Cisco Segmented Generalized Multiprotocol Label Switching for the IP Next-Generation Network

A primary component of the Cisco Systems® IP over Dense Wavelength-Division Multiplexing (IPoDWDM) solution for the IP Next-Generation Network (IP NGN) is the simplification of end-to-end control between IP and DWDM networks. To alleviate high operational expenses (OpEx), increase speed for carrier service activations, and eliminate cumbersome and disparate manual provisioning methods at the transport layer, Cisco® has introduced a new cost-effective and efficient solution based on Generalized Multiprotocol Label Switching (GMPLS). This solution enables both optical and IP devices to dynamically find, identify, and provision optimal paths based on user traffic requirements. Called the Segmentation model of GMPLS (S-GMPLS), this new GMPLS model is a hybrid of current approaches that overcomes several daunting obstacles by allowing both IP and optical networks to maintain their existing segmented administration environments. S-GMPLS allows providers to keep the topology of the IP routing domain isolated from the topology of the optical domains, providing a new way to deploy and realize the benefits of GMPLS while respecting the boundaries of these different organizational boundaries or domains.

This paper presents details of S-GMPLS, an innovative technology from Cisco Systems developed for service providers in their optical networks that utilizes the power of IP/GMPLS control protocols for autoconfiguration of optical wavelengths and separates IP routing and optical network domains to respect those diverse organizational boundaries.

SUMMARY

GMPLS is a proposed IETF standard designed to simplify the creation and management of IP/MPLS services over optical networks. The standard would create a single control plane that extends from IP at Layer 3 right down to the optical transport level at Layer 1.

Since service providers first began transporting IP traffic, an extremely complex, multilayered overlay architecture has evolved to do the job of carrying IP traffic over networks that were originally designed to support voice and fixed circuits technology. Yet today, with the rapid growth of IP traffic promoted by the rapid increase in broadband access, new applications, and new services, these complex overlay networks cannot support rapid service provisioning, dynamic bandwidth management, and flexible service creation to meet user demand.

GMPLS was developed as a unified control plane that extends intelligent IP/MPLS connections from Layer 2 and Layer 3 all the way to Layer 1 optical devices. Unlike MPLS, which is supported mainly by routers and switches, GMPLS can also be supported by optical platforms, including SONET/SDH, optical cross-connects (OXC's), and DWDM. GMPLS therefore allows an entire network infrastructure—from access network to core networks—using a common control plane. Establishing a path to enable optical elements within the transport network to become peers of the routers in the IP network and being able to autoprovion wavelengths driven by the IP control plane can translate to significant savings in operational costs because the networks can cooperatively handle fault correlation in real time. Additionally, service provisioning can also be greatly accelerated.

Until recently there were two basic methods proposed for deploying GMPLS—the peer model and the overlay model, which are discussed later in this paper. Both of these have shortcomings that have impeded adoption of GMPLS by service providers.

Now service providers have a better alternative, Cisco S-GMPLS.

S-GMPLS internetworks with the Automatically Switched Optical Network (ASON) architecture (G. 8080) developed by the ITU. ASON, shown in one of many possible implementations of global optical connection control in Figure 1, is a dynamic signaling-based, policy-
driven control solution over optical and SONET networks through a distributed or partially distributed control plane that provides autodiscovery and dynamic connection setup.

Figure 1. ASON Architecture for Global Optical Connection Control

![ASON Architecture for Global Optical Connection Control](Source: ITU pamphlet.)

ASON enables improved support for end-to-end provisioning, rerouting, and restoration; new transport services, including bandwidth on demand; rapid service restoration for disaster recovery; switched connections in a private network; and support for a wide range of narrowband and broadband signaling types. The user network interface (UNI) is responsible for signaling operations between end-user and service provider administrative domains. The external network-to-network interface (E-NNI) provides multicontrol domain operations for a single service provider and multicontrol domain operations between different service providers. The visibility of the inner structure of the administrative domain is controlled by the policy of the service provider. The internal network-to-network interface (I-NNI) provides intracontrol domain operation. Finally, the OXC system is an electrical or photonic matrix for switching wavelengths.

Cisco S-GMPLS is an excellent solution for the I-NNI and E-NNI portions of the ASON architecture.

**CHALLENGE**

**GMPLS Operation and Deployment Challenges**

GMPLS extends MPLS functionality with the enhancement of forwarding, traffic engineering, and quality-of-service (QoS) capabilities of packet-based networks by creating virtual label-switched paths (LSPs) across a network of label switching routers (LSRs) to optical network devices utilizing time-division multiplexing (TDM), fiber switching, and lambda switching. In a GMPLS network it is therefore possible to find and provision end-to-end paths that traverse different networks. For example, a packet/cell-based LSP can be nested in a TDM-based LSP for transport over a SONET network. The TDM-based LSP can similarly be nested in a lambda-based LSP for transport over a wavelength network. Multiple lambda switch-capable LSPs can be nested within a fiber switch-capable set up between two fiber
switching elements. This forwarding hierarchy of nested LSPs allows service providers to transparently send different types of traffic over various types of network segments.

GMPLS introduces Link Management Protocol (LMP) to manage and maintain the health of the control and data planes between two neighboring nodes. LMP is an IP-based protocol that includes extensions to the Resource Reservation Protocol Traffic Engineering (RSVP-TE) and Constraint-Based Label Distribution Protocol (CR-LDP) signaling protocols.

GMPLS provides the ability to automate many of the network functions that are directly related to operational complexities, including:

- End-to-end provisioning of services
- Network resource discovery
- Bandwidth assignment
- Service creation

Traffic engineering parameters relating to SONET protection support, available bandwidth, route diversity, and QoS are distributed throughout the network. This allows every node in the network to have full visibility and configuration status of every other node. This ultimately provides an intelligent optical network.

As service providers introduce new network elements into their networks, add or remove facilities, or turn up new circuits, the control plane will automatically distribute and update the network with the new information. Contrast this with the operationally intensive manual upgrades and updates performed today. Provisioning of connections often requires a substantial amount of coordination among operations staff located throughout the network. Capacity is assessed, optimal connection and restoration paths are determined, and the connection must be fully tested after it is established.

In contrast with operationally intensive manual upgrades and updates, GMPLS uses advanced routing features, including the Open Shortest Path First (OSPF) protocol and Intermediate System–Intermediate System (IS-IS) protocol and signaling protocols such as RSVP and CR-LDP to build intelligence into the network. The network can then effectively self-discover to dynamically advertise the availability or lack of availability of resources. With such capabilities, multihop connections with optical routes and backup paths can be established in a single provisioning step.

**GMPLS Peer Model Deployment**

In the peer model instance of GMPLS, an NNI allows the IP/MPLS layer to operate as a full peer of the optical transmission layer, as noted in Figure 2. Specifically, the IP routers are able to determine the entire path of the connection, including passing through the optical cross connects and SONET/SDH optical devices.

**Figure 2. Peer GMPLS Topology**

- Routers and optical transport network (OTN) nodes in same network act as peers
- Single instance of a control plane for addressing, routing, signaling, etc.
- More efficient interaction between IP and optical nodes for faster provisioning and optimal path selection
- Applicable to single administrative domain

One of the major challenges for the full peer model deployment can be the lack of separation of administrative organizational boundaries between the routed and optical domains. All of the network elements have to be in a single administrative domain. This can be a problem if there are multiple administrative groups (transport and data) for each within a service provider’s domain or where multiple service providers may be involved. Where optical transport and ISP networks are operated by the same entity, no such separation is required, and the peer model may be suitable.

Another potential challenge with the GMPLS peer model is that it results in the exposure of control and topology information on the transport network between the transport and data groups or between the service provider and customers. This can create both security and operational risks. Today two different organizations are responsible for optical and IP networks in many service provider organizational structures, each with longstanding practices, procedures, and infrastructures. The full peer model assumes the abrupt convergence of technologies and administrative control, an often unsettling organizational challenge.

The full peer model also requires that all of the transport nodes be able to run the full GMPLS protocol suite to interoperate. This would be a significant burden on some of the existing transport equipment, which was designed with manual provisioning in mind. Also, any upgrade would require the entire network or significant part to be down and unavailable as every device is upgraded, another challenge that is not easily manageable in service provider environments.

### GMPLS Overlay Deployment Model

In the overlay model of GMPLS, also called a user-to-network interface (UNI), the router is a client to the optical domain and interacts only with the optical node that is directly adjacent to it (Figure 3). The physical light path is decided by the optical network and not by the router.

**Figure 3. Overlay GMPLS Topology**

- Two Administrative Domains
  - Optical Service Provider
  - Internet Service Provider
- No Exchange of Routing and Topology Information between Optical and IP Networks
  - Routers do not see optical transport topology and vice-versa

The goal for the overlay model is to define a signaling message to provision a circuit from a point of presence (POP) in one IP network to an optical network endpoint or through an optical network to another POP in an IP network. On the UNI no routing protocol is running; it is just a signaling interface.

**SOLUTION**

To overcome the limitations of GMPLS overlay and peer models, Cisco has developed S-GMPLS, which combines the best of both topologies. In the S-GMPLS model, only border routers receive information from the optical devices and from other routers (Figure 4). The
border routers in the four corners between the optical network (dotted lines) and the IP network (solid lines) maintain both routing and optical topology information. Routers in the IP cloud only maintain topology information for their region, and optical devices only maintain optical topologies within the optical network segment.

Figure 4. S-GMPLS Topology

- Border routers receive routing information from the optical devices as well as router
- Border router keeps the optical and router domain topology information in separate routing tables
- No routing information from the router region is carried into the optical region

The border routers use secure domain logical router instances to shield and segment the topology information between the IP domain and the optical domain. They act as gatekeepers between the two and enable a segmented administrative boundary that helps ensure management separation between the two networks, while still unifying the control plane aspects of the two networks. S-GMPLS is now available in Cisco IOS® XR Software on Cisco platforms, including the Cisco Carrier Routing System 1 (CRS-1), and the Cisco XR 12000 Series Routers, allowing optical and IP network administrators to each manage their own end devices as the networks gain a single intelligent IP and optical control plane. The border router has separate instances for IP and optical topologies but does not leak information to either side. Instead, the border router handles routing and signaling for a region, moving traffic back and forth across the border of the networks in a manner similar to how service providers peer in IP networks today. The border router keeps the optical and routing domain topology information in a separate topology database through the use of secure domain routing instances on the border routers. Administrative control of the secure domain routing instances can be provided through both in-band and out-of-band management.

S-GMPLS uses the strengths of the peer model while respecting the separateness of IP and optical administrative domains. Service providers have the choice of supporting either integrated or separated operations groups depending on organizational needs. S-GMPLS brings the benefits of MPLS for efficient use of resources and consistent path selection in a heterogeneous network of routers and optical devices. It also simplifies fault handing. To make the transition to GMPLS smoother and easier for service providers, S-GMPLS allows for incremental deployment of optical regions with little or no reconfiguration of the router region required, making GMPLS more deployable within service providers, and allows control of capital expenditures.

A comparison of the three GMPLS models in Figure 5 shows how Cisco S-GMPLS borrows the best features of the other models while engineering around one of the primary problems that has slowed GMPLS adoption.
An important element of the Cisco IPoDWDM solution is reconfigurable optical add/drop multiplexers (ROADMs), which integrate photonic switching into optical multiplexers. ROADM can provide automated patching capabilities alongside S-GMPLS, which will provide automated provisioning capabilities from an end-to-end perspective across both IP routing and optical platforms.

### Standards Framework Applicability

Table 1 shows the protocol perspectives of the ASON framework. Today there are two applicable standards for UNI: Optical Internetworking Forum UNI (OIF-UNI) and GMPLS-UNI. In the context of S-GMPLS, when considering client layers with intra–service provider and inter–service provider networks, GMPLS-UNI is a preferred choice for UNI because the protocols are drawn from one standards organization, the IETF. Use of OIF-UNI introduces compatibility issues to interoperate with S-GMPLS because the original RSVP-TE signaling protocol in Overlay UNI (O-UNI) is modified and departs from the IETF RSVP-TE RFC.

### Table 1. Comparison of GMPLS Models

<table>
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<th>ASON Framework</th>
<th>Signaling</th>
<th>Routing</th>
<th>Service</th>
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<tr>
<td>OIF-UNI</td>
<td>O-UNI</td>
<td>No</td>
<td>Inter service provider (wholesale), service provider to customer</td>
</tr>
<tr>
<td>Peer</td>
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<tr>
<td>S-GMPLS</td>
<td>RSVP-TE</td>
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<td>Intra service provider, inter service provider</td>
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<tr>
<td>IETF Overlay (GMPLS-UNI)</td>
<td>RSVP-TE</td>
<td>No</td>
<td>Service provider to customer</td>
</tr>
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### CONCLUSION

The deployment of Cisco S-GMPLS will alleviate many of the challenges currently faced with integrated IP and optical network services by making GMPLS more deployable. It brings the opportunity for new service provider revenue with new service offerings such as Gigabit Ethernet, networked storage, video streaming, and VPNs across both network types that can be rapidly provisioned in a more flexible manner while reducing the operational complexity for the service provider. Instead of investing in multiple new networks with differing control architectures that are complex to interoperate and manage and have questionable long-term operational benefits, service providers can now deploy a new generation architecture—S-GMPLS—that is simple, efficient, and automated.
Cisco and NTT Com recently announced that they have successfully demonstrated on-demand network settings and automatic fault recovery between Tokyo and Osaka by utilizing S-GMPLS technology, available on Cisco XR 12000 Series Routers. In the experiment, NTT deployed the S-GMPLS control plane on Cisco XR 12000 Series Routers over a wide-area SDH optical network to demonstrate autonomous network settings. The testing succeeded in running conventional fixed redundant switchover functions and autonomous rererouting functions using S-GMPLS.

FOR MORE INFORMATION

Cisco IP over DWDM Solution for IP NGN:

Cisco CRS-1 1-Port OC-768C/STM-256C Tunable WDMPOS:

Cisco CRS-1 4-Port 10GE Tunable WDMPHY Interface Module: