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ON IMPLEMENTING A MANAGEMENT PLANE FOR SERVICE PROVISIONING IN IP OVER RECONFIGURABLE WDM NETWORKS

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Abstract: The optical management problem is a very practical, but complex and theoretically interesting problem. This paper presents an experimental, service-oriented optical management plane for an ASON, focusing on its design and implementation. A complementary approach with the ASON control plane's functions for service provisioning is adopted, avoiding burdening the management plane with any information not essential for higher level operation. Preliminary results are given for the proposed approach, focusing on average time delays of management entities and qualitative simplicity and distribution of management operation and information in the context of setup and teardown of *soft-permanent* connections. Preliminary results show that the implemented service-oriented management plane is of low complexity, simple and distributed, which we think represents a promising effort towards fulfilling the most relevant challenges of future IP/WDM service management.

Key words: Management plane, ASON, soft-permanent, DWDM

1. INTRODUCTION

The ever increasing growth of data traffic and the consideration of all-optical networking as one of the key growth technologies that will drive the long-term success of the networking industry is motivating the research for intelligent optical network architectures based upon technologies capable of reducing deployment costs, solving the bandwidth demand crunch and providing flexible bandwidth, while making the most optimal and efficient use of the fibre. Service provisioning is expected to be the core of such next-generation data communications networks, resulting in a clear need for exploring the management of optical services over intelligent, pure optical networks to fully realize the potential of the optical architectures and technologies under research.

From a service perspective, existing optical networks provide SONET/SDH and Wavelength Division Multiplexing (WDM) point-to-point services via a suite of network management protocols and applications that rely on semi-manual, long provisioning processes, and with supporting databases often incomplete and error prone. Current management protocols and applications are then responsible for configuring and monitoring transport plane's opaque network elements (with conversions to the electrical domain) as a means to deliver services. In this direction, the IP over optical (WDM, mainly) architecture is widely becoming accepted as one of the most promising candidates for future optical services, since it decreases the layering of optical networks, enhances their reach and intelligence and reduces *opex* and *capex*.

On the other hand, rapidly growing customer demand for promptly provisioned high capacity connectivity is motivating the research community to develop flexible, highly reconfigurable transport plane nodes, as well as to remove electronics from the transport plane and define the use of optical resources needed to carry increasingly dynamic data traffic (services). In this context, wavelength multiplexing is especially interesting because it offers exciting possibilities for meeting growing bandwidth without increasing the number of fibres, whereas the advent of optical cross-connects (OXC) and add-drop multiplexers (OADM) provides the basic capabilities required for optical reconfigurability; however, a new standardized control plane is needed if network operators are to benefit from these capabilities. In management terms, the advent of such a complex, distributed-software control plane results in moving and adding classical management functions to the network, since it removes the need for management systems to care for detailed network connection and topology [4].

This evolving framework modifies the relationship between the traditional planes of optical networks (management and transport), and adds a new plane (control plane), impacting the management plane in the sense that its role is no longer the same as the traditional Fault, Configuration, Accounting, Performance and Security (FCAPS) model, and its interactions with the control plane must be defined. It also creates confusions in service provisioning wording and concepts, since management is no longer associated unambiguously to the management plane but to a combination (with unclear boundaries) of the management plane and the new control plane. On the other hand, management is tending towards decentralization. So, considerable effort is still required for the management of IP over reconfigurable WDM networks and the services supported by them, that is, the evolution from traditional to next-generation network management.

In the context of switched optical networks, like the Automatic Switched Optical Network (ASON), new optical services are introduced, which range from bandwidth on demand to optical virtual private networks (OVPN). These networks offer dynamic connection capability and therefore encompass different kinds of services based upon wavelength connection, which may carry a variety of payload formats over both opaque and transparent transport networks. ASONs support three kinds of connections: classical management-driven (permanent), combining management and control (soft-permanent) and control-driven (switched), and introduce, as IP over optical, a reconfigurable transport plane and a new control plane to render the network intelligent, pushing optical management to evolve.

Motivated by the management evolution that optical networks are experiencing, and aware that in the short run soft-permanent connections are likely to be the first service provided by future optical switched networks, in this paper we present an experimental implementation of an ASON management plane focusing on soft-permanent connectivity provisioning in an IP over reconfigurable DWDM testbed. The remainder of this paper is organized as follows. In Section 2 we present the state of the art in management evolution, as well as the framework and assumptions adopted in this paper for implementing a service-oriented management plane. Section 3 is devoted to the architectural design of the ASON management plane, focusing on the network management system and the agents located in the optical nodes of the experimental testbed. In Section 4 we present preliminary results of the experimental implementation of the architecture proposed in Section 3, focusing on computational complexity, management simplicity and information distribution. In Section 5 we draw conclusions

2. SERVICE-ORIENTED APPROACH

Current networks rely on centralized data, that is, their management planes contain a centralized database beside the network with the mission of maintaining network state. With new changes in optical hardware capabilities, such as optical switching and reconfigurability, IP transport directly over optical and the advent of the optical control plane, the present management situation is not the most suitable for next-generation service provisioning. Then, management evolution is towards a distributed, self-aware and up-to-date management infrastructure, highly contrasted to current service management, which relies on semi-manual, long provisioning processes (TMN based), and with not always updated or robust supporting databases. From a deployment point of view, we assume a gradual migration from current centralized management to next-generation, distributed management integrating intelligence, that is, the control plane. We assume as well that the control plane will gradually integrate traditional management functions dealing with network automation, such as fault management or discovery services. Moreover, other management functions will be shared between the control plane and the management plane. For example, [3] suggests that the introduction of automated neighbour discovery mechanisms be the first step in such migration.

The most relevant standardization efforts underway addressing the introduction of automatically switched networks and intelligent network elements in future IP/WDM management systems are leaded by IETF's Operations & Management Area and CCAMP WG, the TeleManagement Forum's New Generation Operations Systems and Software applied to optical transport networks, ITU-T's Telecommunication's Management Network and OIF's Operations Administration, Maintenance & Provisioning WG. This last effort is proposing high level requirements for the management plane for supporting control plane functions as well as object classes for management of ASON based on the ASON architecture [2, 3, 4]. Moreover, several European research projects address optical services provisioning in optical switched networks both solely via management protocols (IST WINMAN) and combining control plane functionalities and matching layer-specific management solutions (IST LION) [5].

However, to the best of our knowledge, the literature shows confusion about what an optical management plane should be, and lacks of efforts towards designing and implementing management systems compliant with the above-mentioned high-level requirements, showing that the management plane of future intelligent optical networks is a research field that still needs strong investigation. Our position is that for flexible service provisioning, what the management plane should never tend is to replicate the control plane, but rather to be a complementary infrastructure. Besides, it is widely accepted that the trend in optical networking is to push operations down into the network to avoid burdening the management plane with any information not essential for higher level operation, the ultimate goal being to avoid database consistency problems by considering that up-to-date information relies in the actual resources [2]. So, we believe that the management plane should query resources to know about the network. On the other hand, we assume that new value-added services impose three basic requirements on service provisioning by IP over reconfigurable WDM networks. First, provisioning of new connections must be automated, in contrast to current provisioning, which involves manual operations. This results in the need for automatic discovery services, such as topology and resources. Second, provisioning of new connections must be rapid in contrast to current provisioning, which takes days to weeks. This means that optical hardware agility must be preserved, which implies reconfigurability of the transport plane. Third, the migration from the current optical networks to next-generation is expected to rely on service differentiation. So, quality of service (QoS) is expected to be a key feature of future optical networks, in contrast to current lack of service quality. Last but not least, the increasing complexity of optical networks is motivating the decentralization of management, that is, management information and functions distribution.

For these reasons, and bearing in mind the well accepted fact that control and management planes' interactions will be key for designing successful service-oriented management infrastructures, we consider ASON control/management plane interactions for service provisioning (in this paper, for soft-permanent connections) in terms of complementarity. This way we allow the control plane for providing dynamic, fast, reliable, end-to-end IP paths over lightpaths using shared service management by the control (real-time) and management (near real-time) planes. This is based upon the integration of heterogeneous management through optical network element modelling and low-complexity modelling of management data, as well as efficient allocation of management functions between control and management planes ("query the network"). Then, a scenario for soft-permanent service provisioning would start with a call request from the client network, which would be accepted by the optical *Network Management System* (NMS), forwarded to the ingress node's agent (management plane) and mapped to the node's control plane. According to up-to-date resource information, a route would be computed by the control plane and resources would be requested and reserved along the route according to signalling messages that under acceptance of egress and on their way back to the ingress node, would in turn allocate the resources previously reserved [10]. Finally, the NMS would be informed of the service establishment and would inform the client, which would start transmitting.

3. EXPERIMENTAL MANAGEMENT PLANE

The proposed approach for service provisioning is being implemented in an IP/Ethernet over dynamic Dense WDM (DWDM) metropolitan ring based upon the ASON concept [1]. The testbed has a circumference of 105 km and operates up to 8 channels at a speed of up to 2.5 Gbps/channel. Its logical architecture (Figure 1) considers management, control and transport planes, as well as their interfaces (interface between clients and the NMS, considered theoretically but not depicted in Figure 1, since clients will use signalling in the future to request a connection from the ASON). The control plane, compliant to [1], follows the GMPLS architecture and is implemented by three *Optical Connection Controllers* (OCC), each being a 1 GHz bi-processor Linux platform. OCCs are linked through the *Data Communications Network* with a Fast Ethernet control channel (Figure 1). The transport plane is a DWDM metropolitan ring formed by transparent, dynamically configurable OADM nodes, providing up to 8 uni- and bi-directional optical data channels at 1550 nm. The architecture of both planes is fully described in [10]. Last but not least, client networks and IP-based traffic are emulated by a multi-interface broadband tester (Figure 1), compliant to OIF UNI 1.0 and with Gigabit Ethernet as framing.

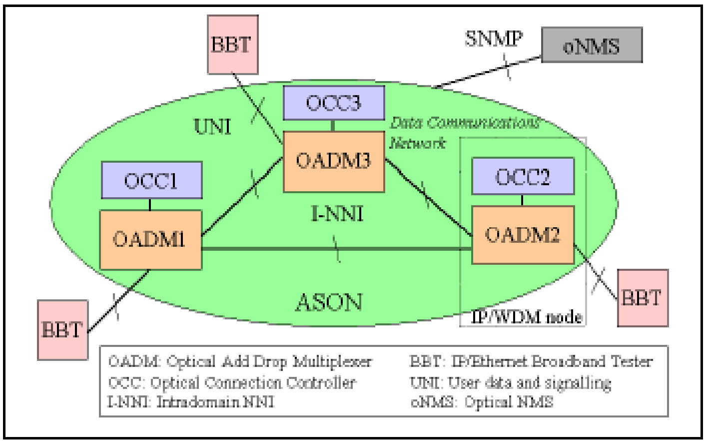

Figure 1. Logical architecture of the ASON/GMPLS testbed

The management plane, responsible for triggering soft-permanent connection setup/teardown and OCC fault, configuration and performance management[1], is implemented through a NMS (1 GHz Windows platform) and three agents (Linux platform), according to the Internet Standard Management Framework. Since the ASON framework allocates the control plane with a number of mechanisms with similar functionality to traditional management functions [1], such as path provisioning or route computation, achieved by means of signalling and routing protocols and involving resource and service discovery, in the context of service provisioning the management plane is responsible for triggering soft-permanent connections, whereas the optical control plane provides the optical transport network with intelligence, allowing dynamic, flexible, real-time provisioning of optical channels, traffic engineering for allocation of routes and resources (DWDM wavelengths), protection and restoration, QoS and OVPNs [10].

[1] No transport plane management is considered in this paper.

In this paper we consider a generic management model compliant to the Internet management framework approach for managing the setup and teardown of soft-permanent optical connections. This model is based upon the manager-agent paradigm, being its key elements in an ASON framework the optical NMS, located in the ASON management plane and acting as an information system manager for network control and monitoring, the agents, located in the optical nodes of the ASON control plane (OCC), the management protocol, upon which is based the Network Management Interface (based upon SNMP in Figure 1, and depicted as NMI in Figure 2) and *Management Information Bases* (MIB), which are abstractions of the optical network's management information consisting of network resources admitting management (managed objects). Due to the requirements of an ASON, in this paper we consider MIB standards for TCP/IP-based networks [7] and an NMI based upon *Simple Network Management Protocol* (SNMP) in line with IETF SNMP Management Framework.

Section 3.1 describes the architectural aspects of the management agent, whereas Section 3.2 is devoted to the manager's architecture (NMS). Note that, for setup and teardown of soft-permanent connections, the above-mentioned key elements interact with each other as follows. The NMS has a mapping of the connection-related managed objects allocated in the agents, and sends management queries and commands to the agents through the NMI via the *Data Communication Network*, whereas the agents store and update their MIBs, answer management queries and send notifications and alarm messages to the NMS. For this purpose, each agent is an SNMP agent consisting of management applications, data transport services and management support functions.

3.1 Optical Connection Controller Agent

Optical Connection Controllers (OCC), core of the control plane, are designed similarly to the architecture proposed in ITU-T Recommendation G.8080, as described in [10]. The most relevant modules 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) [10]. In this section we describe the design of a 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*.

The *OCC Agent* has three major management applications: *Lightpath Setup/Teardown Responders*, *Notification Originator* and *Status Info Responder* (Figure 2). *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 MIBs. Note that in this paper the goal of configuration management is the provision of end-to-end soft-permanent optical connectivity, whose setup and teardown is triggered by means of the NMS and is provided using ASON control plane mechanisms, as described in [10].

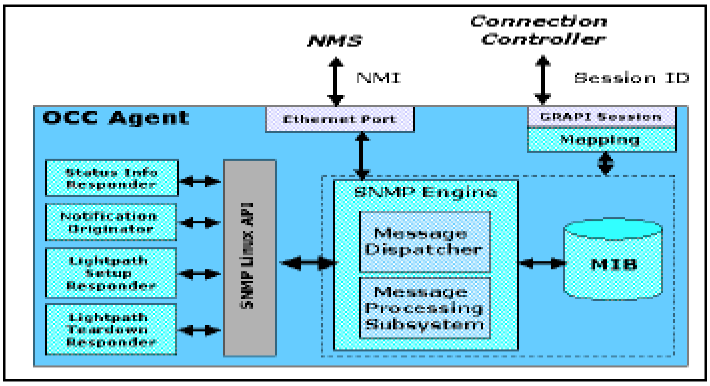

Figure 2. Functional architecture of the *OCC Agent*

The MIB of an *OCC Agent* is a MIB-II with the extensions depicted in Figure 3, and has as main managed objects a table of soft-permanent connections, `lspSpcTable`, to be used by the *Lightpath Setup/Teardown Responders*, and information about the OCC, `sourceOccInfo`, to be used by the *Notification Originator* (control plane alarms and triggered events). These objects are labelled in the Internet registration hierarchy tree (ITU-T X.660) under the level with object identifier .1.3.6.1.4.1.13909 (registered by CTTC as private organization). Managed objects considered for setup and teardown of optical connections are those characterizing an ASON soft-permanent connection, that is: egress (destination) OCC, traffic type (payload or GPID), peakrate and encoding, bi-directionality and continuity options, explicit route[2] and switching type, information about the ingress (source) and the egress of the connection (IP address and up/downstream client interfaces of ingress node, as well as IP address and client interface of the egress node), up- and downstream wavelengths of the lightpath, to be assigned by the control plane's mechanisms, and finally the lightpath identifiers TUNNEL_ID and EXTENDED_TUNNEL_ID. Note that the

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[2] Assigned by the control plane, or (may be) by the NMS with off-line traffic engineering.

TUNNEL_ID is allocated by the optical NMS, whereas the EXTENDED_TUNNEL_ID is chosen to be the ingress node IP address [10]. `lspSpcTable` is indexed by the unique and unambiguous TUNNEL_ID. Due to the particularities of the testbed, the encoding of the Label Switched Path (`lspEncoding` in Figure 3) is *lambda photonic*, the switching capability (`lspSwitchType`) is Lambda Switch Capable, and lightpaths are under the wavelength continuity constraint, whereas for simplicity the identifier of the path (LSP_ID, requested by the control plane modules for establishing a lightpath) is its TUNNEL_ID.

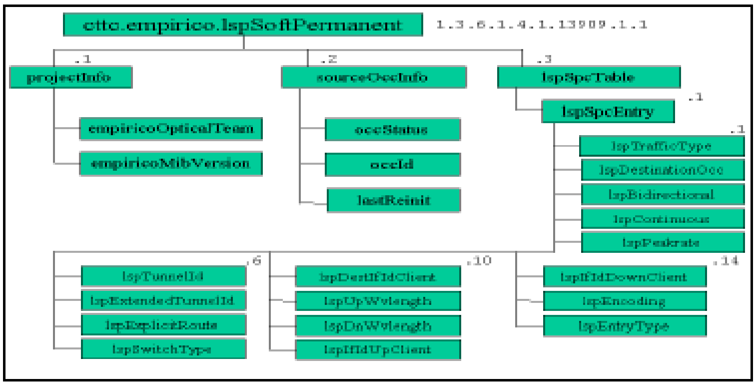

Figure 3. Main objects of the extended *OCC Agent* MIB[3]

As for the *Protocol Controller* for management messages, the *Agent*'s data transport services are located in the application layer and are intended to pack and unpack protocol data units used in SNMP primitives such as Get, Set or Trap. Last but not least, management support functions are MIB access and update modules, as well as SNMP communications protocol stack (UDP/IP layers). For both, we consider an SNMP Linux API (Figure 2).

An additional data transport service that results from the complementary approach adopted for the design of the management plane is the GMPLS RSVP API (GRAPI) library [10], devoted to communication between the *OCC Agent* and the *Connection Controller* (Mapping module, Figure 2). For each setup request triggered by the optical NMS, and after unpacking the associated SNMP message, the *OCC Agent* of the ingress node performs a connection setup request to the *Connection Controller* of the node through the GRAPI. This request is unambiguously associated to a session identifier that will be used for anything related to the optical connection (i.e. modification, status requests or deletion), if it is successfully set up by the

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[3] No connection status objects depicted (for Status Info Responder).

control plane. So, in case of successful establishment of the optical connection, the *Ligthpath Setup Responder* updates the relevant managed objects of the MIB (those corresponding to the `lspSpcEntry` of `lspSpcTable` indicated by the index TUNNEL_ID) characterizing the established connection and sends a successful response message to the *Optical NMS*. Note that, since the TUNNEL_ID is unambiguous, we adopt a session identifier (Session ID, Figure 2) equal to the TUNNEL_ID for a given connection, which simplifies internal database control in the *Agent*.

Note that by using the internal communication mechanism within the management and control parts of the OCC, information distribution is favoured and the MIB is simplified, compared to those being proposed by IETF for managing GMPLS-enabled control planes [11], which show currently high complexity. But, with a view to future upgrades and improvements of such IETF MIBs, the *Agent* is forward-compatible with any MIB, since it easily accepts extensions. Distribution and simplicity are due to the fact that the designed communication mechanism (Mapping module and the GRAPI library, Figure 2) allows accessing real-time updated information contained in the control plane tables, described in [10], and therefore managed objects, PDU processing and MIB accesses are reduced.

For each teardown request triggered by the *Optical NMS*, the *Agent* of the ingress OCC performs a connection teardown request to the control plane's *Connection Controller* trough GRAPI, indicating the session identifier associated to the connection. In case of successful teardown of the optical connection, the *Ligthpath Teardown Responder* of the *Agent* erases the managed objects characterizing the deleted connection (in `lspSpcEntry`) and sends a successful response message to the NMS, which will free the TUNNEL_ID of the torn down channel for future set up of other services. In case of impossibility to perform a soft-permanent request, the *OCC Agent*'s *Lightpath Setup/Teardown Responder* sends an error message to the *Optical NMS* containing the cause of the error and, in case of a failure or an event not triggered by the optical NMS, the *OCC Agent* sends an alarm or a notification message to the NMS via its *Notification Originator*.

3.2 Optical Network Management System

The *Optical NMS* has three major management applications relevant to soft-permanent service provisioning: *Lightpath Setup/Teardown Trigger, Notification Responder* and *Status Query*[4]. These applications are accessed by a Graphical User Interface (GUI, Figure 4). In the context of service provisioning, the *Optical NMS* is responsible for triggering soft-permanent optical connection setup and teardown requests, querying the OCCs of their

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[4] Corresponding to the Status Info Responder of the *OCC Agent*.

status or the status of the soft-permanent connections established, and listening and reacting to alarms (traps) from the control and transport planes. Note that information about switched connections and fault management are out of the scope of this paper.

The *Optical NMS* has a mapping of root identifiers of the managed objects stored in the MIBs of the agents concerning status and connection information, as well as of the client networks and optical transmission/reception equipment attached to each optical node. Moreover, when requesting a connection, the NMS is responsible for assigning lightpath identifiers (TUNNEL_ID and EXTENDED_TUNNEL_ID).

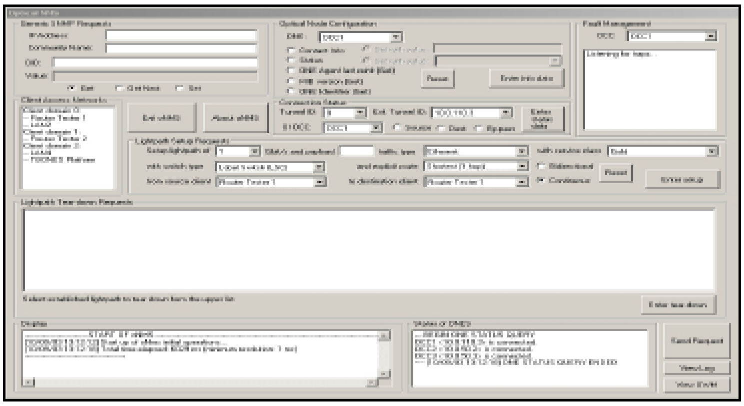

Figure 4. Graphical User Interface of the *Optical NMS*

As for status query, when the NMS is launched, it queries the status of all OCCs connected, according to the client network's mapping stored and regularly updated in the NMS. For all OCCs up and running (object `sourceOccInfo.occStatus` indicating so), the NMS queries possible existing connections the NMS is not aware of (i.e. because of previous NMS unexpected shutdown or *Data Communications Network* failure), updates them in its internal database, "locks" their TUNNEL_IDs and displays them in the GUI, making them available for requesting teardown or status. Analogously, whenever an *OCC Agent* is disconnected, if possible (depending on the cause of the error) it sends an alarm to the NMS via its *Notification Originator* module, and when relaunched, it sends a *coldStart* alarm to the NMS. These mechanisms avoid sending requests to disconnected agents and allow tracking the status of the OCCs. Moreover, the NMS may also query the status of a certain connection to the ingress *OCC Agent* of the connection, which in turn, and using the TUNNEL_ID of the connection, will ask the control plane modules (GRAPI session identifier is TUNNEL_ID), according to the complementary approach described in Section 2. It is the Mapping module of the *OCC Agent* (Figure 2) that, according to TUNNEL_ID and the soft-permanent entry type (`lspEntryType` in Figure 3, related to connection status, such as *active* or *deleted*) will translate the query.

Regarding service quality, which is expected to be a key feature of future optical networks, the implemented management plane considers classes of service, which are translated into different requirements in terms of explicit routes and payload for a given peak rate. Note that, due to the particularities of the testbed, although the management plane supports the request of not continuous soft-permanent connections, the wavelength continuity constraint is applied, which affects service quality in terms of higher blocking probability. Analogously, peak rate choices (Figure 4) are constrained to the capacity of the lasers attached to the client interfaces.

Last but not least, the focus of the NMS implementation has been to provide a trigger for service provisioning and establishing a management-control plane dialogue rather than bringing added value to the information coming from the OCC agent MIBs.

4. PRELIMINARY EXPERIMENTAL RESULTS

Our experiments focus on the main goals of the service-oriented management plane design, that is, computational complexity and management simplicity of the implemented management plane, as well as management information distribution (decentralization). Since the control/management interactions, as well as optical switching are not fully operational in the testbed, results obtained are considered as preliminary, and will be extended in the future to provide end-to-end soft-permanent connection setup and teardown delays.

The experimentation presented in this paper makes use of the following elements of the testbed depicted in Figure 1: the Data Communications Network as a means to transport management messages, the *Optical NMS* (Visual C++/Windows) to generate soft-permanent connection requests, and an *OCC Agent* (C/Linux) to reply to the requests. Moreover, although each fibre of the testbed can carry up to 8 wavelengths due to economic reasons, the TUNNEL_ID pool for a given ingress node has been given a much higher threshold (`MAX_TUNNEL_ID = 80`) to simulate multiple setup and teardown requests, both single and simultaneous (`nb_requests` in a PDU). Due to Windows real-time system constraints, minimum time resolution is 1 ms.

Complexity is measured in terms of time delay. For the *OCC Agent*, this time is computed in the SNMP Engine (Figure 2) for a given or a set of management messages, which comprises package/unpackage, Mapping module and processing time (except the control plane part, thus not counting *GRAPI session* and *Connection Controller* processing time, Figure 2). For the *Optical NMS*, measurements are done analogously. The processing times of the management plane considered in this paper are illustrated in Figure 5. Note that propagation time is across the *Data Communications Network*, where only management messages have been carried in the in-fiber, out-of band control channel [10].

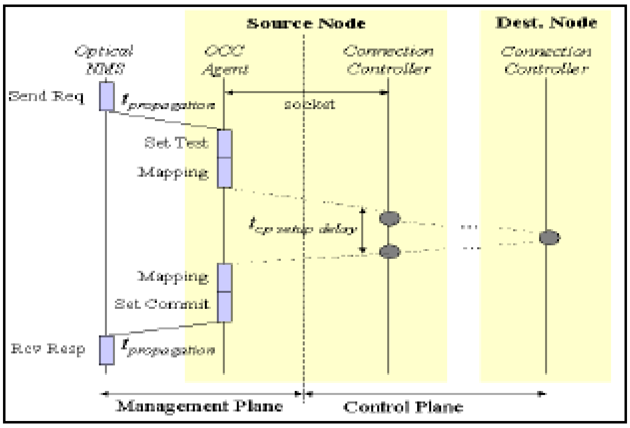

Figure 5. Management plane processing (boxes) and propagation (solid line) times

Figure 6 plots the time delays of the *Optical NMS* and *OCC Agent* for connection requests arriving according to a Poisson process, with exponentially distributed interarrival times with a mean of 30 ms and variable holding time. These values have been chosen due to physically limited TUNNEL_ID pool and to stress MIB writing access, as critical part of SNMP systems due to memory access limitations. Tests have been performed as well for exponentially distributed interarrival times with a mean of 10 to 50 ms and average holding time of 10 to 250 ms and we have observed that for single setup requests, the average processing time of the management plane is around 25 ms (`av_time_req`), wheras for teardown is less than 6 ms. To stress MIB writing, `nb_requests` simultaneous (arrayed) setup and teardown requests have been sent in a SNMP PDU, obtaining average times of less than `nb_requests*av_time_req`. For `nb_requests` > 5 (corresponding to 80 objects in a PDU), the *Agent* system experiments unacceptable buffering delays; this situation will not happen in real performance since SNMP messages to be received by the *Agent* will be of single nature since the *Optical NMS* sends an SNMP PDU per request, that is, series of SNMP messages according to a traffic distribution, but, nevertheless, buffering access and delays need to be studied in the future.

Then, we consider the complexity of the MIB and the communication mechanisms, compared with IETF MIBs proposed for managing GMPLS-based control planes, focusing on service establishment [11] and taking into account the fact that the information flow in GMPLS is extremely dynamic and latency-dependant. Although a detailed comparison to standards has not been done, a qualitative advantage of the presented MIB according to [11] is management simplicity. The MIB containing the managed objects of the soft-permanent optical connections has two main objects, one with three single sub-objects (`occStatus`) and the other being a 16-row table, with single-indexed objects containing integers and strings. Note that this table could be extended to switched connections without modifying its objects (by renaming `lspSpcTable` as `lspTable` and populating it with switched connections parameters obtained through the GRAPI, in addition to actual soft-permanent), which can be considered simple service management.

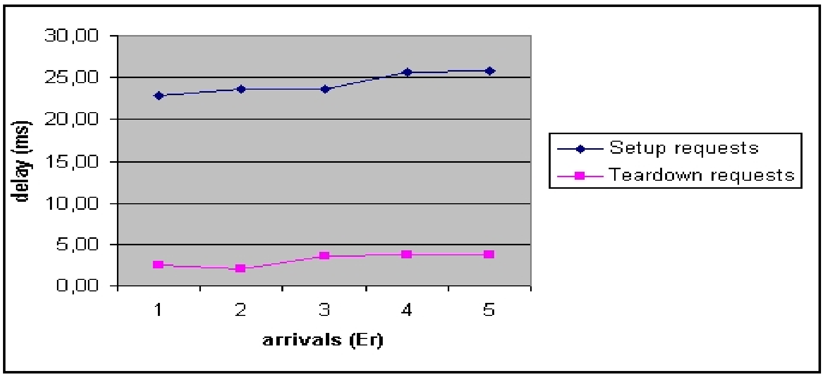

Figure 6. Delay vs. connection arrival

Moreover, management information is distributed across the MIB (MIB II and extended MIB for soft-permanent connections) and the control plane tables located in the OCCs, and regularly updated by monitoring and control plane's mechanisms [10]. Apart from guaranteeing updating, this information distribution assures independence from vendor technology, since the *OCC Agent* can be adapted to a node running a differently implemented control plane, not necessarily based upon GMPLS such as the one in the testbed, simply by adapting the Mapping module (Figure 2), which is used to translate management queries from the *Optical NMS* and for retrieving status information both about the OCC and the links adjacent to it.

Any additional information about nodes and connections can be queried to the control plane's modules and tables [1] through an node-internal communication mechanism (GRAPI session), without needing SNMP messages or MIB objects, which is also simplified, distributed management.

5. CONCLUSIONS

The optical management problem is a very practical, but complex and theoretically interesting problem. With the advent of the IP and WDM layers bridging, and the automation of many network functions through new elements providing intelligence and transport reconfigurability, such as the ASON control plane making use of several protocols and their extensions for optical networks (i.e. GMPLS), and with the trend towards new complex, differentiated and quality-enabled services, novel management challenges are raised and management complexity both at theoretical and practical implementation levels is increased.

Focusing on the challenge introduced by future service management, an approach for provisioning services based on a complementary interworking of the management and control planes has been presented. Then, this approach has been implemented as an effort towards integrating management in ASONs. For this purpose, we have focused on design and implementation issues, as well as given preliminary experimental results over a testbed with GMPLS-based control, SNMP-based management and DWDM transport planes, showing the provisioning of soft-permanent connections with low complexity, in terms of delay and processing time, simplicity (MIB and communication mechanisms), and management information distribution, that is, efficient function allocation between the management and control planes to favour updating and technology independence (data and interface partitioning and alignment).

Future work is in line with the simplification and decentralization of optical management, particularly on extending the complementary interworking with the control plane for switched connections, activation/deactivation of control plane elements, and performance management, both of the transport and control elements, as well as integration of managed objects for GMPLS proposed by IETF [11]. Further experimentation, combining the results shown and control plane signalling mechanisms [12], extending traffic modelling and improving real-time operation of the Windows-based *Optical NMS* platform, will be conducted to fulfil the provisioning demands of future optical Service Level Agreements.

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