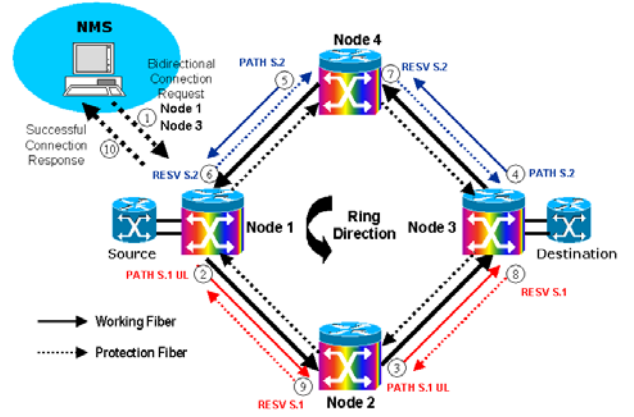


Figure 3. WRP bidirectional lightpath signaling.

Following with the example shown in section III, when a new connection request arrives to the source node (node 1) it creates a new PSB for this session (e.g. session 1) and initiates an RSVP Path message containing a Generalized Label Request Object and other relevant objects, such as ERO and a Label Set Object. If the requested connection is bidirectional, a void Upstream Label Object is also included. The strict path to the destination node follows the same direction of the ring transmission. If requested connections are soft-permanent, that is, triggered by the NMS, the Upstream Label Object specifies the source client point of attachment. Then, the Path message is sent along the fixed route one hop at a time, and each intermediate node processes the Path message before forwarding it to the next node. The Upstream Label Object is ignored in all the intermediate nodes, and is only processed at the destination node.

When the RSVP Path message reaches its destination, it is processed, and a new RSVP Path message (e.g. session 2) is generated automatically and sent to the source node in the same direction of the ring transmission, that is, the new Path message does not travel in the backward direction towards the source. This route includes the source client point of attachment obtained from the received Upstream Label Object. The new Path message does not include an Upstream Label Object. WRP also requires a synchronism of both PSB from both sessions in order to handle RSVP messages, but in this case this is performed in the destination node unlike SRP, in such a way that when a

Resv message with session 2 is received at the destination node, it must generate automatically a new Resv message with session 1. Note that although this proposal does not have label contention problem with respect to SRP, the source node only establishes an optical connection when a Resv message of session 1 is received, which causes in long setup delays, increasing the time that network resources are over-reserved.

## V. EMPIRICO TESTBED GENERAL OVERVIEW

The EMPIRICO testbed is based on an ASON/GMPLS network constituted by a metropolitan DWDM ring with three dynamically configurable OADMs, allowing the establishment of real-time, dynamic, end-to-end connections between client equipments. Figure 4 shows the logical architecture of the testbed, currently being developed at CTTC laboratories.

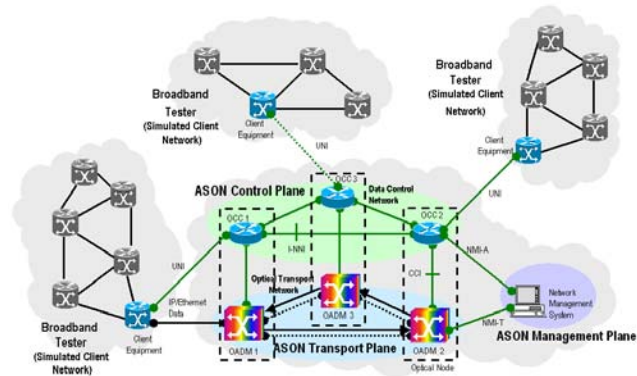


Figure 4. Logical architecture of EMPIRICO testbed.

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 *Optical Connection Controllers*, OCCs over the *Data Communication Network*, DCN. Each OCC has been implemented on a Linux platform with two 1 GHz processors, acting like an IPv4 router. The DCN has been implemented through full duplex Fast Ethernet links transported out-of-band on wavelengths of 1310nm (Figure 5). architecture.- A more detailed description of the EMPIRICO logical architecture can be found in [9].

## VI. EXPERIMENTAL PERFORMANCE EVALUATION

In this section, we investigate the performance of the two lighthpath setup proposals over the control plane of the experimental testbed. Firstly, we describe the main assumptions adopted and then we present the results and discussions:

- All the lighthpath requests have been assumed as bidirectional connections over the unidirectional OADM ring of EMPIRICO testbed.

- Lighthpath requests arrive according to a Poisson process, and the lighthpath holding time is exponentially modeled with a mean of 100 ms.
- To avoid having almost zero size lighthpath holding time (holding time inferior to setup delay), we have added a small fixed time of 10ms to the lighthpath holding time (*offset time*).
- The traffic is uniformly distributed among all node pairs.
- Each data point is obtained over a simulation of 10.000 connection requests.
- Each link supports 16 wavelengths. The time to configure an OADM node is 10ms.

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. 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. The comparison of WRP and SRP with the proposed LCP strategies are mainly focused on two results: the blocking probability and the setup delay. The former refers to the probability that a connection cannot be established due to resource contention along the path. The latter refers to the time required to establish a connection once a connection request arrives.

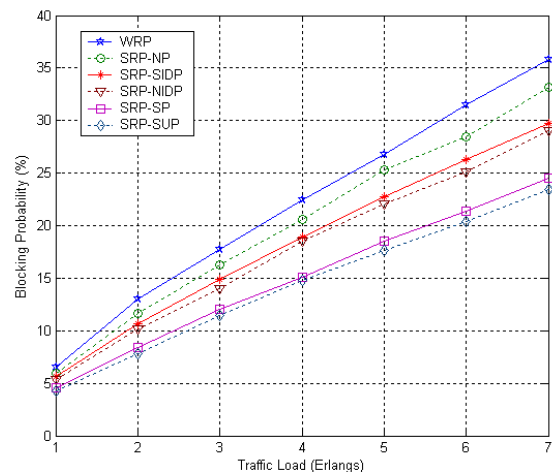


Figure 5. Blocking probability.

Figure 5 plots the obtained blocking probability vs. load for WRP and SRP. SRP has been evaluated with no label contention policy (SRP\_NP), Node Identifier Policy (SRP\_NIDP), Session Identifier Policy (SRP\_SIDP), Shared Label Policy (SRP\_SLP) and with Shared Unlocking Policy (SRP\_SUP) in order to evaluate the weight of the label contention. As explained above, the SRP always exhibits an upgraded behavior respect to the WRP approach, even when no label contention policy is applied (SRP\_NP). In general the blocking reduction of the SRP\_NP is about 10 percent compared to WRP. The IETF's proposal (SRP\_NIDP) performs better than SRP\_SIDP, reaching a blocking reduction up to 21%, 14% and 6% respectively for WRP, SRP\_NP and SRP\_SIDP when the total offered load is fix at 3 Er. But clearly this proposal is not the most optimum in terms of blocking probability due to the fact that it has not

been conceived for solving the contention for a set of wavelengths. From this evaluation it can be inferred that SRP\_SLP and SRP\_SUP are the two proposals that perform better, reaching a reduction of the blocking probability for the SRP\_SLP approach up to 35%, 28% and 18% respectively for WRP, SRP\_NP and SRP\_NIDP. The introduction of the release of the set of wavelengths that has been lost due to label contention policies (SRP\_SUP) introduces a blocking reduction about 5% in average with respect to SRP\_SLP. It can be inferred that this reduction could be particularly more noticeable in large networks where wavelengths paths span multiple hops.

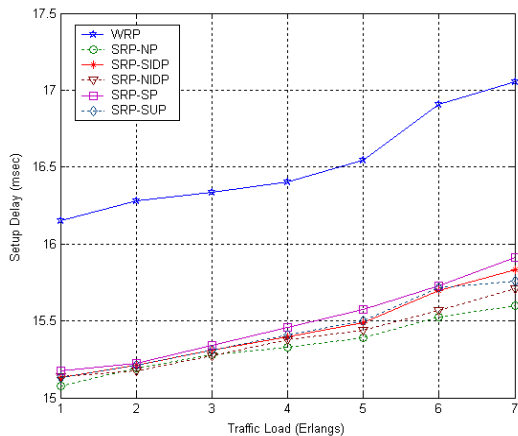


Figure 6. Setup delay.

Figure 6 shows the setup delay vs. load. Obviously, SRP presents lower delays than WRP, reducing the setup delay up to 8%. The reason has been mentioned above, that is, WRP establishes the bidirectional lightpaths sequentially while SRP makes it in parallel. For example when the total offered load is fix at 3 Er, the setup delay is about 16,30 ms for WRP and 15,30 ms for SRP-NP (this time also includes the optical switching time for configuring the OADM nodes). Regarding with the proposed LCP strategies, SRP-NP presents the lower setup delay due to no extra calculation is needed. At the same time, SRP-SLP and SRP-SUP are the two LCP that presents a higher setup delay due to the small computational overhead introduced, increasing the setup delay only about 0,15% for low loads and 2% for high loads compared to SRP-NP. Surprisingly SRP-SUP presents lower setup delay than SRP-SLP. As shown, the connection setup delay increases as load increases due to the fact that each OCC has to support more sessions, causing the increase of the queuing delay at each OCC.

## VII. NC&M: CONSIDERATIONS ON MANAGEMENT/CONTROL INTERWORKING

In optical networks, network control and management (NC&M) functions have been traditionally performed by the management plane. With the advent of the control plane, this situation is changing and at the same time making current monolithic approaches to optical management not optimal for next-generation intelligent, service oriented networks. In other words, the control plane results in

moving and adding management functions to the network, and is leading to a paradigm shift in optical management. In such a context, the interactions of control/management planes must be defined as a way to fully realize the potential of future optical networks. To this respect, the *Optical Internetworking Forum* (OIF) is proposing requirements for the management plane in support of control plane functions, and the *International Telecommunications Union* (ITU) is working on a management framework for ASON (G.fame) [13], whose first draft is expected by May 2004.

In this section we summarize the approach for modeling the interactions between control and management planes for providing services in WDM metro networks presented in [11], detail the GMPLS oriented MIB module implemented and extend preliminary experimental results for provisioning of soft-permanent connections (SPC).

### B. NC&M interworking approach

In the work presented in sections IV to VI, the NMS is not responsible for synchronizing the provisioning of optical connections. This management modeling adopted is motivated by the assumption that the control plane will gradually integrate traditional management functions dealing with network automation, and the vision that control and management planes' interactions will be key for designing successful service-oriented optical networks. In the specific case of service provisioning, we have focused our approach for integrating management in GMPLS enabled WDM networks on management of control plane information related to service provisioning, and function allocation between the management and control planes. The pillar of our interworking approach is the following statement: control/management plane interactions are complementary to allow the control plane for providing dynamic, fast, reliable, end-to-end IP paths over lightpaths through shared network management by the control (real-time) and management (near real-time) planes.

In other words, for flexible soft-permanent connection provisioning, either using SRP or WRP, the management plane does not replicate the GMPLS control plane. Modeling GMPLS control and management planes interactions in terms of complementarity leads to a simple (low-complexity), distributed (no centralized data and efficient allocation of management functions between planes), and up-to-date ("query the network") management infrastructure [11]. Besides, the trend in optical networking is to push operations down into the network. This avoids burdening the management plane with not essential information, and eliminates database consistency problems by considering that up-to-date information relies in the actual resources.

Control/management interactions are based upon the following facts:

- **Low-complexity modeling of data:** Since control and management planes operate on the same resources, modeling is approached by partitioning, keeping each plane aligned. Partitioning is applied to control plane related status information [11], only replicating GMPLS objects involved in the high-level setup and teardown of optical connections

(Management Information Base, MIB, module illustrated in Figure 7).

- **Efficient allocation of management functions between control and management planes:** The GMPLS control plane has a number of mechanisms with similar functionality to traditional management functions, such as path provisioning or route computation, achieved by means of signaling and routing protocols [1], involving resource and service discovery. The management plane is then responsible for SPC triggering, and fault, OCC configuration and performance management [11].
- **Management of new elements (OCCs)** is performed by the management plane via the NMI-A interface [1], for which simple agents in OCCs and a correct *Operations, Administration and Management* flow are crucial. In EMPIRICO testbed, NMI-A carries management information in Fast Ethernet over the Data Communications Network, and the NMS interacts with the OCCs via their the *Simple Network Management Protocol* (SNMP) based agents containing GMPLS-OCC-CTTC-MIB (Figure 7), in request (setup and teardown of SPCs, configuration management), as well as notification and alarm scenarios (control plane faults and switched connections' notifications) [11].

### C. OCC management agents and GMPLS oriented MIB

The most relevant modules of OCCs concerning the establishment and deletion of soft-permanent connections are the *Connection Controller* (responsible for managing the setup and teardown of optical services) and the *Protocol Controller* (in charge of mapping the parameters of the controller's interfaces into management messages, among others) [9]. In [11] we describe the design of the SNMP management agent located on the OCCs (management applications and MIB), which we name OCC Agent, its interactions with the *Connection Controller* module of the OCC's control plane part, and the implementation of the Protocol Controller module in the OCC Agent. OCC Agents are responsible for replying soft-permanent optical connection setup and teardown requests triggered by the NMS through accessing and updating the management information stored in their MIB (Figure 7).



Figure 7. Service related objects of OCC Agent's MIB<sup>2</sup>.

<sup>2</sup> GMPLS-OCC-CTTC-MIB. No connection status objects depicted.

As for the design of GMPLS-OCC-CTTC-MIB, we believe there is certain confusion about what exactly the optical management plane is. Approaches in the literature tend to run all functionalities on a management platform, duplicating information. Providing ASON services and interfaces on the management plane is complementary to the control plane as long as no managed objects contain control plane data.

Therefore, our aim is to avoid 'copying' service provisioning related data into managed objects. Therefore, we have designed the MIB module GMPLS-OCC-CTTC-MIB. This module (Figure 7), is compliant with the Internet Management Framework and runs on any optical network element with a control plane. Service provisioning objects are those of *IspCnxTable* and *IspCosTable*. *IspCnxTable*, indexed by the lightpath's TUNNEL\_ID, contains service provisioning information, while *IspCosTable* deals with service quality characteristics of OCC clients. In a setup request, the NMS sends all objects of *IspCnxTable* except channels (allocated by the control plane) and optionally connection route, the control plane being responsible for path calculation. Through an internal interface, the GMPLS engine informs the management plane of *IspUpWavelength* and *IspDnWavelength* (Figure 7) values, as well as *IspConnectionRoute* if no explicit route was requested, which is the case in the EMPIRICO testbed due to the fact that the control plane is responsible for path computation. SNMP response and notification (Trap, Figure 9) messages are sent to the NMS by the source OCC agent.

### D. Experimental results

Experimental results of obtained in the EMPIRICO testbed's management plane [11] show that GMPLS dynamism is preserved in SPC through the management infrastructure presented, which adds an average delay of 25 ms and 6 ms for SPC setup and teardown (respectively, Figure 8) in the process of service provisioning (Figure 6).

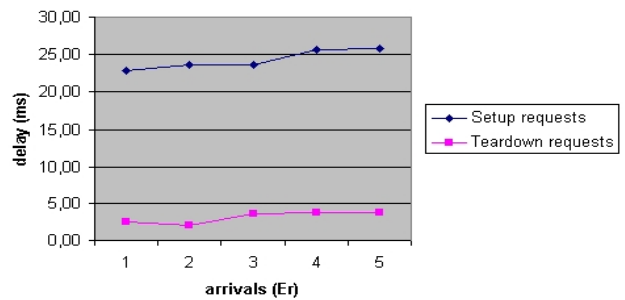


Figure 8. Management plane delays for SPC.

When combining the management infrastructure with the GMPLS control plane, the event sequence (messages and processing) for setting up and tearing down SPCs is illustrated in Figure 9. To evaluate NC&M interworking over the testbed, we assume the following: lightpath requests are bidirectional over the unidirectional OADM ring and have Premium class, connection (wavelength granularity) requests arrive to a centralized network

operation station (NMS), are buffered and served on a FIFO basis, all having the same class of service. Traffic distribution among nodes is uniform. Due to Windows real-time constraints, minimum time resolution is 1 ms. Setup delays obtained (average 38 ms for 100 requests, longest path 70 km and optical switching time not considered), confirms preliminary results (Figure 8) and shows suitability to optical SLAs, which suggest sec to min delays for Premium bandwidth on demand (e.g. in [12], setup is 1 min). Average delay for release of connections in the same conditions is 20 ms.

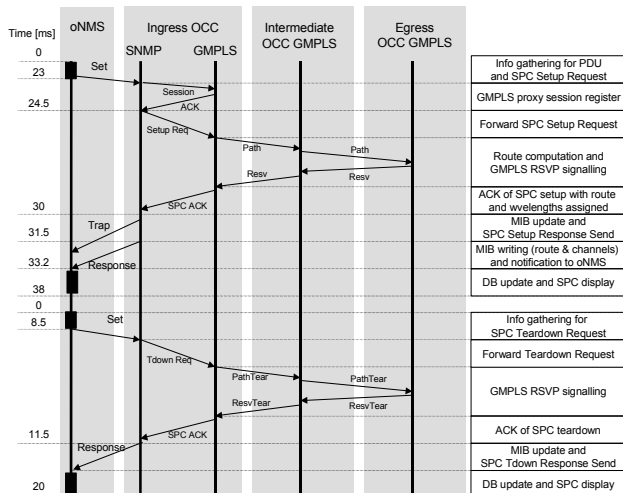


Figure 9. NC&M event sequence for SPC.

## VII. CONCLUSIONS

This paper presents the impact of the label contention on dynamic bidirectional connection provisioning over unidirectional OADM rings implemented on a real ASON/GMPLS testbed. Two new GMPLS-based protocols proposals, named SRP and WRP, have been employed, considering the provisioning of bidirectional optical connections over unidirectional metro DWDM ring using a distributed GMPLS control plane.

WRP has long setup delays, instead SRP minimizes the setup delay but introduces label contention, that may occur if two RSPV Path messages traveling in opposite directions allocate the same resources at the same time at both sides of the link. Both SRP and WRP employ a forward aggressive reservation scheme based on the Label Set Object, so the contention for labels affect to sets of wavelenghts. This paper has presented new strategies of label contention policies for wavelenght sets applied at SRP, showing that SRP-SUP can reduce significantly the blocking probability up to 40% with respect to WRP, and 23% with respect to the LCP proposed by the IETF (SRP-NIDP), that only considers contention between single pair of wavelenghts, having very few impact on the setup delay due to its low complexity.

Last but not least, control planes of next-generation metro networks can make use of GMPLS related protocols and their extensions for optical networks, which raises novel management challenges. Our NC&M interworking approach, achieving ms-order bandwidth on demand

provisioning through adding low burden to GMPLS operation, is an effort for management integration.

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