Some Open Issues in the Optical Networks Control Plane

Josep Solé-Pareta, Xavier Masip-Bruin, Sergio Sanchez-Lopez, Salvatore Spadaro, Davide Careglio
Advanced Broadband Communications Lab (CCABA), Universitat Politècnica de Catalunya (UPC)
Jordi Girona 1-3, 08034 Barcelona, Catalunya, Spain
{pareta, xmasip, sergio, careglio}@ac.upc.es, spadaro@tsc.upc.es

ABSTRACT

The growth of bandwidth demand for data traffic drives the evolution of the current transport networks towards the introduction of the Automatic Switched Optical Network (ASON). Introducing automatic switching capabilities in optical networks means designing and implementing control functionalities. Such as functionalities are hosted at the network Control Plane, and mainly consist of providing signalling and routing mechanisms distributed throughout the network. This paper addresses some issues still under discussion on the definition of a suitable control plane for optical core networks. Specifically, we deal with the routing protocol, which defines the distribution of topology information, the path selection and the association of nodes in a network; and with the routing mechanism, which allows selecting the path according to attributes of the connection requests and the available resources in the network. We also deal with the traffic engineering strategies used to optimise the use of these resources and give a quick view of future trends in Optical Networks.

Keywords: Network Control Plane, Automatic Switched Optical Network (ASON), Routing in ASON.

1. INTRODUCTION

The introduction of high capacity and reliable transport networks is being necessary in order to cover the growing needs of Internet traffic demands. New incoming Internet applications increasingly request greater capacity and guarantee of traffic delivery. Optical Transport Networks (OTN) with automatic switching capabilities (ASON, Automatic Switching Optical Networks) appears as a potential solution to cope with such a situation. While current SDH networks give only transport capacity, future ASONs will allow dynamic set-up and tear-down of optical channels (OCh). A key issue to resolve to achieve this functionality is to define a Control Plane, which is responsible for the routing and signalling process.

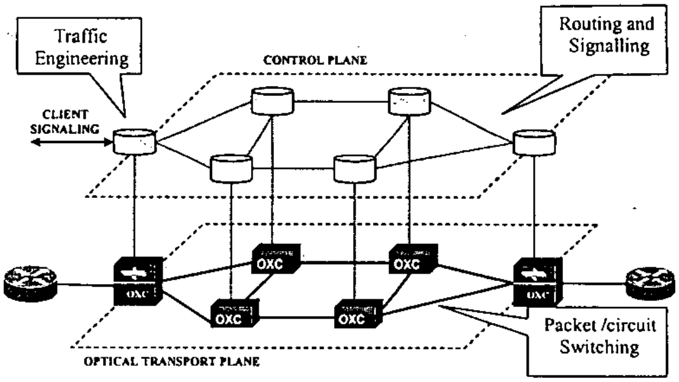


Figure 1. Optical core network layers: control plane and transport plane.

The automatic set-up/tear-down functionality can allow network operators to provide for Traffic Engineering (TE) directly in the optical layer through Lightpaths routed and signalled by the Control Plane. The main target of TE is to optimise the network resources utilization. A key aspect in the TE is the routing process. The routing process selects routes according to the incoming traffic demands. A method to trigger such traffic demands need to be defined. In this paper we deal with some aspects of the control plane, mainly those hardly related to the routing process. In particular we describe current available control plane models, and approaches under development (Section 2). Then, we present some considerations on routing functions for ASON control plane, with specially emphasis on the inaccuracy state information problem. Also, some methods to trigger the incoming traffic demands are briefly described (Section 3). Finally, future directions and emerging paradigms in optical networking are discussed (Section 4).

This work is partially funded by the Commission of the European Union under the COST 266 Action and by the MCYT (Spanish Ministry of Science and Technology) under contract FEDER-TIC2002-04334-C02-02.

2. CONTROL PLANE GENERAL ASPECTS

A Control Plane consists of the following aspects:

- A network signalling, which enables a way of communication between entities that request services and entities that provide services.
- A signalling protocol, which governs this communication. It is used for establishing, maintaining and releasing optical channels (lightpaths).
- A routing protocol used for distributing topology and available resources information throughout the network. This information is then used by a routing algorithm to computes the proper route.
- An Address scheme, which identifies each optical network element within the network.

2.1 Control Plane Models

Optical network provides a service to external clients in the form of fixed bandwidth (lightpath). These client networks (typically IP/MPLS networks) at the edge of the optical networks must necessarily establish such paths before communication at the client layer can begin. At this point both client and optical network control planes are acting. Three different models can be differentiated depending on the integration of both control planes:

- *Overlay model:* The client routing, topology distribution and signalling protocols are independent of the optical layers. Therefore a different control plane exists for client and optical networks
- *Peer model:* A single routing protocol runs over both the client and the optical domains. Therefore, the client network knows the optical domain topology information. In this model a common address space exists. Thus, only one control plane exists in this model.
- *Augmented model:* It is an overlay model, but routing and topology client information can be transparently transported through the optical network.

2.2 Control Plane Approaches

Currently, two different approaches are being considered to implement the Control Plane optical transport networks, namely MPLS based and PNNI based. The IETF points out the Generalized MPLS (GMPLS) as an extension to the MPLS Traffic Engineering control plane model to include optical networking. The ITU-T have just issued recommendation G.7713 about an optical control plane based on the ATM Private Network to Network Interface (PNNI) paradigm, which convert Optical PNNI (O-PNNI) in an alternative to the GMPLS approach. PNNI is expected to be suitable for ASON after some appropriate modifications. As a mature technology, the PNNI can be very practical for a seamless migration from current transport networks to ASON.

On one hand, GMPLS uses IPv4 and/or IPv6 addresses. However, O-PNNI will use Network Service Access Point (NSAP) addresses, and so no common address space may be built with IP based networks, which excludes the Peer model for the O-PNNI approach. Unlike GMPLS, O-PNNI may support Soft Permanent Virtual Connection (SPVC) that is one of the ASON requirements. Moreover, O-PNNI may incorporate a Connection Admission Control (CAC) to indicate whether an optical node can admit a new connection. In GMPLS, the support of CAC does not seem to be well developed at this moment. The PNNI hierarchical structure extended to O-PNNI will allow supporting multiple levels (up to 104) and therefore is scalable for very large networks. In GMPLS, OSPF and IS-IS only support two hierarchical levels.

On the other hand, separated control and transport planes are recommended for ASON. To support separated planes GMPLS includes additional signalling information compared with MPLS. A similar effort has to be done in O-PNNI. Neither O-PNNI nor GMPLS support Service Discovery, a concept introduced by the OIF, which consists of querying transport service characteristic before the optical UNI signalling establishes the connection.

Furthermore, in GMPLS, OSPF and IS-IS use Traffic Engineering specific extensions to propagate QoS information. These parameters are stored at each node, and a modified Constrained Shortest Path First (CSPF) protocol computes a path through the network. O-PNNI routing protocol may include QoS arguments in the lightpath requests. Also, O-PNNI may incorporate a "crankback" mechanism to support rerouting around failed component at the connection setup.

Table 1 includes a brief comparison between both GMPLS and O-PNNI approaches considering the above-mentioned issues.

Table 1. Comparison of GMPLS and O-PNNI.

CONTROL PLANE REQUIREMENTS	GMPLS	O-PNNI
Addressing	Yes	Yes
Connection Admission Control	No	Yes
Hierarchical structure	2 levels	Up to 104 levels
Separated control and data plane	Yes	No
Service Discovery	No	No
Path selection with QoS	Yes	Yes

3. ROUTING FUNCTIONS FOR ASON CONTROL PLANE

Routing is the control plane component used to select paths in order to set up connections across one or several carrier networks. Unlike traditional IP/MPLS networks where the routing process only looks for the optimal route, in an optical scenario the routing process, named *Routing and Wavelength Assignment* problem (RWA) [1], must find both the physical nodes and links that configure the lightpath (routing subproblem) meeting TE objectives, and the wavelength/s to be used on all the links along the lightpath (wavelength assignment subproblem), in such a way that the network resources are optimised.

In general the RWA is differently addressed depending on the availability of wavelength conversion capabilities. Wavelength routed networks without wavelength conversion are known as *wavelength-selective* (WS) networks. In such a network, a connection can only be established if the same wavelength is available on all the links between the source and the destination (*wavelength-continuity constraint*). This may cause high blocking probability. Wavelength routed networks with wavelength conversion are known as *wavelength-interchangeable* (WI) networks. In such networks, each router is equipped with wavelength converters so that a lightpath can be set up using different wavelengths on different links along the route.

There are three approaches to dealing with the routing subproblem: *fixed-routing*, *fixed-alternate routing*, and *adaptive routing*. *Fixed routing* always selects the same pre-computed route for a source-destination pair. In *fixed-alternate routing* a set of fixed pre-computed lightpaths exists for a source-destination pair, and one of them is selected according to a certain heuristic. In *adaptive routing* the lightpath is dynamically selected depending on the current network state, according to a particular heuristic, such as the *shortest path* or the *least-congested path* (LCP). The LCP selects those links with the most available wavelengths to carry the lightpath. Notice that approaches based on fixed routes reduce the complexity, but unlike adaptive routing may suffer from higher connection blocking. A large number of different heuristics has been proposed for the wavelength assignment subproblem: Random, First-Fit, Least-Used, Most-Used, Min-Product, Least-Loaded, Max-Sum and Relative Capacity Loss, etc., which can each be combined with different routing mechanisms.

In accordance with considerations above described, routing functions include two parts, namely network information dissemination and constraint-based path computation. The former distributes topology and available resource network information among nodes taking into account scalability aspects, the latter focuses on the mechanism used to optimally select paths. In [2] we propose a routing information exchange protocol providing ASON with a hierarchical structure, a topology information dissemination mechanism and a protocol extension to distribute topology and resource information about non-optical clients through the ASON. Constraint-based routing is a Traffic Engineering (TE) tool, which selects paths according to certain QoS requirements in order to increase global network utilization. Path selection mechanisms depend on the accuracy of available network information, input requirements and the internal computation algorithm. The consequence of an incorrect path computation will affect the connection for the entire time that is in use. Thus, path computation is a critical aspect and has to be carefully performed.

3.1 Routing under Inaccurate Network State Information

Several causes may motivate the existence of inaccuracy in the network state information, namely the topology state aggregation in hierarchical networks, the propagation delay, the triggering policies used to reduce the amount of signalling messages needed to keep network state databases updated. New routing mechanisms must be generated that includes the network state inaccuracy as a parameter to be considered when selecting the lightpath, in order to perform the Routing and Wavelength Assignment (RWA) in dynamic networks. Although the effect of having inaccurate routing information in the path selection process has been widely analyzed in an IP scenario and some mechanisms has been proposed in the literature to deal with this problem, no many contributions can be found addressing the similar problem for optical networks.

In [3] is shown by simulation the effects produced when having inaccurate routing information in the lightpaths selection process in terms of blocking probability. In fact, introducing a certain degree of uncertainty by adding an updating interval of 10sec, in [3] it is verified that over a fixed topology the blocking ratio increases when routing is done under inaccurate routing information. Some other simulations are performed to show the effects on the blocking ratio due to changing the number of fibres on all the links. The final conclusion of this paper is that new RWA algorithms that can tolerate imprecise global network state information must be developed for the dynamic connection management in WDM networks.

In [4], the routing inaccuracy problem is addressed by modifying the lightpath control mechanism, and a new distributed lightpath control based on destination routing is suggested. The mechanism suggested in [4] is based on both selecting the physical route and the wavelength on the destination node and adding rerouting capabilities to the intermediate nodes to avoid blocking a connection when the selected wavelength is not really available in any intermediate node along the lightpath. The main weaknesses of this mechanism are that since the rerouting is performed in real time in the setup process, the wavelength usage deterioration is directly proportional to the number of intermediate nodes, which must reroute the traffic, and that the signalling overhead is not reduced, since the RWA decision is based on the global network state information maintained on the destination node, which must be perfectly updated.

To counteract this problem, in [5] we propose the *BYPASS Based Optical Routing* (BBOR) routing mechanism assuming that the simpler and most significant source of inaccuracy to be addressed is the updating process. Note that in order to keep the network state information correctly updated, the routing protocol must include an updating mechanism. In general, this updating mechanism is implemented by a triggering policy that may be based on either a periodical refresh, or a certain threshold value, which defines when an updating message must be flooded throughout the network. The lost of accuracy introduced by the updating mechanism is due to the necessity of reducing the number of updating messages. BBOR is a new adaptive source routing mechanism based on inaccurate global network state information that computes dynamic explicit lightpaths in an ASON without conversion capabilities, aiming to reduce the connection blocking probability due to performing routing and wavelength assignment decisions under inaccurate routing information. Basically BBOR consists of two main components, namely a triggering policy adapted to the RWA problem to reduce the routing signalling, and a bypass routing algorithm to counteract the effects of the routing inaccuracy produced by this routing signalling reduction. The main BBOR characteristic is that it allows several nodes along the selected path to dynamically reroute the setup message to a different route (bypass-path) when, due to the wavelength unavailability produced by computing the selected paths according to inaccurate routing information, this setup message would be rejected in any of these intermediate nodes. BBOR acts in a similar way that protection and restoration rerouting algorithms.

The routing mechanisms discussed so far, appear as a potential solution to reduce the impact of the routing inaccuracy problem in optical core networks based on circuit switching. However, unlike circuit switching networks, where wavelength availability is the critical parameter, when optical core networks will be based on packet switching, a new attribute will have to be taken into account in the lightpath selection, that is, the available bandwidth. It will be necessary to redefine routing mechanisms to cope with this problem. A first approach to address the routing inaccuracy problem in an MPLS over optical packet switching networks scenario can be found in [6].

3.2 Traffic Engineering in the Optical Layer

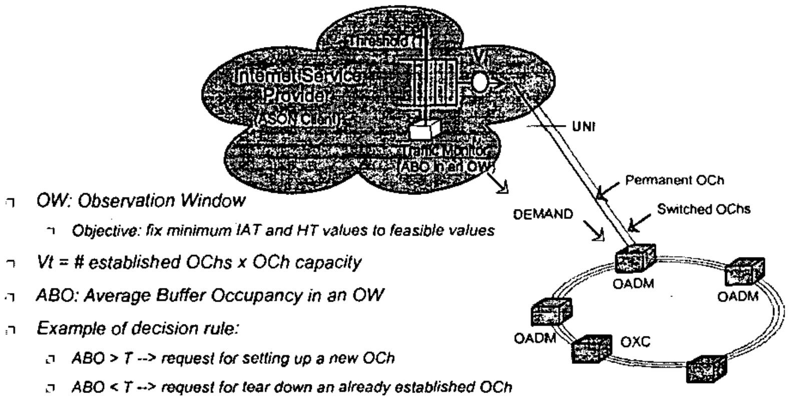
User behaviour as well as market conditions, weather conditions, accidents, faults, etc. can cause significant and unexpected fluctuations in the volume of traffic offered to transport networks. A big problem that arises for network operators is how to adapt the network topology to respond to the changes in the traffic demands. In ASON networks the automatic set-up and teardown of lightpaths can be used for the logical reconfiguration of the networks as a consequence of significant variations in the volume of traffic.

Reconfiguration of optical networks under dynamic traffic has been studied [7], [8], but in these studies the future traffic demand is assumed to be known. For an IP/MPLS environment the in [9] a traffic-driven Label Switched Path (LSP) establishment technique is proposed. In such a case LSPs are dynamically established/torn down when there is some traffic towards some destination node and released during idle periods. In particular, a simple LSP set-up policy has been proposed in which an LSP is established whenever the number of bytes forwarded within one minute exceeds a predefined threshold. This technique does not require a-priori knowledge of the traffic demands.

In [10] we suggest a mechanism to trigger the requests for set-up/tear down of optical channels in an IP over ASON environment. It has to be underlined that since IP is expected to be the layer integrating most of video-voice-data applications, IP-based networks are likely to become the main client network of ASON. The proposed method is based on monitoring the IP traffic at client layer. Traffic monitoring is installed at the ASON client (e.g. the egress router of an ISP network), and has to be designed to monitor a parameter of the IP traffic. The monitoring function can be done by monitoring, either the instantaneous value, or the average value (computed periodically) of that parameter.

Triggering mechanisms based on monitoring the instantaneous variations of the IP traffic parameters may lead to Control Plane instabilities, because it requires to set up/release high-capacity connections too often. Thus, we consider a scheme based on monitoring the traffic periodically and estimating future traffic requirements (i.e., a triggering mechanism based on a traffic-predictability-driven approach).

Figure 2 shows an example of a possible scenario where the triggering demands for setting up/tear down ASON connections is based on IP traffic monitoring of the aggregated traffic outgoing from a big client of metropolitan ASON (e.g. an Internet Service Provider (ISP)). The scheme consists of using an Observation Window (OW) and the triggering mechanism taking actions on the basis of packet occupancy of the output buffer, computing the average during this OW and triggering a connection demand accordingly. A new connection demand is triggered when this value is greater than a threshold, and an already established connection is released when the average buffer occupancy is lower.



- *OW: Observation Window*
  - *Objective: fix minimum IAT and HT values to feasible values*
- *Vt = # established OChs x OCh capacity*
- *ABO: Average Buffer Occupancy in an OW*
- *Example of decision rule:*
  - *ABO > T --> request for setting up a new OCh*
  - *ABO < T --> request for tear down an already established OCh*

Figure 2. An ISP requiring dynamic connections from an ASON.

The request for a new channel is based on the established channel bandwidth utilization. In such a way, network congestion as well as optical channels under-utilization can be counteracted.

4. OPTICAL NETWOK TRENDS

An intense debate has been ongoing in the last few years about which has to be the network model to adopt, aiming at identifying the degree of optical transparency to be achieved, and the proper flexibility of optical networks. Definitely, optimizing the network is the trend in the next generation of routing and switching products.

To this end, GMPLS technology extends MPLS to encompass different switching granularities: time-division (e.g. SDH/SONET, PDH, G.709), wavelength (lambdas), and spatial switching (e.g. incoming port or fibre to outgoing port or fibre). Resulting optically circuit switched networks can offer explicit transfer guarantees and some degree of flexibility, but nevertheless the network still remains based on circuit with considerable delay to confirm circuit establishment. Moreover, the network consists of a complex, multi-layers structure with no easy manageability for protection/restoration, traffic engineering, and scalability/upgradability issues. For these reasons, future networks should be able to serve client networks, including packet-based networks such as Internet, where a highly dynamic connection pattern with a significant portion of bursty traffic between communicating pairs is expected.

In this perspective, it is important to consider the new emerging optical network scenarios. Indeed, in spite of the extraordinary advances in transmission capacity, optics has not penetrated much into the switching and management part of the network and optical networks are still in their infancy. New optical components such as Tunable Wavelength Converters (TWCs), Semiconductor Optical Amplifiers (SOAs), 3R optical regenerators are currently under development aiming at providing very high integration degree and low power consumption [11].

Exploiting these new devices, a finer granularity can be realised with the Optical Burst Switching (OBS) technique [12]. This is a switching technology that offers a dynamic mechanism to set up with low latencies high-capacity end-to-end optical data connections. It improves wavelength utilization by introducing a certain degree of dynamic resource allocations. OBS paradigm can be enhanced through MPLS-like label-switching techniques to achieve the so-called Labelled OBS (LOBS).

In a longer-term scenario, a finest switching granularity can be achieved by means of Optical Packet Switching (OPS) techniques [13], which requires very fast all-optical switches (switching time in the order of nanoseconds), and more complex network node architectures. In particular, the contention resolution issue is the main problem of designing OPS networks. Contention resolution may be performed in the space domain, by means of deflection routing, in the time domain, by means of queuing (typically by means of fibre delay lines), and in the wavelength domain, by means of wavelength multiplexing in the WDM links, or by using a combination of such techniques. In particular, some recent works show that very good performance may be achieved with a very limited complexity if an MPLS-based control plane is integrated in the contention resolution algorithms [14].

Figure 3 shows the relation between the switching time required by the different switching paradigms and the switching time provided by the incoming optical components.

Current open issues in the optical networks Control Plane has to be addressed considering not only the ASON paradigm, but also the OBS and OPS paradigms.

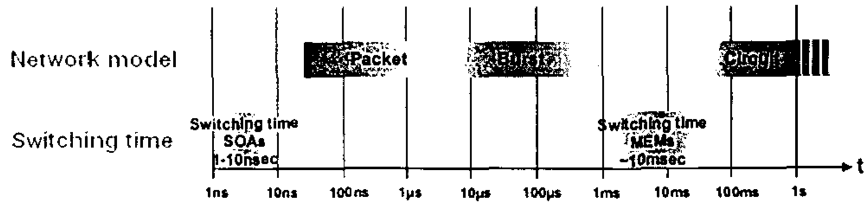


Figure 3. Network model versus switching time.

5. SUMMARY

Future infrastructure for supporting public telecommunication networks will be based on optical networks, which will have to be data centric focused. Such an infrastructure will not be just the pure replacement of current SDH/SONET infrastructure; it is being required to include some intelligence in the network, which will be provided by a Control Plane.

The definition of a Control Plane for Optical Networks still have some open issues, such as the approach to be based on (GMPLS or O-PNNI), the Routing mechanism, the proper traffic engineering strategies to be used, etc. In this paper we have presented an overview of these open issues focused in the Automatic Switched Optical Networks (ASON), and a quick view of the future optical network trends, which also have to be taken into account in the design of the Control Plane for Optical Networks.

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