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Analytical study and experimental validation of soft-permanent provisioning delays in ASON/GMPLS

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***Abstract*—The end-to-end provisioning delay will be a crucial metric for Service Level Agreements because rapid, dynamic service provisioning is expected to be the killer application for the success of future optical networks. In this paper we study analytically and assess experimentally, in an ASON/GMPLS test bed, the delays experienced by all the network elements and components involved in the provisioning of soft-permanent connections. This is done according to an approach for designing the management-control architecture which is compliant with the ITU-T.**

Keywords-* *Soft-permanent connections, provisioning, optical networking, ASON, GMPLS.

I. INTRODUCTION

The accelerating growth of data traffic is motivating the research for more efficient, flexible, intelligent optical network architectures. In this direction, IP over Wavelength Division Multiplexing (WDM) is becoming accepted as one of the most promising candidates. Generalized Multi-Protocol Label Switching (GMPLS) is also thought to be an integral part of next-generation networks, especially as control plane of the Automatic Switched Optical Network (ASON), because it renders optical networks intelligent. Current networks offer permanent connections configured on the transport plane via a suite of management protocols and applications. The ASON framework [1] will allow for dynamic services (connections), known as soft-permanent (SPC) if they are triggered by the management planed and established by the mechanisms of the control plane, and switched (SC) if they are triggered and established in the control plane. These connections will have strict establishment and release delays if they are to serve for dynamic applications, such as Grid computing.

Since ASON is a framework, it provides guidelines rather than strictly defined models for service provisioning. Therefore, many alternatives exist to implement dynamic service provisioning. The goal of this work is to assure a bounded end-to-end setup delay for SPC requests in order to meet the optical Service Level Agreements (SLA) that are being defined. An example of such SLAs is the 1-min setup delay for Premium bandwidth on demand [2]. Such bound is first approached analytically, focusing on the delay introduced by the management plane, and then evaluated experimentally in an ASON/GMPLS setting. The focus is on the management plane because it represents the near real-time part of SPC provisioning, since control plane is distributed and real time oriented in nature [1]. However, for better understanding, control plane modeling is outlined as well. Detailed experimental results of GMPLS in the test bed used in this work can be found in [3]. The remainder of this paper is organized as follows. In Section II we present the problem statement and system model for SPC provisioning. Section III outlines the approach adopted for SPC provisioning in ASON/GMPLS. In Section IV we detail the analytical study for bounded provisioning delay, whereas Section V deals with the experimental verification of our analytical approach for setup requests. In Section VI we draw conclusions.

II. PROBLEM STATEMENT

Let N be an optical network composed of M nodes and V links. Each node has three functional planes: control (Optical Connection Controller, OCC) [1], transport part, which may be either an Optical Add-Drop Multiplexer (OADM) or an Optical Cross-Connect, and management (agent). The network is a single domain managed by a Network Management System (NMS). Each node is interconnected to neighbour nodes with fiber pairs (one for Optical Multiplex Section protection) according to a (unidirectional) ring topology. Each fiber may carry up to C wavelength-multiplexed data channels. The Data Communications Network (DCN) carries control and management data in a dedicated channel in- or out-of-fiber with capacity r_{DCN}. Fig. 1 illustrates the system model.

We want to find analytically an average value for the connection setup delay of optical connections of soft-permanent type, defined in ITU-T Recommendation G.ASON [1], and validate it experimentally. Moreover, we want to check whether the values suggested for optical SLAs, e. g. [2], related to setting up a bandwidth on demand service are in line with this average value.

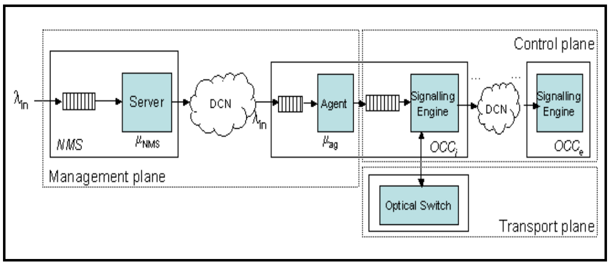

Figure 1. System model for SPC provisioning

III. APPROACH FOR SOFT-PERMANENT PROVISIONING IN ASON/GMPLS

In future networks, in order to request an SPC users will contact the Network Operations Center. There, an operator will enter the parameters of the connection (through a Graphical User Interface, GUI) to the NMS and the request will be forwarded from the NMS to the control plane via management agents embedded in the optical nodes (Optical Connection Controllers, OCC, according to ASON [1]). For simplicity, we assume that the optical network supports a single service quality and only intra-domain requests (see Fig. 1).

The control plane provides 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. A typical scenario for SPC provisioning starts with a call request from the client, which is accepted by the NMS, forwarded to the ingress node's agent and mapped to the node's signaling engine. According to up-to-date resource information, a route is computed by the control plane and resources are requested and reserved along the route according to signaling messages which, under acceptance of egress and on their way back to the ingress node, allocate in turn the resources previously reserved [3]. Finally, the NMS is informed of the service establishment through the ingress management agent. Fig. 2 depicts the scenario described.

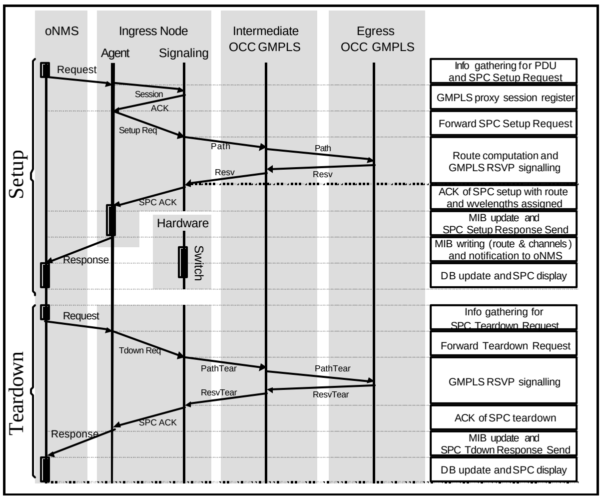

Figure 2. Event sequence for SPC provisioning

Thanks to the distribution of management information in all functional planes of ASON [1], setup and teardown delays are reduced, as we describe in [5].

IV. ANALYTICAL STUDY

Both the management messages carrying SPC requests and the control plane signaling messages needed to establish or release this kind of connections are carried over the DCN. We assume that r_{DCN} is sufficient. Then, the end-to-end delay that a message involved in service provisioning can face from the moment it enters until it exits the optical network is denoted by

$$D = D_{MP} + D_{CP} + D_{TP} \tag{1}$$

where D_{MP} is the delay due to the management plane (NMS, agents embedded in each OCC and latency of management messages, that is, propagation and transmission delays), D_{CP} is the delay incurred at each OCC (signaling), along with the signaling latency delay, and D_{TP} is the delay of optical hardware, which encompasses the execution of control plane commands to establish or release channels (mainly switching). The average value of D can be expressed as

$$D = D_{NMS} + D_{ag} + D_{lat} + D_{sig\text{-}pr} + D_{switch} \tag{2}$$

where D_{NMS} and D_{ag} are the average delays within the NMS and the agent of the ingress OCC [5] and $D_{sig\text{-}pr}$ is the average processing delay in the signaling path [3], which includes call and signaling protocol processing delays in each node along the path. D_{switch} is the average switching delay of the ingress optical matrix, which depends on its technology. D_{lat} is the average round-trip latency of management and signaling messages in the DCN. Its value is related to the transmission medium of each link, the capacity of the control channel (r_{DCN}) and the length of the management and signaling messages.

The following analysis deals with the values of D_{NMS}, D_{ag} and $D_{sig\text{-}pr}$. Note that we only consider the metric of end-to-end delay, defined as the sum of all the delays along the path from source to destination. Under the assumption of Poisson traffic with exponential inter-arrival and holding times for SPC requests, D_{NMS} and D_{ag} can be expressed as

$$D_{NMS} + D_{ag} = \frac{1/m_{NMS}}{1 - r_{NMS}} + \frac{1/m_{ag}}{1 - r_{ag}} \tag{3}$$

where m_{NMS} and m_{ag} are the service rates of the NMS and the management agent, and r_{NMS} and r_{ag} are the utilization of the NMS and the agent, respectively. $?_{in}$ is the arrival rate of SPC requests to the queue of the system model depicted in Fig. 1. Due to the fact that we model the NMS as an M/M/1 queuing system with infinite capacity, incoming requests for the agent (outputs of the NMS) are as well of Poisson nature with arrival rate $?_{in}$, as described in [4].

[6] provides an expression for the mean call setup delay in optical circuit-switched networks, from which $D_{sig\text{-}pr}$ can be expressed as

$$D_{sig-pr} = \frac{B_{sig}}{r_{DCN}}\left(1 + \frac{r_{sig}}{2(1 - r_{sig})}\right)(m+1) + D_{sp}\left(1 + \frac{r_{sp}}{2(1 - r_{sp})}\right)m \tag{4}$$

where B_{sig} is the cumulative size of signaling messages used in the setup provisioning process, r_{DCN} is the signaling link rate, m is the number of OCCs on the end-to-end path and D_{sp} is the signaling message processing time at each OCC. This expression is obtained from the approximation of the queuing delays for the signaling link and call processors with M/D/1 queues at loads ρ_{sig} and ρ_{sp} [6]. Since we assume Inter-Arrival Times (IAT) between SPC requests to be exponentially distributed, an M/D/1 queuing model is in principle quite accurate with respect to really, especially when signaling message lengths and processing delays are more-or-less constant, which is the case in ASON/GMPLS networks.

V. EXPERIMENTAL VALIDATION

Here we describe experimental tests performed in an ASON/GMPLS setting that operates 8 Dense WDM channels per fiber in C-band at up to 2.5 Gbps, due to economic reasons. $M = V = 3$, $L = 35\ km$ and the network topology is a ring. The control channel of the DCN is a Fast Ethernet carried in O-band. The NMS is implemented in a 1.5GHz Windows Platform, and is interconnected to the DCN through OCC1 (link L_{NMS}).

The OCCs are 1GHz Linux routers. This architecture is depicted in Fig. 3 and is further detailed in [3]. Since the transport plane of the test bed is not fully deployed, experimental validation cannot be done for D_{switch}. Switching time of commercial optical 2x2 switches, which is the architecture adopted in the test bed's transport plane [3], can be as low as 3 to 5 msec [7, 8]. Therefore, a typical value of 5 msec is used in Fig. 4.

Control and management messages involved in the provisioning process, described in [5] are based on IP. Management messages are compliant to the Simple Network Management Protocol (SNMP), whereas control messages are compliant to the Resource reservation Protocol (RSVP) with GMPLS extensions.

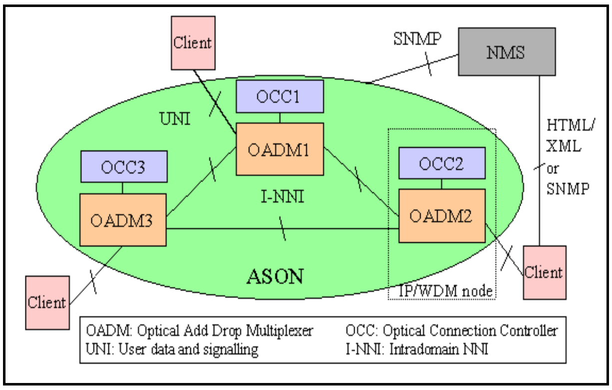

Figure 3. Logical architecture of the test bed

Traffic load is uniform for all OCCs. Since OCC1 is directly connected to the NMS through an Ethernet cable of length L_{NMS}, the end-to-end path for management messages is

$$L_m = \begin{cases} 2L_{NMS} & \text{, if ingress node is OCC1} \\ 2L_{NMS} + 2L & \text{, otherwise} \end{cases}$$

Concerning the transmission delay, there are two management messages (SNMP Set and response [5]) for each provisioning request. There are as well as many RSVP Path messages as links between the ingress and egress OCCs, and the same for Resv messages [3].

IATs $(1/?_{in})$ range from 26 ms to 5 s. The values of m_{NMS} (25 ms) and m_{ag} (3 ms) have been obtained experimentally as part of our work in [5, 10], since analytical values are hard to obtain. This verifies $l_{in} < m_{NMS}$, which is part of the steady-state conditions for the NMS (M/M/1 system) [4], in particular. On the other hand, a software router's performance is affected by several issues, being the most important the host's hardware architecture, the forwarding program's software architecture, the network interface card's hardware and its driver architecture [9]. In other words, analytical values for D_{sp} are also difficult to obtain. Therefore D_{sp} has been obtained experimentally, with an average value of 0.5 msec.

As for D_{lat}, typical propagation delay of CAT5 cable is 555 nsec at 10 MHz (20 ns/m for CAT5E) and 5 µsec/km in optical fiber. To calculate the transmission time, length of GMPLS/RSVP messages is 202 and 210 bytes for B_{Path} (1 and 2 hops) and 162 bytes for B_{Resv}. Length of SNMP messages is $B_{Set} = B_{Rsp} = 371$ bytes (14 object identifiers [5]). As in [6], we assume 0.8 for ρ_{sig} and ρ_{sp}. Finally, r_{DCN} is $100\ Mbps$.

Fig. 4 depicts the setup provisioning delay obtained analytically and the experimental results obtained (300 tests for each value). [5] details the rationale and setting of these experiments.

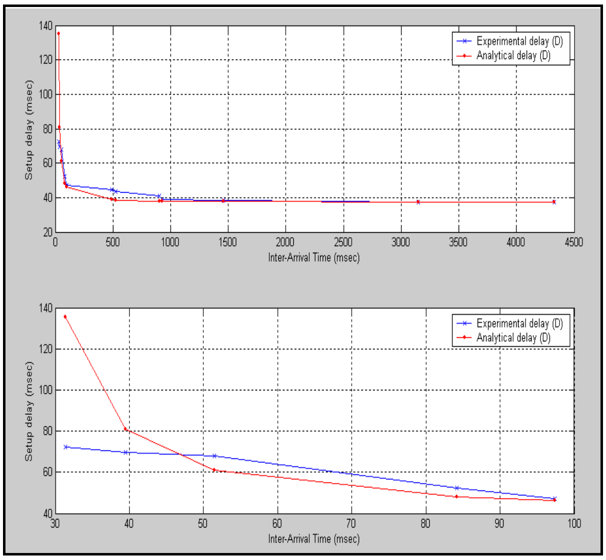

Figure 4. Analytical vs. experimental delay

The upper part of Fig. 4 plots IATs in the range [26, 5000] ms, whereas the lower part focuses on low IATs (26 to 100 ms). In general, the analytical model has 85-95% accuracy with respect to the experimental results for IATs higher than 50 ms, that is, $l_{in} < 0.5 \cdot m_{NMS}$. Analytical delays for IATs below 35 ms range from 100 ms to infinity (asymptotically), which is not consistent with the experimental behaviour of the network, as depicted in the lower part of Fig. 4. Note that we give a range of the accuracy percentage due to the ± 2 ms end-to-end inaccuracy of the Windows OS in which the NMS of the test bed is implemented, and where we gather setup delays.

It is sensible to suppose IATs of SPC requests to be higher than twice the NMS' service time in single queue, single server systems such as the one modelled here, since SPCs are not expected to be as dynamic as switched connections. Therefore, scenarios for which our model behaves well seem realistic at least in the first stages of deployment of ASON/GMPLS networks.

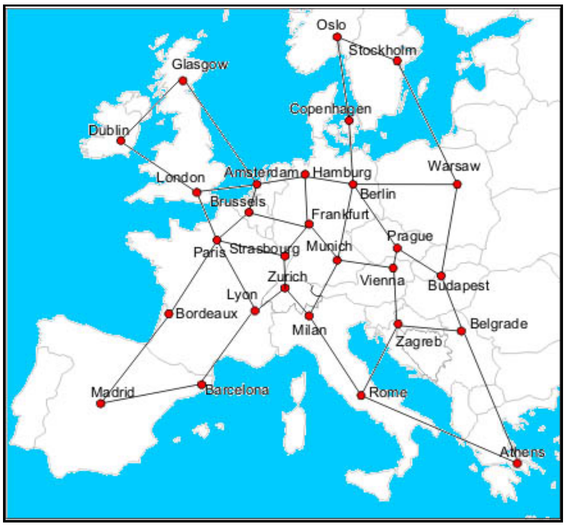

Figure 5. European optical network (COST 266)

In [2], Fawaz et al. suggest an end-to-end setup delay of 1 min for a bandwidth on demand service of Premium class. Let's imagine that the European optical network (Fig. 5) is upgraded as ASON/GMPLS. As an example, if users request the establishment of pan-European SPCs from Barcelona to Oslo (shortest path spanning 8 links) with IATs of 30 ms, the analytical model gives an end-to-end delay of less than 200 ms, which is 300% faster than the suggested delay [2]. Therefore, the management-control plane architecture outlined in Fig. 2 and described in previous works of the authors [3, 5, 10], allows not only dynamic services but it may assure as well SLA's parameters concerning establishment and release delays. Note that the model can be easily extended for teardowns, for which the values of m_{NMS} and m_{ag}, as well as B_{sig}, B_{Set} and B_{Rsp}.

VI. CONCLUSIONS

End-to-end provisioning delay will be a crucial metric for Service Level Agreements because rapid, dynamic service provisioning is expected to be the killer application for the success of future optical networks. In the literature, provisioning of SPCs is studies from a modelling perspective and from an experimental viewpoint. In this paper we have presented an analytical study of the end-to-end delay of SPCs in a control plane enabled optical network. The approach for providing SPCs is distributed between the management and control planes.

This analysis has been assessed in an ASON/GMPLS test bed that verifies SPC provisioning as defined by the ITU-T [1] and has a control plane based on GMPLS. Results show that the analytical model matches the experimental results for $l_{in} < 0.5 \cdot m_{NMS}$, which seems a realistic scenario in next-generation intelligent optical networks.

Further work includes the extension of the analytical model for multi-server NMS and Quality of Service (queuing and signaling priorities), the optimization of the test bed's NMS architecture in terms of time accuracy and service time and the performance of experimental tests with a future outgrowth of the test bed, featuring an ASON/GMPLS ring with 9 nodes.

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REFERENCES

[1] ITU-T G.8080, "Architecture for the Automatically Switched Optical Network (ASON)", November 2001.

[2] W. Fawaz, B. Daheb, O. Audouin, M. Du-Pond, nad G. Pujolle, "Service Level Agreement and provisioning in optical networks", IEEE Communications Magazine, Vol. 42 (1), pp. 36-43, January 2004.

[3] R. Muñoz, C. Pinart, R. Martínez, A. Amrani, and G. Junyent, "An experimental ASON based on OADM rings and a GMPLS control plane", Journal of Fiber and Integrated Optics, Vol. 23, Nb. 2-3, pp. 67-84, March-June 2004.

[4] I. Adan, and J. Resing, "Queuing theory", Department of Mathematics & Computing Science, Eindhoven University of Technology. Feb. 2001.

[5] C. Pinart and G. Junyent, "Experimental test of management integration in GMPLS enabled metro WDM networks for service provisioning", in Proc. 30th European Conference on Optical Communication (ECOC 2004). Stockholm, Sept. 2004.

[6] M. Veeraraghavan, H. Lee, and Z. Zheng, "File transfers across optical circuit-switched networks", in Proc. 1st International Workshop on Protocols for Fast Long-Distance Networks (PFLDnet), Geneva, February 2003.

[7] "Specifications of MEMS add/drop 2x2 switch", DICON Fiber Optics Inc., available at http://www.diconfiberoptics.com/products/scd0061/

[8] "Specifications of MEMS-based 2x2 switch", DMEMSCAP, available on-line at http://www.memscap.com/datasheets/MOS2x2secu.pdf

[9] O. I. Lepe Aldama, "Modeling TCP/IP software implementation performance and its application for software routers", PhD dissertation. Universitat Politècnica de Catalunya, December 3 2002.

[10] C. Pinart and G. Junyent, "On implementing a management plane for service provisioning in IP over reconfigurable WDM networks", 8th Working Conference on Optical Network Design and Modelling (ONDM 2004). Ghent (Belgium), February 2-4 2004.