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GMPLS Signaling Applicability Statement

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1. Status of this Memo

2. Abstract

This memo describes the applicability of GMPLS signaling to IP over Optical (IPO) networks. The underlying premise behind GMPLS signaling for IPO networks is discussed and pertinent limitations are highlighted. Throughout this discussion, GMPLS-RSVP (RSVP-TE with GMPLS extensions) will be used to exemplify the class of protocols under consideration. This memo also describes the subsets of GMPLS signaling message exchanges that are needed to support connection management between optical switches, and between IP/MPLS routers and optical switches in IP over Optical networks.

3. Summary for Sub-IP Area

3.1 Summary

This document describes the applicability of GMPLS signaling to IP over Optical Networks.

3.2 Where does it fit in the Picture of the Sub-IP Work

This work fits in the IPO Working Group.

3.3 Why is it Targeted at this WG

This is one of chartered deliverables of the IPO working group.

3.4 Justification

The WG should consider this document because it describes how the existing GMPLS signaling protocols can be used in IP over Optical networks. This information is especially useful to the IETF community because it delineates the subset of GMPLS signaling functionality that are useful in IPO networks.

4. Introduction

This memo describes the applicability of GMPLS signaling protocols to connection management in IP over Optical (IPO) networks. The basic function of the GMPLS signaling protocols is to setup, maintain, and teardown connection services in different types of transport networks. This memo relates only to the applicability of the GMPLS signaling capabilities in IPO networks. The applicability of GMPLS routing protocols to IPO networks are covered in a separate document.

The term IP over Optical networks generally refers to optical transport networks that posses one or more of the following two main characteristics: (1) They are used to preponderantly transport IP traffic and (2) they employ IP (e.g. GMPLS) protocols in their control plane. An optical network utilizing GMPLS in its control plane may also transport other types of digital clients other than IP traffic.

This memo is concerned specifically with optical networks that utilize GMPLS signaling protocols in their control plane, irrespective of the type of digital clients and payloads carried in their transport plane. The definition of IPO networks, for the purpose of this applicability statement, encompasses the OCh layer of the ITU-T Optical Transport Networks (OTN) described in [8], especially when such networks utilize GMPLS protocols in their control planes.

The factors that motivate the application of IP-based control plane protocols (such as GMPLS) to optical networks were articulated in reference [5].

5. Overview of GMPLS Signaling

GMPLS signaling protocols are general purpose control plane protocols supporting signaling transactions in different types of switched transport networks with different switching technologies. The GMPLS signaling protocols are derived from the corresponding IETF MPLS signaling protocols, (e.g., RSVP-TE [4]) through a process of extension and generalization. The GMPLS signaling protocols employ the same protocol machinery as the underlying protocols from which they were derived, but include additional protocol features to support signaling capabilities in a multitude of switched transport networks.

The main aspects of GMPLS signaling are documented in a number of IETF memos [1,2,3,6,7]. There are two broad classes of GMPLS signaling protocols that are being standardized by the IETF: (1) those based on RSVP-TE and (2) those based on CR-LDP. Both classes of protocols perform similar functions and either of the two can be used to fulfill the necessary signaling transactions in a particular context. However, recent surveys conducted within the IETF suggest that GMPLS signaling protocols derived from RSVP-TE are the most predominantly implemented in the industry (see e.g. reference [10]).

It is significant to point out that the GMPLS architecture does not mandate either of the two classes of GMPLS signaling for a particular application. Therefore this applicability statement does not prevent an implementation from utilizing either of the two categories of protocols.

6. Applicability of GMPLS Signaling to IPO Networks

GMPLS is an appropriate signaling mechanism for establishing end-to end connections in optical networks utilizing embedded software control planes. GMPLS signaling provides the ability to perform signaling transactions for connection setup and connection release operations in optical networks. GMPLS does not impose restrictions on the implementation of the data communication network (DCN) that is used for conveying signaling messages. This means that GMPLS can be employed in optical networks where the control channel is implemented (1) in-band, (2) out-of-band in-fiber, (3) or out of band and out-of-fiber.

GMPLS signaling messages provide the flexibility to control the path traversed by a particular connection within an optical network and to manage the allocation of resources used by the connection along the path. Some of the major benefits derived from GMPLS signaling in optical networks include the following, which are consistent with the requirements stipulated in [12]:

- Rapid Circuit provisioning
- Flexibility
- Enhanced survivability
- Interoperability

6.1 Provisioning Capabilities

One of the key benefits of GMPLS signaling in IPO networks is the automation and expediting of the provisioning of optical connections within the optical domain. With GMPLS signaling, it is possible to specify the route traversed by an optical connection (for example, using the Explicit Route Object in GMPLS-RSVP). It is also possible to specify the bandwidth for the optical connection.

In an optical network, the labels exchanged by the GMPLS signaling protocol equate directly to an abstract representation of the optical resources to be used by the connection. Depending on the characteristics of the optical domain, the labels may represent individual wavelengths, wavebands or whole fibers. While whole fibers may be identified using numbered or unnumbered interfaces, the identification of ports, wavelengths and wavebands is a local matter for resolution between adjacent nodes in the network. In the case of wavelength routed optical networks, where the wavelength is the basic unit of resource allocation, it might be convenient to use a standardized convention for spectrum allocation such as the ITU grid.

The conventional MPLS signaling protocols (e.g., the basic RSVP-TE protocol) are based on downstream-on-demand resource allocation and label binding. This means that in conventional MPLS signaling, label allocation proceeds from downstream nodes to upstream nodes. GMPLS signaling improves this scheme by supporting the concept of "suggested label" where an upstream node can suggest a label to a downstream. This concept is particularly useful in optical networks for the following reasons: (1) it can help to decrease provisioning latency by enabling anticipatory policies that allow optical network elements to reconfigure their switching elements during the forward pass of the signaling messages; and (2) in wavelength routed optical networks, it can permit wavelength assignment by upstream nodes.

GMPLS signaling also suppports the concept of "label set" which is another improvement over conventional MPLS signaling. The significance of this concept in wavelength routed optical networks is that it allows upstream nodes to restrict the set of labels, hence wavelengths, that can be allocated by downstream nodes.

In contexts in which network edge elements are capable of processing signals from many different devices, it may be necessary for them to indicate the bandwidth and encoding of the traffic associated with a particular connection, and perhaps the required switching behavior of the optical devices. GMPLS signaling includes extensions offering this capability.

The principles of traffic engineering (that is performance optimization of networks) are very important in optical networks. In optical networks, traffic engineering is applied almost exclusively through routing control. GMPLS signaling allows to explicitly specify the path traversed by an optical connection. The path itself may be computed online or offline using an appropriate path computation mechanism which is not part of GMPLS signaling. This facility allows to constrain routes to fully or partially constrain the routes traversed by an optical connection. This facility can also be used to resolve resource contention and blocking problems, thereby optimizing optical resource

Constraints associated with optical resources may be taken into consideration by a path computation engine when selecting the explicit route to be traversed by an optical connection. In this case, the path computation engine will calculate a path subject to pertinent constraints -- together with attendant resources to allocate on each hop, and specify these attributes in the explicit route object that is embedded in the signaling messages. This capability may be enhanced on a hop-by-hop basis by having each network element provide resource availability information and suggestions for label allocation to its neighbor.

Additionally, it may be important to constrain the choice of optical resources (wavelengths, wavebands, or fibers) along a path. This capability offers a number of advantages. For example, it can be used to allow more effective assignment of switching resources in optical networks consisting of a combination of electrical switching elements (requiring OEO conversion) and photonic switching elements (PXCs without OEO conversion). It can also substantially reduce wavelength contention and resolve wavelength conflicts in transparent sub-networks containing PXCs, where wavelength conversion cannot be performed at some or all nodes. Additionally, this capability can be used to reduce connection setup latency and signaling instability in networks containing some classes of PXCs, in which the underlying switching technology has a non-negligible finite reconfiguration delay and may require a finite stabilization time. The "suggested label" and "label set" features are some of the capabilities of GMPLS signaling that allow to constrain the choice of optical resources.

6.2 Advanced Provisioning

6.2.1 Bidirectional Light Paths

Optical connections are often required to be bidirectional. This can be achieved by sequentially signaling two independent unidirectional optical connections, in opposite directions, one from each terminating endpoint. However, this approach is not very efficient in terms of signaling overhead and connection setup latency. This approach also makes it difficult to achieve route symmetry, so that both optical channel trails in opposite directions take the same physical path through the network.

GMPLS addresses the aforementioned issue by supporting the establishment of bidirectional optical connections using just one round-trip signaling message transaction. The approach adopted by GMPLS signaling has the added advantage that both directions of the optical connection can follow the same path, achieving the desired goal of route symmetry in optical networks. When establishing bi-directional optical connections, resources can be independently allocated to the two directions, and conceptually other types of constraints can be independently imposed as well. However, in an operational context, it is likely the two directions of a bi-directional optical connection will be assigned similar resources and satisfy similar constraints.

The capability to establish bi-directional optical connections does not, however, preclude establishing uni-directional optical connections in contexts where uni-directionality is required in IPO networks. Clearly, this degree flexibility is very advantageous as the requirements imposed on optical networks will evolve and change over time.

6.2.2 Signaling Setup Time

Many optical devices have high stabilization times. GMPLS allows a node to pipeline signaling and device programming such that it can suggest to its adjacent nodes which optical resources should be used and proceed to program and reconfigure those resources before the signaling exchange with its neighbor has completed. In the worst case the node must provision new resources when the signaling completes, especially if the suggested resources to be allocated are declined by the downstream node.

6.2.3 Alarm-Free Setup and Teardown (Alarm Suppression)

Many optical networks report alarms if a service is provisioned but no signal is present (such as loss of signal and loss of light alarms). For example, if an optical connection is provisioned, but a laser somewhere along the path is not turned on in a timely fashion, an alarm may be raised. This situation can also occur during connection reconfiguration, when the path traversed by an existing connection is altered.

For a variety of reasons, it is often desirable to suppress alarms during optical connection setup, reconfiguration, and teardown. During these times it is reasonable to expect that lasers may be turned on or off sequentially, and it is not necessary to raise certain types of alarms, especially alarms suggesting failure within the network.

GMPLS offers a mechanism to indicate that a connection setup is in progress. When such an indication is present, an optical device may suppress certain types of alarms during the signaling transactions. Once the optical connection has been established, GMPLS can be used to signal that alarms should be enabled.

Similarly, GMPLS can be used to indicate that connection teardown is in process so that optical devises can suppress pertinent alarms during the teardown process.

6.3 Survivability Features

Survivability is a critical consideration in IPO networks. Within the optical domain, there is generally a requirement for flexibility in the manner in which resilience properties of optical connections are specified and implemented. There is also a general requirement to minimize service interruption following network outages for services that are intended to be survivable. The spectrum of protection/restoration capabilities that can be associated with a particular connection can be quite large including different protection levels (unprotected, 1+1, 1:1, 1:n, m:n), and different types of restoration (local restoration, end-to-end restoration, etc). In 1:1, 1:n, and m:n protection scenarios, it may also be desirable to route "extra traffic" (preemptable low priority traffic) over the protect resources to increase the efficiency of asset utilization.

GMPLS signaling provides a range of capabilities to support different types of protection/restoration mechanisms and consequently to enable a variety of survivability options in optical networks.

6.3.1 Connection Specific Survivability

A key requirement for the development of signaling protocols for the optical domain in IPO networks is the need for features to support intelligent fault management, as noted earlier.

There are four major steps involved in fault management: (1) fault detection, (2) fault localization, (3) fault notification, and (4) fault recovery.

Fault detection and fault localization in optical networks are not covered by GMPLS signaling. These aspects are the responsibility of the hardware, the transport plane, and link management protocols (such as LMP [11]).

One of the major attributes of optical networks is that nodes downstream of faults are the ones most likely to detect the fault (such as loss of signal and loss of light problems). Therefore, there is a requirements to notify nodes upstream of the fault so they can initiate recovery actions. In the case of 1:1 and general m:n protection schemes, it is also important to coordinate the actions of the originating node and destination node for a connection so that they can both switch to the pre-establish protect path.

GMPLS signaling protocols include fault notification mechanisms for reporting errors across the network, from the nodes that detect the faults to the endpoints (originating and destination nodes) of the connection. Furthermore, these fault notification mechanisms are defined to traverse the route of the connection, so that each node along the path will be informed of the anomaly and can take appropriate remedial action to rectify the problem or initiate recovery actions to restore affected traffic. The fault notification messages can also be targeted to specific nodes using an appropriate encapsulation.

However, where the location of the repair points are predetermined and known, this method of propagating fault notifications can be slow. It is to be noted that GMPLS-RSVP specifically includes a method that allows repair points to advertise their existence during connection setup, or later when the connection is modified. This capability allows fault notifications to be sent directly to these repair points, expediting the process of notification and consequently reducing the time to recover from failures.

Fault repair (hence service restoration) may be accomplished by signaling new optical connections after a fault notification message is received (in the case of restoration), or by switching traffic to pre-established protection paths (in the case of protection). Some solutions may require coordination with other nodes in the network during (or before and/or after) the recovery of affected traffic to alternate paths (e.g., some hardware solutions for 1+1 and 1:1 protection, bidirectional optical connections, removal of extra traffic, etc). GMPLS-RSVP (but not GMPLS-CR-LDP) allows such nodes to advertise their existence during optical connection setup or later during modification operations associated with connection reconfiguration, so that they can also be recipients of fault notification messages which are sent to them directly.

6.3.2 Decoupling of Control and Transport Planes

In IPO networks, it is an important operational requirement on the part of carriers to decouple the Control plane from the Transport plane within the optical domain, so that faults occurring within the control plane will not affect existing services within the optical transport plane.

In many optical networks there is no facility for in-band control signaling since that would require both GMPLS signal and bearer traffic termination at each node. Some implementations of optical networks may offer in-fiber but out-of-band solutions where a particular wavelength is dedicated to function as a control channel. Other alternatives include an out-of-fiber control channel that exists in parallel with the fiber carrying bearer traffic, and a control channel that is routed separately and independently through an external IP network.

There are two important implications of the scenarios mentioned above. One is the concept that failures in the control does not necessarily imply of the transport plane. Hence, unlike conventional IP/MPLS networks, failure of the transport plane cannot be inferred from failure of the control plane. The second important implication is that switching and reconfiguration activities in the transport plane should not be initiated by control plane failures.

GMPLS addresses this important operational issue by decoupling the path of the GMPLS signaling message (i.e., the signaling data communications network) from that of the bearer traffic transported by the transport plane (unlike in conventional IP/MPLS networks where the two are closely coupled). This decoupling of the control and bearer channels implies that any of the in-band or out-of-band control channel solutions may be used for GMPLS based optical connection management. In particular, the use of IP encapsulation by GMPLS signaling allows control packets to be routed through distinct networks that may include other GMPLS-capable nodes that must not examine these control packets in order to propagate them appropriately.

This decoupling allows the transport plane to be immune to control plane failures, whether these are hardware or software related, so that existing optical connections are not interrupted by failures occurring within the control plane.

With the decoupling of the control plane and transport plane, failure detection associated with transport bearer services is no longer the responsibility of the control plane. Rather, fault detection and fault localization are the responsibility of the hardware and the link management protocols (such as LMP [11]) in the network. When such faults are detected using appropriate mechanisms within the transport plane or using LMP, they can be propagated to the control plane so that the control plane can initiate failure notification actions to pertinent nodes within the network.

Because failures can occur within the control independent of the transport plane, it is now the responsibility of the control plane to recover its state (to match that of the transport plane) when control plane connectivity is recovered after a failure. GMPLS-RSVP includes a graceful restart procedure that allows network nodes to re-learn their state from neighbors on recovery. A similar process is being developed for CR-LDP and is likely to become available for GMPLS-CR-LDP.

6.3.3 Reliable Message Delivery

Reliable message delivery is an important part of dependable and expeditious connection setup, reconfiguration, and teardown. GMPLS includes facilities to ensure prompt and reliable delivery of signaling messages.

GMPLS-CR-LDP achieves this by using a reliable transport (TCP).

GMPLS-RSVP achieves the same function by applying Message Ids to all control messages and retrying the messages until they are acknowledged.

6.4 Architectural Considerations

The IPO framework document [9] specifies different architectural alternatives for deployment of IP over Optical networks. The architectural alternatives specifically concern the interconnection models between control entities on IP/MPLS routers and control entities on optical transport network elements, especially when the IP and optical domains both utilize GMPLS control plane protocols.

GMPLS-RSVP can be used as a signaling protocol between a client (e.g. IP/MPLS router) and an optical transport network in an overlay interconnection model.

GMPLS-RSVP can also be used as a signaling protocol between optical network elements across an interior NNI (I-NNI), and as a signaling protocol between subnetworks across an E-NNI (Exterior NNI) interface.

6.5 Deployment Considerations

Several distinct deployment scenarios for GMPLS signaling in IPO networks can be identified. These include:

- Deployment within an optical subnetwork with no signaling interactions with entities outside of the network.

- Deployment within a subnetwork with signaling interactions with entities across the subnetwork where all subnetworks belong to the same administrative entity.

- Deployment across networks where the networks belong to different administrative entities. In this case, special care should be given to security considerations.

In the case of deployments supporting signaling transactions across networks or subnetworks, the network elements performing the signaling transactions may utilize similar switching technologies or different switching technologies.

6.5.1 Restrictions

There are certain restrictions that may limit deployment of the existing class of GMPLS signaling protocols in some IPO operational contexts. In the following paragraph, we highlight some of the operational scenarios in which certain restrictions may apply.

- Signaling protocol transactions across trust domains: When GMPLS signaling is required to traverse administrative domain boundaries it may be necessary to take security issues into considerations. These security implications across trust domains are not adequately covered by the existing protocol machinery.

7. Security Considerations

The security considerations relating to the GMPLS signaling protocols are documented in the pertinent IETF protocol specific documents. This applicability statement does not introduce new security issues. It should be pointed out, however, that special precaution must be taken to ensure that unauthorized entities cannot successfully initiate or execute GMPLS signaling protocol transactions in IPO networks.

8. References

8.1 Normative References

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[5] D. Awduche and Y. Rekhter, "Multiprotocol Lambda Switching," IEEE Communications Magazine, June 2001.

8.2 Informative References

[6] E. Mannie, et al, "Generalized Multi-Protocol Label Switching (GMPLS) Architecture," Internet Draft, Work in Progress, 2002.

[7] D. Papadimitriou, "Generalized MPLS Signalling Extensions for G.709 Optical Transport Networks Control," Internet Draft, Work in Progress, 2002.

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