ADRENALINE testbed: User management of lighpahts over intelligent optical WDM networks through GMPLS and XML

R. Muñoz, C. Pinart, R. Martínez, J. Sorribes, G. Junyent

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R Muñoz, C. Pinart, R. Martínez
Telecommunications Technological Center of Catalonia (CTTC)
Gran Capità 2-4, 08034 Barcelona, Spain.
{raul.munoz, carolina.pinart, ricardo.martinez}@cttc.es

J. Sorribes, G. Junyent
Polytechnic University of Catalonia (UPC)
Jordi Girona 1-3, 08034 Barcelona, Spain.

Abstract

More and more each day users (universities, hospitals, residential, etc) require not only high-bandwidth data transport networks, but also dynamic control of the network infrastructure through a user-friendly interface. The objective of this paper is to present the ADRENALINE [1] *testbed, a hybrid platform that combines both real and emulated optical nodes and DWDM links based on a distributed GMPLS-based control plane (RSVP-TE signaling for lightpath provisioning and OSPF-TE routing for topology and optical resources dissemination), and a distributed management plane combining the industry standard SNMP with user-friendly XML based tools to allow users the dynamic provisioning of lightpaths.*

1. Introduction

The accelerating growth of Internet traffic, together with its bursty pattern, is motivating the research on not only high-bandwidth transport networks but also on dynamic transport networks based upon recent advances in optical networking technologies such as Wavelength Division Multiplexing (WDM), reconfigurable Optical Add Drop Multiplexers (R-OADM) and Optical Cross Connects (OXC), capable of providing reconfigurable high-bandwidth, end-to-end optical connections. The automation of the future optical networks can be achieved by means of a distributed optical control plane (i.e. routing and signaling), which can be based on the Generalized Multiprotocol Label Switching (GMPLS) [1], an extension to MPLS for fiber, wavelength, waveband and TDM switching.

Moreover, new applications based on Grid (i.e. telesurgery, e-learning, etc.) have recently emerged and require huge bandwidth (e.g. lambdas) between universities, hospitals, schools, etc. Therefore there is an increasing interest in allowing the user to gain control over the optical network infrastructure through a user-friendly interface. User management of lightpaths can be achieved with or without the “presence” of network operators. In the former, operators maintain end-to-end network state using a distributed control plane and interfacing with the user through signaling (User-Network Interface, UNI) and/or via the management plane (with distributed technologies such as the eXtensible Markup Language, XML). In the latter, Customer Premises Equipment allows users to create end-to-end optical Virtual Private Networks across domains in which state is maintained at the edges, through the use of service oriented technologies such as Globus Toolkit or Jini/JavaSpaces [2]. Note that both cases may share the use of XML.

The objective of this paper is to present the ADRENALINE testbed, an outgrowth of EMPIRICO [3]. The ADRENALINE testbed is a hybrid platform that combines both real and emulated optical nodes and links based on a distributed GMPLS-based control plane and a distributed management plane combining the industry standard Simple Network Management Protocol (SNMP) with user-friendly XML based tools to allow users the dynamic provisioning of lightpaths. The ADRENALINE testbed comprises 9 Linux-based routers which emulate Optical Connection Controllers (OCC) for the GMPLS-based distributed control plane, and 3 Windows-based PCs which emulate the Distributed Optical Managers (DOM) for the management plane. Moreover, the ADRENALINE testbed is equipped with 3 R-OADMs and 2 OXCs, as well as SNMP-enabled all-optical transport monitors and 3 optical fiber links. The ADRENALINE testbed has the peculiarity of combining both real and emulated links, allowing the dynamic configuration of several kinds of ring or mesh networks and links alternatives.

The remainder of this paper is organized as follows. A general overview of the main technologies employed in the ADRENALINE testbed is described in 2. In 3 the general architecture of the ADRENALINE testbed is presented. We give insight into the main experiments mainly based on the ADRENALINE testbed in 4. Finally 5 concludes the paper.

2. Background Technology

2.1. GMPLS-based distributed control

Under a GMPLS-based distributed control each node makes its decisions based on the network state information (topology and wavelength resources) it maintains, which can be either local o global. In GMPLS-based networks, enhancement to IP interior gateway protocols (IGP) (e.g. extended Open Shortest Path First - Traffic Engineering, OSPF-TE, or Intermediate System - Intermediate System, IS-IS) can be used to flood (periodically or threshold-based) network state information so that each node in the network can have a global knowledge of the network state, using link-state advertisement (LSA) update messages. Based on global information, a routing and wavelength assignment (RWA) algorithm can be implemented at the source node, in a manner which efficiently utilizes network resources and maximizes the number of lightpaths that can be established. Then, the lightpath setup and teardown procedure can be implemented by signaling protocols, such as the extensions to Resource ReSerVation Protocol - Traffic Engineering (RSVP-TE) and Constraint Routing - Label Distribution Protocol (CR-LDP).

For the case in which a node only knows the status of its immediate links (no routing protocols are employed), the problem of finding a route can be simplified using a fixed/fixed-alternate routing based approach, in which a single/set fixed route is/are predetermined for each source-destination pair. Regarding wavelength selection, it becomes more complicated, as the source node does not know which wavelength will be available along the entire path. Collisions are likely to occur if attempts to establish lightpaths for two contemporary connection requests are initiated over a particular link from both directions simultaneously, especially when no wavelength converters are available and a lightpath must be established using the same wavelength on all the links along the path (wavelength-continuity constraint). In general, reservation protocols [4] 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). Parallel reservation is not GMPLS-compliant. Thus, the local knowledge-based scheme may lead to a higher level of blocking than the global knowledge-based scheme, but it does not require the maintenance of update messages.

2.2. XML/SNMP distributed management

The management plane of the ADRENALINE testbed is responsible for soft-permanent connection (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 flow is shared by the control (real-time) and management (near real-time) planes.

Optical networks are usually managed through SNMP managers and agents [5]. Other common mechanisms are the Transaction Language One (TL1), which is an ASCII-based command language used mainly in switches, cross connects and fiber-optic systems, and the Common Object Request Broker Architecture (CORBA), a distributed, object-oriented framework used for inter-domain management communications and in the Network Management Interface (NMI) between a manager and its agents.

Distributed technologies are the most suitable to allow user management of lightpaths, due to the inherent decentralization of triggering the provisioning process if users are to be in control of lightpath establishment and deletion. Some of the most popular technologies for distributed management are CORBA, Java Remote Method Invocation (RMI), Open Distributed Management Architecture (ODMA) and Distributed Component Object Model (DCOM).

Since next-generation optical networks are expected to be heterogeneous, the main disadvantage of these technologies is that both the client and the server must have similar or the same engine and operating system for these technologies to work. Therefore, the above-mentioned technologies do not support true distributed components, that is, client and servers with different operating systems, running on different machines and networks. Instead, XML based communications are a very powerful technology. Rather than creating or reinventing protocols, XML runs on top of HyperText Transfer Protocol (HTTP), with or without intermediary layers, such as the Simple Object Access Protocol [6]. The combination of HTTP and XML allows using the web for information sharing, which paves the way towards integration and platform independence, and creates a new distributed, self-managing model for management [5]. Hence, XML/HTTP may be included as part of the optical management service protocol, together with the management communication protocol, which in this work is SNMP.

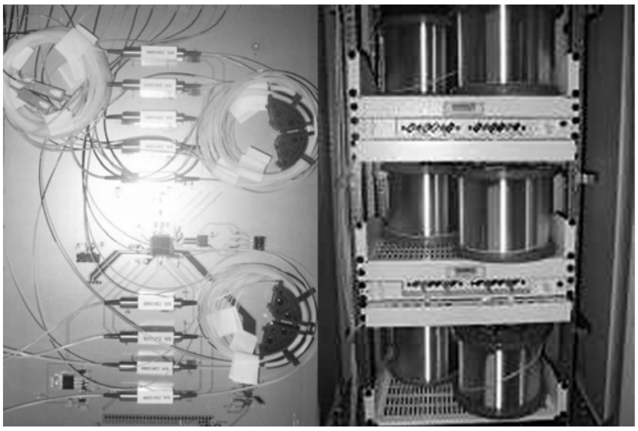

Figure 1. a) R-OADM. b) Optical Fibber Bobbins

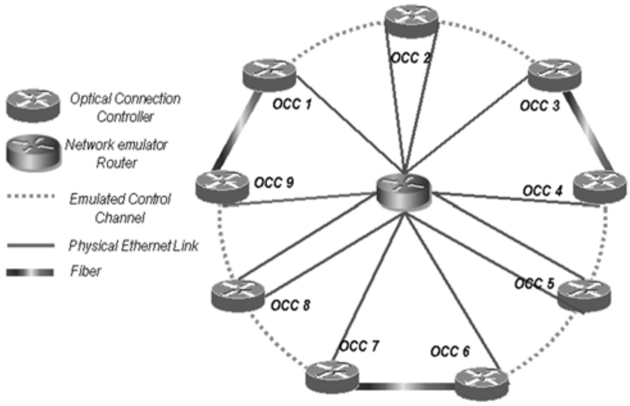

Figure 2. Example of ring topology based on real and emulated links

3. ADREANALINE's architecture

As mentioned before, the ADRENALINE testbed is a hybrid platform composed of real and emulated optical nodes/links whose topology can be configured dynamically. The main research lines of the ADRENALINE testbed are the implementation and experimentation of a GMPLS-based distributed control plane and a distributed management plane containing user-friendly web-based tools. The ADRENALINE testbed also counts with optical hardware such as 3 R-OADMs (Figure 1.a, 2x2 optical switches), being capable of adding or dropping up to 8 wavelengths, and 2 OXCs, composed by a 32x32 optical switch each one, as well as 3 SNMP-based DWDM transport monitors and 3 optical links of 35km each (Figure 1.b). This optical hardware is only used for validating control and management experiments, therefore it does not have a fixed structure and is only configured in function of control and management experiments that will be carried in specific tests. Therefore the architecture of the transport plane will not be discussed any further. Instead, this section will concentrate on the distributed control and management plane architecture, functionality and implementation.

3.1. Control Channel

To enable the communication between nodes for routing, signaling (control plane) and link management (management plane) there must be a pair of IP interfaces that must be mutually reachable between each pair of nodes, known as control channel. This control channel can be a direct IP link between both nodes or an IP network. Likewise, the interface over which the control messages are exchanged may not be the same interface over which data flows. The ADRENALINE testbed supports two types of links, real and emulated:

- Real links: 3 optical fiber links implemented according to the in-fiber, out-of-band approach. Control messages are based on Fast Ethernet (100Mb/s) links carried over a separate channel at 1310 nm that shares the physical optical link. Each optical link is composed by bobbins of 35 km (Figure 1.b).
- Emulated Links: Implemented out-of-fiber. Control messages are also based on Fast Ethernet links carried over a dedicated link separated from the data-bearing optical link. We employ a network emulator software installed on a centralized Linux-based PC that allows emulating fixed packet delays, packet losses, bandwidth limitations, etc., between each pair of nodes of the network. These links can be configured dynamically allowing several types of network topologies.

Each node in the network can choose between the three real links or the emulated links in order to get connected with the rest of the nodes of the test bed. There is no restriction in the number of emulated links that each node can support, since we employ the concept of Virtual LAN (VLAN) for multiplexing LANs in the same physical Ethernet card. Figure 2 shows an example of a ring network implemented in the ADRENALINE testbed using 3 real links and 6 emulated links. The solid lines represent the Ethernet interfaces going from an OCC and the network emulator PC. The dotted line represent the "virtual" emulated control link between two OCCs.

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[1] This work is part of the NetCat and TBONES (ITEA 02024 and FIT-070000-2003-936) research projects

Figure 3. View of GMPLS-distributed control plane at CTTC R&D Laboratories

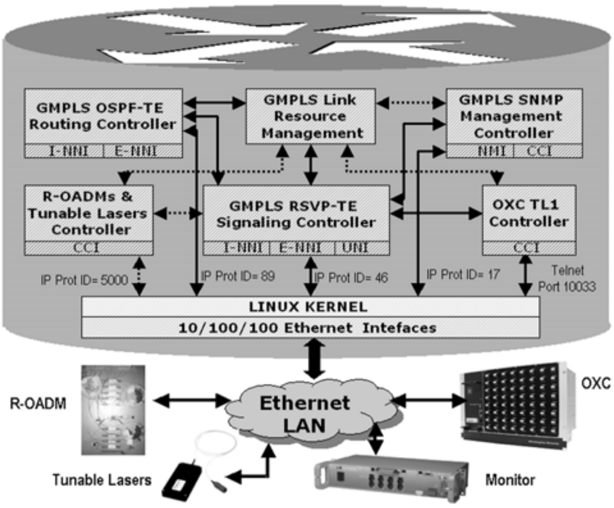

Figure 4. OCC Architecture

3.2. GMPLS-based distributed control plane

Just as it has been explained in section 2.1, in order to implement a GMPLS-based distributed control plane, each optical node needs a connection controller for making its own decisions. These OCCs have been implemented through Linux-based PCs acting like IPv4 routers with a Pentium IV 2,6 GHz processor and with three Gigabit Ethernet cards which allow VLANs. Specifically the GMPLS-based distributed control plane of the ADRENALINE testbed is composed by 9 OCCs (figure 3). The architecture of each OCC is depicted in figure 4.

Currently ADRENALINE connection controllers only support Lambda Switching Capability (LSC), being equipped with the following interfaces according to figure 4.

3.2.1. Network Management Interface (NMI): The NMI interface communicates agents and managers, as well as agents among themselves. Each GMPLS node contains an agent, called management controller, which communicates with the distributed managers through the NMI for soft-permanent connection requests, as well as control plane configuration and performance management. Management controllers may communicate as well with other agents through this interface. An example of such communication is the forwarding of alarms from transport monitors to management controllers for protection based on GMPLS, as described in section 4.2.4. In this work, the NMI is based on SNMP, and therefore management controllers contain a Management Information Base (MIB) compliant with the data model of the testbed [7].

3.2.2. User Network Interface (UNI): UNI is the interface between IP client equipment and the optical network, allowing client equipment to request dynamic provisioning of optical connections under a client-server relationship. Currently we have implemented the UNI interface based on the GMPLS-overlay compliant model proposed by the IETF, establishing a client-server relationship. Its main features are:

- The signaling protocol employed is RSVP-TE as specified in [8]. Client equipment attached to the testbed can be IP/GbE or POS, being emulated by a broadband tester. The broadband tester can simulate several clients, each one with several interfaces. It has been programmed in order to generate UNI optical connection requests according to a Poisson process, and holding times distributed exponentially. The traffic demand matrix between the UNI clients can follow both a uniform (the traffic is uniformly distributed among all client pairs) and a non-uniform scheme (the traffic among all client pairs depends on "popularity"). The same broadband tester has been programmed to switch on the corresponding client laser (and generate and perform analysis of the IP packets). In the same way, the broadband tester has also been programmed to take statistics of the UNI connection generation such as blocking probability, setup delay, holding time, distribution of generated connections between pairs of clients, etc.
- The routing protocol interactions between clients of the ADRENALINE testbed can follow either an overlay, peer or augmented model. According to the overlay model there is no routing instance between the client and the testbed. Under the augmented model there are actually separated routing instances between the edge network node and the edge client but information from one routing instance is passed through to

the other routing instance (reachability information). In this model there is limited sharing of information. Finally, under the peer model the edge client node acts as a peer of the optical transport network, in such a way that a single routing protocol instance runs over the client and the optical domain. A common IGP routing protocol (OSPF with the appropriate extensions) is used to disseminate the topology information. Therefore, this permits the client to compute an end-to-end path to another client across the optical network.

- No Neighbor Discovery protocol is implemented, therefore all neighbor information must be manually configured.

3.2.3. Internal Network Network Interface (I-NNI): I-NNI is the interface between two optical nodes that belong to the same administrative domain (e.g. vendor). The I-NNI implemented is based on the GMPLS signaling and routing function description according to the IETF, but it also incorporates proprietary extensions to RSVP-TE and OSPF-TE in order to do research on specific topics related with signaling, routing and protection that will be explained in section 4. The main features of I-NNI are:

- The signaling protocol employed is RSVP-TE [IETF RFC 2205, 2961, 3209 3473, 3477]. The signaling supports both soft-permanent connections (connections triggered by the Management System) and switch connections (connections triggered by a UNI client).
- The routing protocol within a single administrative domain (I-NNI) is OSPF [IETF RFC 2328] supporting Type 10 Opaque-LSAs [IETF RFC 2370] (domain/area scope) with the extensions to TE (Opaque Type 1) [IETF RFC 3630] and GMPLS [10]. These extensions provide to the routing protocol to populate and collect not only reachability and network topology information, but also TE and resource information which will be used by the corresponding Path Computation Engine (PCE). The PCE computes optimal routes with constraints, achieving network topology reconfiguration within a domain affecting the administrative revenues.
- No Neighbor Discovery protocol is implemented, therefore all neighbor information must be manually configured.

3.2.4. External Network Network Interface (E-NNI): E-NNI is the interface between two optical nodes that do not belong to the same administrative domain (e.g. vendor), but both domains belong to the same Autonomous System (e.g. carrier). The E-NNI implemented is based on the GMPLS-overlay compliant model proposed by the IETF [8], based on the concept of single session. The main features are:

- The signaling protocol employed is RSVP-TE. This interface supports GMPLS signaling specification [IETF RFC 3473, 3477], reliable RSVP message delivery, RSVP summary refreshed and RSVP bundle messages as specified in [IETF RFC 2961]. Path_State_Removed flag in Path-Error and graceful deletion procedure [IETF RFC 3473] are also supported. RSVP graceful restart [IETF RFC 3473] is not supported.
- The routing protocol employed trough the E-NNI interface (multi-domain) is the classical OSPF [IETF RFC 2328]. On this interface the routing protocol provides reachability information and abstract topology information but neither TE nor resource information would be shared among different domains, which is critical to preserve the routing protocol scalability and confidentiality. Considering this kind of exchanged information, two path computation methods for computing inter-domain TE LSPs can be taken into account. The first path computation method is called per-domain path computation whereby each entry boundary node is responsible for computing the path to the next exit boundary (ABR or ASBR) until reaching the destination node using the intra-domain TE and resource information described above. In the second method a PCE is used to compute an end-to-end partial or complete path across multiple domains using the information flooded by the routing protocol among such domains.
- No Neighbor Discovery protocol is implemented, therefore all neighbor information must be manually configured.

3.2.5. Connection Control Interface (CCI): Connection Control Interface is the interface between the control plane and the optical hardware of the node for monitoring and configuring purposes. Currently a proprietary protocol based on IP is employed for the implemented R-OADMs and the tunable lasers, and in the near future it is expected to upgrade it with GSMP. The OXCs are configured and monitored using TL1, therefore each OCC is equipped with a TL1 controller that is in communication with the Link Resource Manager and the GMPLS RSVP-TE controller.

3.3. Distributed management plane

In late 2001, ITU-T specified the architecture and requirements for the ASON [9] as applicable to layer transport networks, which is known as G.ASON. G.ASON describes the set of control plane components that are used to manipulate transport network resources in order to provide the functionality of setting up, maintaining and releas-

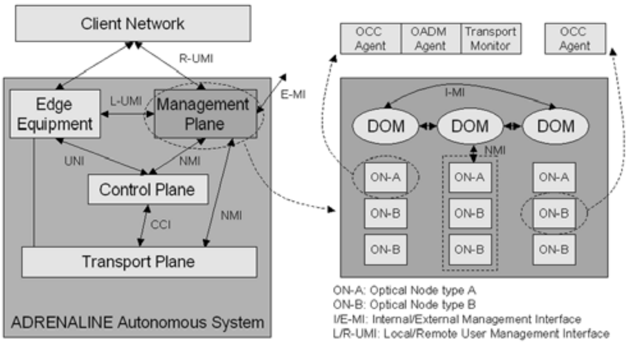

Figure 5. Distributed management plane

ing optical connections in ASON settings. However, neither details of the Data Communication Network (DCN), which provides the communication paths to carry signaling, routing and management information, nor of the management plane are given in G.ASON.

Generically, the ASON management plane performs management functions for the transport and control planes, and the ASON system as a whole, and must provide coordination between all the ASON planes. In ASON, the NMI is split into NMI for control (NMI-A) and transport (NMI-T) functional planes. In this work, the management plane is compliant with ASON and is composed of distributed optical managers (DOM), which perform as control plane, transport plane and resource managers, a gateway, which is responsible for proxying with remote soft-permanent connection requests, and SNMP agents at each optical node. Note that agents are embedded not only in optical (active) hardware (OADM or OXCs) but also in control plane's Optical Connection Controllers (OCC). Figure 5 depicts the architecture of ADRENALINE's management plane. Detailed architecture of OCC and OADM agents can be found in [11], [7], [12]. The management controller (Figure 4) is the aggregation of OCC and OADM agents.

As for interfacing (figure 5), user-driven provisioning of an optical service encompasses combining existing and emerging technologies, adapting optical network elements and making protocols and communication mechanisms cooperate, the goal being that a user, agnostic to optical network resources and management, can ”point and click” a service. Therefore, in the management plane SNMP is used as part of the classical management-agent paradigm, existing in nearly all networks, whereas XML is used for distributed communications. SNMP is the protocol of the NMI, as well as the local user to management interface (L-UMI), which communicates edge client equipment with the management plane to request soft-permanent connections and to obtain IP metrics for performance management purposes [12]. Since XML provides information encoding, whereas HTTP provides transport of such information over any IP infrastructure, including IP/WDM (optical) networks, XML/HTTP is included as part of the optical management service protocol, namely the remote user to management interface (R-UMI), which is used to request connections via user-friendly web-based tools, and the interface between optical managers, both within ADRENALINE Autonomous System (I-MI) or with external networks (E-MI). Using the web for E-MI optimizes the use of out-of-fiber DCNs, which is the common case when interconnecting large networks, especially from different operators.

4. ADRENALINE's experiments

4.1. User management of wavelengths using GMPLS, SNMP and XML

ADRENALINE clients may request optical connections in two ways: if they are UNI enabled they may request provisioning directly to the control plane by sending appropriate messages to the OCC they are linked to (step 1 in figure 6) and otherwise, they may request services though the optical management plane either locally (L-UNI) or remotely (R-UMI). Figure 6 illustrates a simplified view of connection requests in the ADRENALINE testbe.

Step 1 in SPC requests is split in two phases in case of “local access” to the management plane: users connect to the network operator (step 1a), either as traditionally (phone, fax, e-mail) or automatically via edge L-UMI enabled equipment (SNMP). In the ADRENALINE testbed, UNI is implemented in the control plane, therefore L-UMI and UNI are different interfaces. Then, the request is sent to the OCC agent (step 1b), which forwards it to the control plane (step 1c) for UNI requests, clients connect directly to OCCs (setp 1). After step 1 (or 1a-b-c), GMPLS control plane signaling starts for the optical connection to be provisioned. [7] describes the distributed processing of the DOM and OCC agents (including backwards step 3), whereas [3] describes the GMPLS mechanisms for establishing a connection (step 2). The result of these actions is processed in the DOM or in the edge equipment (step 3 for UNI) and it is then that the user can start data transmission. Note that in case of SPC, currently the whole process takes hours to weeks due to the semi-manual operations needed.

In case of “remote access” to the network, users connect to the ADRENALINE wavelength service. Figure 6 illustrates steps 1 (1a-1 and 1a-2) and 3 for “remote” connection requests (step 2 remains the same). A customer may request a connection through a GUI at http://netcat.cttc.es or through its SOAP client, if it has one, which will initiate the process by making a SOAP request. In this process, the client refers to the WSDL file which resides in the

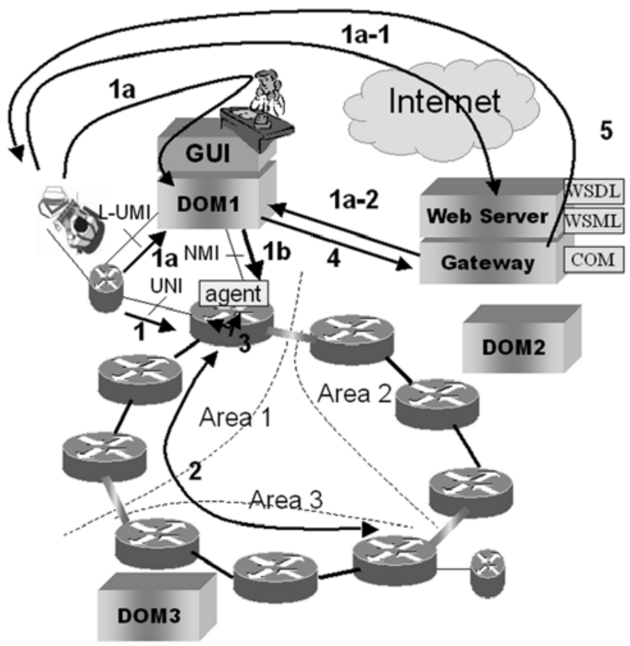

Figure 6. Service Provisioning in ADRENALINE

ADRENALINE server to form a valid SOAP request and, once validated, it sends the request to the server using HTTP. All requests from the web GUI are valid, so they are directly sent to the required DOM. This is step 1a-1 in figure 6.

ADRENALINE's SOAP listener receives the request and makes sure the request adheres to the schema defined in WSDL. Then, the listener calls in the COM component, residing in the gateway manager, with the help of the WSML file, and the request if forwarded to the DOM (step 1a-2). Then, analogously to "local" requests, the request is sent to the OCC agent (step 1b). The result of the request (step 2) is retrieved by the OCC agent, as for "local" requests, and sent back to the DOM. It is then that the DOM packages it into an XML response (step 4) in accordance with the scheme defined in WSDL and the user receives the response, unpacks it, processes the result and starts transmitting data (step 5). In [13] we detail the architecture of the management plane for remote service provisioning and the structure of XML files.

Figure 7 illustrates the delays for local and remote provisioning of soft-permanent connections for one area of the ADRENALINE testbed. These delays are split in two parts: the optical networking, involving the manager and OCCs (agents and GMPLS daemon), and the Internet side, involving the web server, the gateway and the user site. Since Internet delays are difficult to analyze and depend much on the user access technology, such as ADSL or dial-up modem, and Internet dynamics, in Table 1 we provide examples of user site delays obtained with common access technologies and rates.

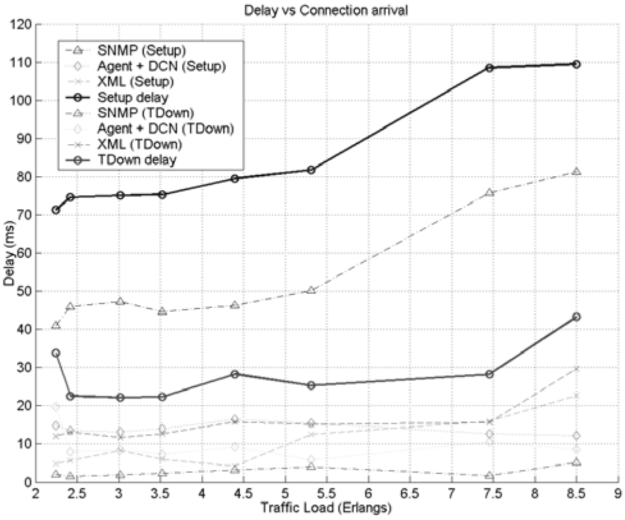

Figure 7. Delays vs. connection arrival

Access	Rate	Setup Delay	Teardown Delay
Modem	56 kbps	488.9 ms	355.4 ms
ADSL	256 kbps	351.1 ms	280.3 ms
Cable	1.6 Mbps	337.6 ms	278.8 ms
Fiber	10 Mbps	320.3 ms	277.9 ms

Table 1. End-to-end provisioning delays

4.2. Specific GMPLS-based control experiments

4.2.1. Experimental GMPLS-based lightpath reservation protocols for unidirectional rings: 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 [14] we presented and compared the performance of the first two experimental proposals of GMPLS RSVP-TE bidirectional lightpath provisioning over a unidirectional OADM ring, called Whiting Reservation Protocol (WRP) and Salmon Reservation Protocol (SRP). 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.

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 the Label Set Object. Basically in SRP the source node generates in parallel two RSVP connection requests. One of them requests the downstream wavelength in the same direction of the ring (clockwise). Instead, the other connection segment requests the upstream wavelength in opposite direction of ring transmission (counter-clockwise). Both RSVP connection segments are associated using de field session name of the Session Attribute Object. This name identifies univocally both connection requests. WRP is based on avoiding label contention problem increasing the setup delay. Contention occurs between two RSVP Paths traveling in opposite direction that allocate the same resources at the same time. In WRP the source node generates a RSVP connection request requesting the downstream wavelength. Once the connection request has arrived to the destination, it generates automatically a new RSVP connection request to the source node requesting the upstream wavelength.

4.2.2. Label wavelength policies: In [15] we have presented three new strategies of LCP for wavelength sets that improve significantly the performance of SRP with respect to WRP. These three new strategies are compared with the IETF's proposal, in which the node with the higher identifier wins the contention. The new proposed strategies are based on the concept of session identifier, and basically the main idea of each policy is:

- SIDP: The session with the higher identifier wins the contention of the wavelengths
- SLP: The labels in contentions are shared between both sessions that are in contention.
- SUP: Is based on SLP but when a session loses wavelengths that are in contention, the session that has won the contention generates an intermediate Path-Error of the loser session releasing the wavelength that has been lost in the contention.

These strategies show that blocking probability can be reduced significantly up to 40% with respect to WRP (figure 8), and 23% with respect to the label contention policy proposed by the IETF, that only considers contention between single pair of wavelengths, having very few impact on the setup delay due to its low complexity.

4.2.3. Flooding global wavelength information through RSVP-TE in unidirectional rings: In [16] we propose an enhancement to GMPLS which allows to have global wavelength resource information using a fixed routing scheme without LSA update messages based on SRP. This new reservation protocol is based on a hybrid reservation protocol that combines both FRP and BRP, using the Suggested Label Object and the Label Set Object. Therefore combining a Label Set Object based on a Backward Reservation Scheme, and a Suggested Label Object (based on a FRP), it could be possible to do a Forward Reservation based on a single label (conservative), and if it fails, the Backward Reservation would continue the connection request.

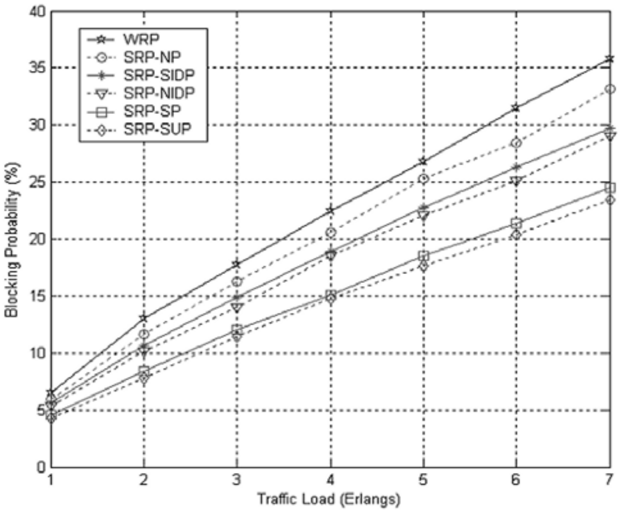

Figure 8. Performacne analysis of WRP and SRP with the proposed LCP.

The main drawback of this reservation scheme is that the suggested label is chosen by the source node that only has local information. In this case the wavelength of the Suggested Label is chosen randomly from the label set. So there is no guarantee that the label suggested by the source node be available along every link in the path. In order to solve this drawback we propose a simple enhancement to the GMPLS signaling protocol that can be used to flood global wavelength state information when bidirectional connections are requested over unidirectional-based WDM rings. In our proposal each node in the ring has a global wavelength resources table, indicating which wavelengths are available in all the links of the ring, and using new GMPLS-based extensions to RSVP Path and Resv messages it is possible to update the wavelength resources table every time that a bidirectional connection is requested. This improvement reports a reduction of the blocking probability up to 34%.

4.2.4. OULSR protection based on GMPLS-based control plane: Currently we are working on OMS protection for unidirectional rings based using the GMPLS-based control plane of ADRENLAINE testbed. In each optical node, the incoming fiber is monitored using a 5% of the transmitted power. This wavelength monitoring allows to fix a mini-

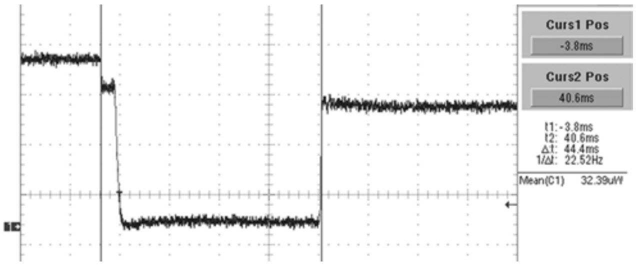

Figure 9. Optical Protection Delay

mum power threshold. Once it has been passed to, the monitoring generates automatically a SNMP alarm to the OCC of the same optical node. Then the GMPLS-based control plane of the ADRENALINE testbed localizes the failure and notifies the alarm to the node at the other side of the link failure. The sweep of the monitoring is about 10ms, and the switching time of the optical switches also is about 10ms. With these equipments we have had times between 45 and 55ms to recover the failure using the protection fiber, just as it can be seen in figure 9. More information can be found in [18].

4.3. Specific management experiments

4.3.1. Performance of SNMP-GMPLS dialogue: Unlike centralized and hierarchical paradigms, cooperative paradigms are goal-oriented. The price to pay is higher implementation complexity, so in order to alleviate this, we use SNMP and GMPLS to form a constructive cooperation to deliver optical services (in this work, SPCs) and to achieve control plane configuration and performance. In[7] and [11] we described the MIB module for provisioning and the distributed approach used in the dialogue of the management plane (SNMP) and the control plane (GMPLS). In short, since SNMP comes from centralized and hierarchical distributed paradigms [17], we make management complementary to GMPLS control through allocating functions to both planes so that no functionality or data is replicated, and flexible collaboration of the control plane's real-time and management plane's near-real-time mechanisms is achieved. Combining SNMP and GMPLS makes agents ”intelligent”, that is, autonomous, cooperative, reactive and proactive [17].

[7] describes the complexity introduced by the management plane when requesting soft-permanent connections in terms of delay. In summary the GMPLS-SNMP dialogue is responsible for only 20-30% of the total delay. This simplicity can be assessed qualitatively as well through considering the complexity of the MIB and the communication mechanisms, compared with IETF MIBs proposed for managing GMPLS-based control planes [11].

4.3.2. Distributed, intra/inter-area management: The functions of the information system manager (traditionally, NMS) are split in as many DOMs as areas. Although DOMs might be seen as Element Management Systems (EMS), the difference with NMS-EMS hierarchy is that DOMs do not follow the traditional management approach. There is no top-level manager (NMS) delegating operations to mid-level managers (EMS). In the ADRENALINE testbed, DOMs are mid-level managers that manage optical devices, whose agents cooperate with one another and, in turn, DOMs cooperate among themselves. A special DOM is the gateway manager, which is the web server [13].

Currently, each DOM performs intra-domain management via SNMP. Moreover, DOMs accept remote setup/teardown requests from a web server via XML [13] and will perform as well inter-domain management. The modular architecture of DOMs will allow for different technology implementations for managing inter-domain issues, through the use of appropriate gateways. A first choice is an XML-based E-MI, according to the philosophy of remote provisioning (R-UMI). In contrast to XML, CORBA is a mature component technology currently in its second design generation. Then, customizing existing SNMP-CORBA gateways, the ADRENALINE testbed may have intra/inter-area management based on CORBA without replacing any agent or DOM module. Then, CORBA and XML will be compared in terms of performance for intra/inter area management.

4.3.3. Service Level Agreement (SLA) verification: In terms of performance management, the ADRENALINE management plane is a hybrid platform that allows the retrieval of analogue information of optical signals (wavelength, power, optical SNR and their drifts), component failures (dialogue with the transport plane [12]) digital parameters (BER through an analyzer and IP metrics through L-UMI) and network utilization (through SNMP-GMPLS dialogue). As for the component failures and transmission impairments, preliminary results show delays in the range of 50-100 ms in the detection and recovery of performance degradations made solely by the management plane.

Figure 10 illustrates the recovery of a service whose SLA determines that one of the conditions for out-of-service is a power degradation of 10 dB. Out of service is caused by cut-off of a laser, and the criterion for restoration, decided by the DOM, is to switch the service to another laser. Recovery time with degraded SLA is 52.3 ms (total recovery is 96.4 ms in an area).

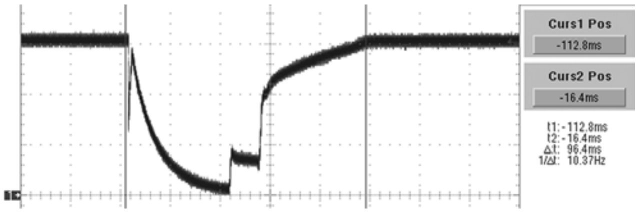

Figure 10. Channel power vs. time

5. CONCLUSIONS

This paper has presented the architecture and implementation of the ADRENALINE testbed, a hybrid platform that combines both real and emulated optical nodes and DWDM links based on a distributed GMPLS-based control plane (RSVP-TE signaling for lightpath provisioning and OSPF-TE routing for topology and optical resources dissemination), and a distributed management plane combining the industry standard SNMP with user-friendly XML based tools to allow users the dynamic provisioning of lightpaths. Moreover we have also presented some experiments done in the ADRENALINE testbed such as novel GMPLS-based distributed control protocols for unidirectional rings, optical protection driven by the GMPLS control pane, performance of SNMP-GMPLS dialogue and SLA.

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