

Service Level Agreement and Provisioning in Optical Networks

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ABSTRACT

This article proposes a service level agreement applied to the optical domain (O-SLA), which is expected to be the near- and long-term network technology thanks, among other things, to the great bandwidth capacity offered by optical devices. After an exposition of the rationale behind an optical SLA, parameters that could be included in this O-SLA, as well as their values for four classes of services, are proposed. Different client (wavelength or subwavelength) and service types (from leased wavelength to bandwidth on demand) are distinguished when necessary. The last part of this article presents issues related to the provisioning of services emanating from this O-SLA.

INTRODUCTION

In an environment of fast changing technologies and uncertain business tendencies, network operators, constructors, and organizations face new challenges to keep up with the increasing bandwidth needs of our world. This is a major driver for the technological development of optical networks, which are foreseen in the future as data-centered optical networks with reduced numbers of electronic elements. As these new and complex networks appear, automation of configuration and management tasks must be done, and it is in this context that the creation of specifications and standards becomes mandatory, yielding to definitions and proposals such as the one discussed in this article. However, in the objective of convergence toward a unified network, a key feature is the capability to offer differentiated services in a single network, to accommodate the different requirements of the various clients. In addition, service differentiation is a valuable opportunity for operators to increase their income from their infrastructure, by selling high added-value services and getting rid of the present business situation where voice traf-

fic is still dominant for revenue in spite of its ever lower weight in volume.

A service level agreement (SLA) is a formal contract between a service provider and a subscriber that contains detailed technical specifications called service level specifications (SLSs).

An SLS is a set of parameters and their values that together define the service offered to a traffic stream in a network [1]. Until now, no standards for the contents of an SLS have been defined, but interesting proposals have been published as Internet drafts by the Internet Engineering Task Force (IETF) [2].

Because optical network technologies belong to an emerging domain, until now, no SLAs have been defined that are adapted to the specific needs of optical networks. Some work has been done in defining SLAs for traditional IP networks [2-4], but these do not consider important issues involved in optical technologies, and therefore do not meet the requirements and exigencies of next-generation optical network operators and service subscribers. This work focuses on defining these SLAs specifically adapted to the relationship between optical network operators and their diverse clients. Moreover, we propose a policy-based provisioning approach to services described in this O-SLA.

BACKGROUND

In this article the relationships defined by an O-SLA consider a service provider to be an optical carrier operator, and a service subscriber to be either an optical client or an IP or multiprotocol label switching (MPLS) client (Fig. 1).

An optical client subscribes to optical network services from the optical carrier operator with a granularity equal to a wavelength, waveband (set of wavelengths), or complete fiber.

The optical client would typically be another peer optical operator whose network interacts with the optical carrier operator in order to provide other network services to its own clients.

An IP or MPLS client, within the context of

this proposal, subscribes to network services with a granularity smaller to that of a wavelength; therefore, its network traffic may undergo a process of grooming or aggregation by the optical operator's network. We suppose here that the aggregating device is an IP or MPLS router. Compared to the previous case, it allows, as we will see, other opportunities to differentiate the service.

An example of an IP client could be an Internet service provider that subscribes to optical network communication services from the optical carrier operator, and provides IP services to smaller clients of its own.

As shown in Fig. 2, different types of services can be envisioned in an optical network, which differs in several dimensions: the degree of variability of the bandwidth, the degree of automation of the connection establishment, and the degree of customer visibility on the resources that are allocated to him.

We have first a *leased-line* type of service where the bandwidth is not often changed and that consequently can tolerate a low level of connection automation. In the *preprovisioned bandwidth* case we suppose that bandwidth variations exist but have been scheduled in the SLA so that the carrier can easily preprovision the resources. *Bandwidth on demand* service is more constraining for the operator as it requires real-time provisioning of bandwidth without previous knowledge of demand variations. A high level of connection automation is then mandatory. Finally, the *optical virtual private network (O-VPN)* [5] is a multipoint-to-multipoint service where the customer has at least visibility of the resources allocated to him and possibly the opportunity to partially directly manage them.

TRAFFIC AND PERFORMANCE PARAMETERS FOR OPTICAL SERVICE LEVEL SPECIFICATIONS

Generic parameters, applicable to any SLS, such as service boundary, service schedule, and flow identifier, will not be discussed here. Furthermore, some values for O-SLS parameters are proposed for four classes of service (from platinum to bronze, excluding best effort traffic for which no guarantee at all is provided).

CONNECTION SETUP TIME

The connection setup time specifies how long it will take for a service connection to be established once it has been negotiated and requested. Connection setup time might be expressed in seconds, minutes, hours, or even days, depending on the client demands and service characteristics.

In fact, while the service schedule determines the periods in which the connection will be active as well as the duration of each period, the connection setup time determines the time that will pass between a service connection request and actual connection activation.

For an operator, a longer time to establish a connection means more time to guarantee resources allocated to this connection by proper-

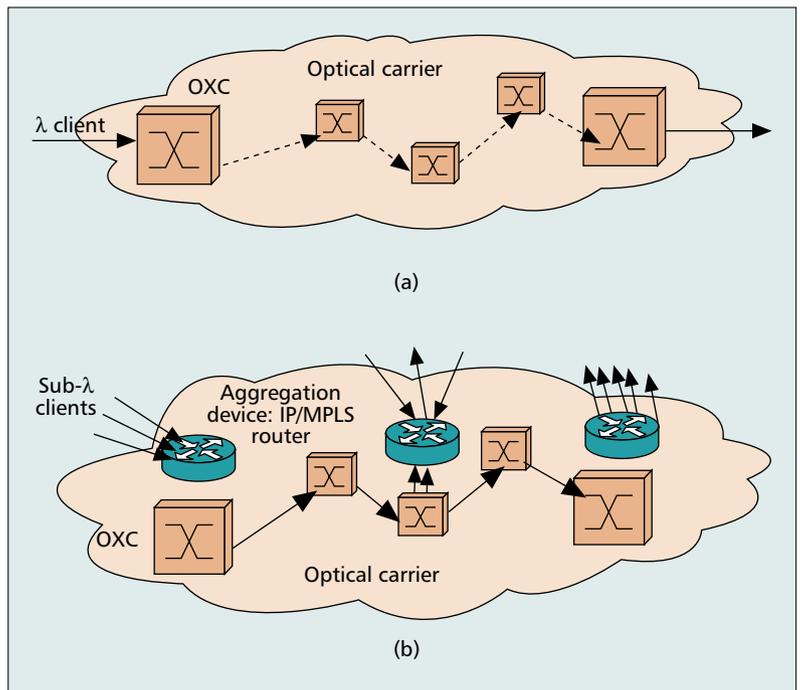


Figure 1. a) Optical client; b) IP/MPLS client.

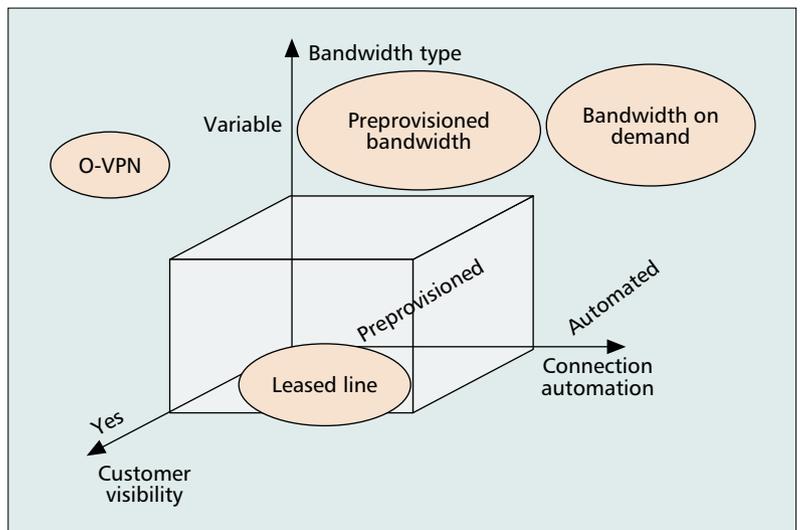


Figure 2. Typology of services.

ly optimizing routing and wavelength assignment or rearranging the network configuration, modifying other connections if necessary. As fewer optimization possibilities exist when connection setup must be rapid, this service must be charged at a higher price.

Table 1 shows an example of what could be the specification of the connection setup times for the different classes of service. We distinguished two cases for which connection setup time has a different meaning. For leased line and preprovisioning bandwidth services, it represents the time between service ordering and service availability; a relatively long time can be tolerated, involving administrative processes and possibly some manual network configuration. For bandwidth on demand service, we deal with more real-time automatic provisioning, and the

	Premium	Gold	Silver	Bronze
Leased line, preprovisioned bandwidth	24 h	4 days	2 weeks	2 months
Bandwidth on demand	1 min	10 min	1 h	12 h

■ **Table 1.** Connection setup times.

	Premium	Gold	Silver	Bronze
Out-of-service criterion	Degraded BER = 10^{-4}	Degraded BER = 10^{-3}	Fault (LOS)	Fault (LOS)
Recovery time with degraded SLA	Not specified	50 ms	500 ms	5 s
Full recovery time	50 ms	300 ms	5 s	5 min
Service unavailability	10^{-5}	10^{-4}	10^{-3}	10^{-2}

■ **Table 2.** Service availability and resilience.

order of magnitude proposed for the connection time parameter is radically shorter.

SERVICE AVAILABILITY AND RESILIENCE

We propose the following parameters for differentiation of service availability (this applies equally to optical and IP/MPLS clients):

- Out-of-service criterion
- Service recovery time
- Recovery time with degraded performance
- Service mean down time

The out-of-service criterion controls the triggering of the resilience mechanism. It can be a fault (loss of power) or degradation (degraded bit error rate, BER) as some applications may tolerate degraded BER and others will not.

Next, we defined two recovery times. The first, service recovery time, defines the time needed to recover the full initial SLS parameters. It can be completed with a shorter second time period during which the connection is recovered but some degradation of SLS parameters (in particular service performance guarantees) are tolerated. Note that no particular resilience scheme (restoration or protection, + 1 or $M:N$, etc.) is indicated in the SLS; this decision pertains to the operator and should not be made visible to the client, the only constraint for the operator being to fulfill the specified recovery times.

The service mean down time is the maximum service breakdown time allowed during a year. It can be specified in seconds or as a percentage.

Table 2 shows an example of what these different parameters could be for the four classes of service.

ROUTING CONSTRAINTS

The process of routing connections within the network offers several possibilities for service differentiation.

Routing Stability — Routing stability determines whether or not optical traffic trunks can be rerouted, and when it is agreed by the optical operator and its clients that the traffic trunks

can be rerouted, it also specifies how often this will take place.

From the client point of view, routing stability is another critical attribute of the O-SLS, since relevant QoS parameters such as delay, throughput, jitter, and loss can be degraded if rerouting takes place very often. Rerouting can also induce some service interruption, affecting overall service availability. In some cases, certain applications might be especially sensitive to rerouting for clients using this kind of application; the periodicity of rerouting should be set to be very small or null. On the contrary, for applications that are insensitive to rerouting periodicity, a higher periodicity might be set in exchange for lower billing for the service.

From the optical operator point view, routing stability is a very important issue because when a client requests a service that involves a long duration or permanent connection that cannot be rerouted due to specific application and business characteristics, the operator has strong constraints. One of these concerns optimization of network resource allocation, because the optical operator cannot tear down the client's permanent connection even if overall channel utilization becomes very low; this results in a waste of bandwidth and optical resources. Additionally, the routing blocking probability increases due to the inability to reroute a certain connection. Given the number of constraints such a service imposes on the optical operator's network, the optical operator can apply higher billing for this kind of service, thus compensating for the inconvenience of avoiding rerouting for a certain connection.

On the other hand, routing stability allows the optical operator to re-optimize its network resource allocation from time to time, tear down connections in case of underutilization, and decrease routing blocking probabilities by providing more possible routes when calculating paths to establish new requested connections.

Route Differentiation — This attribute involves physical path differentiation, and also shared risk link group (SRLG, as defined by the IETF [6]) path differentiation. Clients who desire to themselves manage protection and restoration of their connections may request services consisting of two or more label switched paths (LSPs) that do not belong to the same SRLG, or share any physical links or nodes. Clients might also demand, for security or other reasons, a service in which none of the links and/or nodes pass through a certain country or territory.

For optical network operators, such services represent important routing constraints and, just like the routing stability attribute, the routing blocking probability increases due to the necessity to use different physical paths for two or more LSPs that begin and end at the same end points of the network. This also has an important impact on network resource allocation optimization and efficient utilization. Additionally, when determining the different routes to set up connections throughout the network, these routing constraints need to be considered, which involves complicated routing tools and mechanisms. Due

	Premium	Gold	Silver	Bronze
Routing stability	2 times/year	1 time/month	1 time/week	No limitation
Route differentiation	Optional Fully supported (link, node, SRLG)	Optional Partially supported (link, node)	Optional Partially supported (link)	Not supported
Confidentiality	Optional Fully supported (O/E, grooming)	Optional Partially supported (grooming)	Not supported	Not supported

■ **Table 3.** Service differentiation in routing.

to these complications and constraints, the optical operator can apply higher billing for this kind of service in order to compensate for these inconveniences.

Confidentiality — Confidentiality is a very important issue in all network and information services in general. Optical networks are no exception; thus, different confidentiality levels and constraints need to be defined. The confidentiality attribute defines what level of confidentiality will be associated with the service subscribed in the O-SLS. In optical networks, the best way to provide a confidential connection is using a transparent connection. A lower confidentiality level for an IP/MPLS is to avoid any grooming with other clients on the same wavelength. This can be applied to part of the route only, in the area of the network considered critical. This represents for the operator additional constraints impacting resource usage efficiency.

Distance — This attribute represents the geographical distance between the endpoints of the network involved in the service defined by the O-SLS. The distance attribute should be defined for service billing purposes only. For example, a client subscribing to a service with a connection from Paris to London will pay less than another client subscribing to the same type of service but with a connection from Paris to New York.

Classes of Service and Routing Constraints — Table 3 shows the proposed parameters for the different classes of service. Route differentiation and confidentiality are options that are fully, partially, or not supported according to the class of service.

SERVICE PERFORMANCE GUARANTEES

For an IP/MPLS client the performance parameters will be those of a classical IP network, particularly impacted by the priorities given to the different clients in the routers performing the aggregation. These parameters are delay, jitter, throughput, and packet loss [2].

For an optical client where no aggregation occurs in the optical network, the performance parameter list is restricted to throughput and delay. The difference from the previous case is that the throughput can only have discrete values that are multiples of the bit rate granularity offered by the optical network, and the delay is impacted by the propagation distance only as no buffering occurs. Table 4 shows the values that

	Premium	Gold	Silver	Bronze
Case 1				
Throughput	$n \times X$ Gb/s			
Maximum delay	25 ms	50 ms	Unspecified	Unspecified
Case 2				
Throughput	Any ...	Any ...	Any ...	Any ...
Maximum delay	35 ms	100 ms	500 ms	5 s
Jitter	3 ms	10 ms	50 ms	1 s
Packet loss	10^{-9}	10^{-6}	10^{-4}	10^{-2}

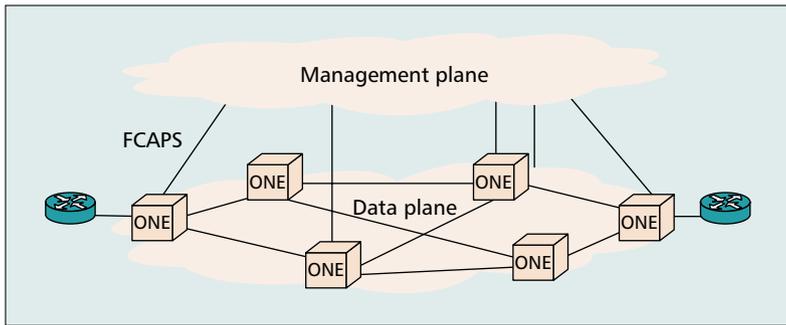
■ **Table 4.** Performance guarantees.

could be allocated to these parameters for each class of service.

TRAFFIC CONFORMANCE AND EXCESS TREATMENT

Before the traffic of the client enters the optical network, testing of the traffic conformance characteristics must be carried out by the optical carrier operator in order to determine if the traffic conforms to what has been agreed in the O-SLS under the traffic conformance attribute. If the traffic test determines that the data flow is in agreement with the traffic conformance parameters defined for that data flow, the data flow is considered in-profile traffic; otherwise, if there is a violation of the traffic conformance parameters previously defined, the traffic is considered out-of-profile traffic. The excess treatment attribute determines how the service provider will process excess or out-of-profile traffic. Excess traffic may be shaped or degraded. Considering that one of the key characteristics of next-generation optical carrier networks being deployed is the ability to provide guaranteed quality of service (QoS), under normal circumstances no excess traffic should be dropped; it should be shaped or degraded. Only where accepting and processing excess traffic compromises the network's capacity to ensure the QoS guaranteed to all other users at that time in the network may excess traffic be dropped. Typically, the regime could be shaping for premium and gold classes, and degradation for the two other classes.

IP/MPLS Client Case — Considering the case of an IP client, the traffic conformance attribute describes the characteristics of the data stream identified by the flow identifier. The traffic conformance attribute contains a set of parameters that describe what the data stream should look



■ **Figure 3.** Traditional provisioning approach; ONE: optical network element.

like to get the QoS guarantees indicated in the O-SLS by the performance parameters attribute. The following is a nonexhaustive list of potential conformance parameters [2]:

- Peak rate p (bits per second)
- Maximum transmission unit (MTU) M (bytes)
- Minimum packet size (bytes)

Excess traffic can be shaped at the entry point of the network until it becomes in-profile, and then be forwarded through the network. Degradation for an IP client means that out-of-profile traffic will be forwarded by the routers connected to the crossconnects (Fig. 1b) with inferior QoS guarantees, resulting in degradation of logical performance.

Optical Client Case — Considering the case of an optical client, the above parameters are not relevant as we do not have access to client packets. However, the same approach of physical parameters can be adopted to classify the client as in-profile or out-of-profile. The following is a nonexhaustive list of potential conformance parameters:

- Wavelength drift (nm)
- Power (dBm)
- Error rate
- Chirp (GHz)
- Optical signal-to-noise ratio (OSNR)

“Physical shaping” could then be envisioned for the out-of-physical profile signal through optical-electrical-optical (OEO) regeneration provided by the optical carrier. In the absence of such regeneration, the physically out-of-profile signal will naturally undergo degradation by further propagation in the optical network. However, the relevance of such parameters depends on the way the optical client is connected to the optical network. In the likely case where the signal is systematically regenerated at the interface, they would not apply.

PROVISIONING PROCESS

Provisioning the optical network to meet the objectives defined by service contracts is a major concern for optical carrier operators. This process involves the setup of lightpaths subject to traffic requirements and current network state.

THE TRADITIONAL APPROACH

Up to now lightpath establishment in optical networks has been carried out manually via the management plane. Nonetheless, this approach

suffers from several limitations, since the manual establishment of explicit LSPs with associated QoS parameters would be slow, prone to error, and laborious to network administrators.

In fact, the optical network has traditionally been viewed as functionally divided into two planes (as shown in Fig. 3): a data or bearer/transport plane and a management plane.

The management plane functions in this architecture include five areas:

- Fault management
- Configuration and connection management
- Accounting management
- Performance management
- Security management

Maintaining all the complexity in the management plane resulted in sophisticated management systems difficult to implement. Furthermore, these legacy systems require specially trained personnel to monitor and maintain the network [7]. Circuit provisioning using these management systems is conducted manually, which makes it more error-prone and implies longer setup times for an end-to-end circuit.

THE EMERGING APPROACH

To cope with the limitations of the aforementioned architecture, a new one is being defined where a distributed control plane is appended (Fig. 4) [8]. The main driver for the introduction of this control function is the need for automation in both traffic engineered optical path setup and fault handling.

It is then necessary to have a suite of control plane protocols that are flexible enough to support overlay, peer, and hybrid models, and to provide routing, signaling, and efficient recovery techniques [9].

In this regard, generalized MPLS (GMPLS) [6] is being introduced as the most suitable control plane solution for next-generation optical infrastructure. The work being carried out at the IETF on GMPLS provides a framework in which the well-known and proved MPLS paradigm is being extended to be a control plane, not only for routers and legacy equipment — synchronous optical network (SONET) and add/drop multiplexers (ADMs) — but for optical crossconnects (OXC) as well.

One of the merits of GMPLS stems from its ability to automate circuit provisioning in optical networks. Connection management complexity related to LSP setup/modification/teardown is thus reduced. This simplification is realized through a suite of protocol extensions currently under standardization in the IETF.

Figure 5 presents the functional GMPLS building blocks that would be distributed along the different network nodes. The link state Internet Gateway Protocol (IGP), which can be either OSPF or Intermediate System to Intermediate System (IS-IS) with optical-specific extensions, is responsible for distributing information about optical topology, resource availability, and network status [10]. This information is then stored in a traffic engineering (TE) database. A constraint-based routing function acting as a path selector is used to compute routes for the desired LSPs. This route calculation accounts for the information collected in

the TE database as well as the traffic requirements specified through the SLS parameters. Once the route has been computed, a signaling protocol such as Resource Reservation Protocol with TE (RSVP-TE) is used for path activation (i.e., instantiation of the label forwarding state along the computed path).

GMPLS also contributes to automating the fault management process, through the introduction of a new Link Management Protocol (LMP) [11] and the definition of new protocol messages (notify in RSVP-TE [12]) for fault notification.

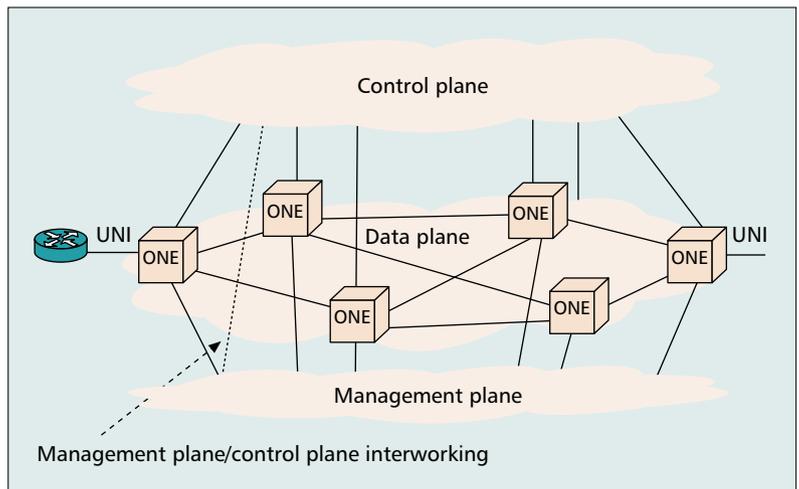
It is clear from this new approach that the management complexity, which was concentrated at the management plane level, is now divided between the management and control planes. For instance, as stated before, the GMPLS control plane is capable of performing fault and connection management in a fast distributed way. This would alleviate the intricacies in overall network management. The service provider will thus be able to quickly and efficiently build high-capacity optical infrastructures supporting fast connection provisioning. Hence, new types of services requiring stringent connection setup times such as bandwidth-on-demand services would have the desired fast deployment time.

GMPLS MANAGEMENT ISSUES

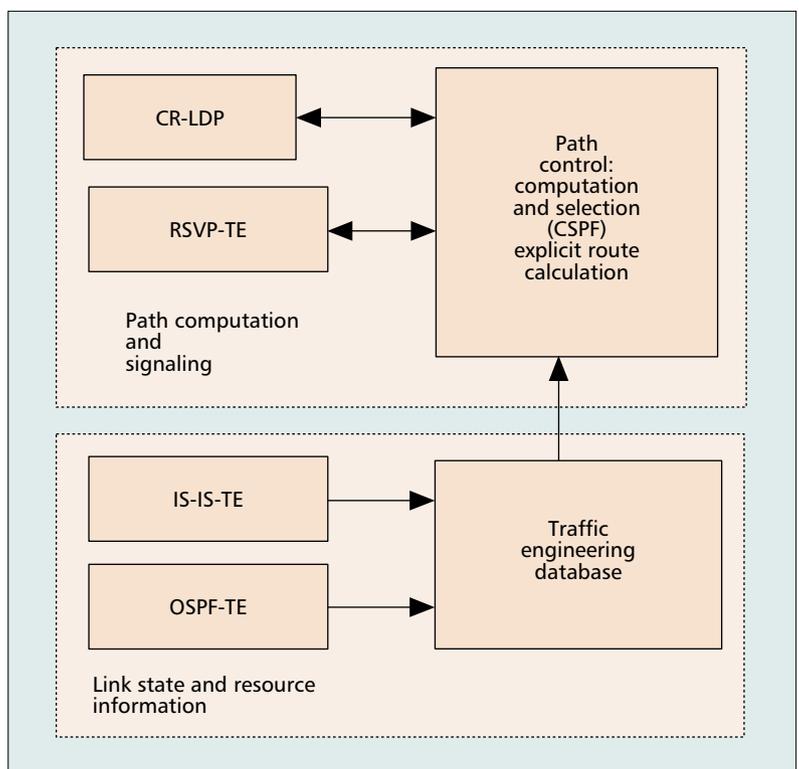
In order to provision and manage optical services in this new architecture, the management plane must operate in conjunction with the GMPLS control plane. This latter may need additional information to meet the operator's expectations. In other words, the SLAs contracted between the operator and its clients provide the rules governing the interaction between the management and control planes. In this interaction scheme, the operator uses management functions to guide the control operations to engineer the network according to business rules.

SNMP MIB Management — Within the IETF, several drafts pertaining to GMPLS management using management information bases (MIBs) were published. Some of these MIBs were intended to provision the control plane, with appropriate configuration parameters needed to set up tunnels [13]. But still, in this approach low-level objects related to implementation details are provisioned to the control plane by the management plane. For instance, the MIBs contain objects like *tunnel link protection* and *session attributes*, intended to be conveyed by the RSVP-TE signaling protocol to instantiate the tunnel. Moreover, bridging the gap between the high-level service objectives stated in the SLA and low-level MIB attributes is an issue that must be considered. For example, the translation of the *service availability and resilience parameters* expressed at the O-SLA level must result in a *protection scheme* to be used at the MIB attribute level.

Based on the previous arguments, we can state that GMPLS network management could be further simplified. This simplification takes place when an intermediate abstraction level of



■ Figure 4. Emerging provisioning approach; ONE: optical network element.



■ Figure 5. GMPLS functional blocks.

managed objects, situated at a higher level than the MIB, is provided to abstract away some of the implementation details in GMPLS. The existence of such an intermediate abstraction level would also help bridge the gap between service level objectives and the corresponding MIB attributes.

Policy-based management holds the promise of providing such simplification in network management through the use of a policy information database (PIB) at a higher abstraction level. In fact, the policy architecture provides a mechanism to link the service level objectives to specific network element configuration in an automated way so that service trends are met.

The O-SLA defined in this article provides us with guidelines on how to manage GMPLS-enabled optical networks. As such, the different policy categories that can be used for this purpose may be inferred from the SLS parameters.

Policy Usage — The O-SLA defined in this article provides us with guidelines on how to manage GMPLS-enabled optical networks. As such, the different policy categories that can be used for this purpose may be inferred from the SLS parameters.

With regard to their impact on the functional plane, the SLS parameters defined in the O-SLA are classified into:

Traffic-flow-related parameters: *flow Id, traffic conformance, and excess treatment.* This is normal since flow id identifies the traffic flow for which the service is to be provided. While traffic conformance indicates the profile based on which the traffic is classified as either in- or out-of-profile, excess treatment precisely describes the treatment for out of profile traffic.

Control-plane-related parameters: *routing constraints, service performance guarantees, and service availability and resilience.* It is normal to find such parameters under this class, since these parameters characterize the lightpath that will be set up using the control plane.

Based on the above classification, the following policy categories are identified as crucial to ensure efficient management of GMPLS-enabled optical networks:

- Routing policies
- LSP life cycle management policies
- Flow management policies

The first category concerns routing policies. These policies offer the possibility to restrict the path taken by the lightpath and ensure the requested performance characteristics.

The performance of a lightpath is tightly related to the characteristics of the links assigned to it. Hence, route calculation is an important step during lightpath creation. In GMPLS networks, the path computation feature is fulfilled by a constraint-based routing (CBR) [14] function that uses the following information as input:

- SLS parameters characterizing the lightpath; for example, performance guarantee parameters (bandwidth, delay)
- Attributes associated with resources; TE link attributes indicating resource availability in the optical network
- Other topology information

Based on this information, a CBR process on each node computes explicit routes for lightpaths originating from that node. In this case, the explicit route is a specification of a path that satisfies the requirements expressed in the SLA, subject to constraints imposed by resource availability and other topology state information.

However, the SLS parameters characterizing a lightpath are twofold:

- Quantitative parameters such as performance guarantee parameters (bandwidth, delay)
- Qualitative parameters: such as route differentiation, and confidentiality attributes

While the CBR function is capable of dealing with quantitative attributes, it is not for qualitative ones. In other words, how can we build a lightpath satisfying the confidentiality attribute? How can we avoid some links being associated with the lightpath in order to satisfy a certain route differentiation requirement? The answers to these two questions can be given in routing

policies. In fact, resources are administratively assigned a certain “color” such that resources with the same color belong to the same class. This color concept is already defined as an attribute of TE links [10], so the idea is to provide each TE link a certain color based on routing policies. As stated before, these policies are built based on the qualitative attributes characterizing the lightpath in the O-SLA. In this case the path would be explicitly restricted to specific subsets of resources identified by a common color. For example, if the route differentiation SLS parameter of the O-SLA states that the lightpath is not supposed to pass through a certain country, *X*, based on routing policies the links falling within this country would be provided a certain color, *Y*, by the management plane. At the same time the path computation process would be instructed to exclude color *Y* during route calculation.

The last two policy categories, LSP life cycle management and flow management policies, have already been treated in the literature [15] in the context of MPLS-TE. However, as GMPLS is a generalized form of MPLS-TE, it is thus normal to extend them into GMPLS-based networks.

LSP life cycle management policies deal with OXC configuration related to initiating, maintaining, and removing lightpaths. The third and last category of policies, flow management policies, deals with classification directives for mapping data flows onto lightpaths. It is important to filter flows that will use network resources based on the flow id directive defined in the O-SLA. Once the traffic flow is identified, policing and shaping are applied based on the *traffic conformance* and *excess treatment* directives.

Future Work — Future work will address the definition of the whole management architecture taking into account the aforementioned policy categories. The main purpose is to translate the SLS parameters into actual directives for the described provisioning mechanisms handled by the GMPLS control plane.

CONCLUSION

The worldwide network domain tendency to evolve toward transparent optical networks is imminent; therefore, it results of great importance and interest to contribute to the development and improvement of these emerging technologies. Part of this crucial work is being done by important groups and organizations through different research projects. This article aims at contributing to this purpose of finding, enhancing, and proposing appropriate solutions to existing problems.

Relevant steps in SLA definition have been taken by different organizations and standardization groups, and their results represent a good basis to define any type of SLA. After having analyzed these projects and studied the major trends, issues, and needs concerning optical networks and the technologies therein, the O-SLA described in this article has been proposed for the purpose of meeting both clients’ and opera-

tors' needs, and to provide a guideline concerning service negotiations and agreements.

In order to activate a service in the network, an O-SLA contracted between a client and an optical operator has to be provisioned. In this regard, this article discusses several possible provisioning approaches in optical networks. Based on this discussion, a policy-based scheme has been retained as a suitable candidate to ensure service activation in a GMPLS-enabled optical network. Hence, different policy categories were introduced from the perspective of management architecture definition.

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The O-SLA described in this article has been proposed for the purpose of meeting both the needs of clients and operators, and to provide guidance concerning service negotiations and agreements.