PAPER

Latest Trends in Generalized Multi-Protocol Label Switching Standardization

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SUMMARY
[NOTE: This section changed for Reviewer 1's comment (4) and 3's comment (1)]
This paper presents the latest trends in Generalized Multi-Protocol Label Switching (GMPLS) standardization within the Internet Engineering Task Force (IETF). GMPLS is a suite of control and management plane protocols, extended from MPLS, to cover any connection-oriented technology, such as packet (or MPLS), Time Division Multiplexing (TDM) and optical. GMPLS allows automated network operations, distributed at the network equipment level, with multi-vendor and multi-layer interoperability. As such, it is expected that GMPLS enables control and management of the transport network by standardized mechanisms, not by proprietary management systems and interfaces. In addition, GMPLS offers opportunities to integrate control and management of multiple network layers. The basic suite of GMPLS protocols, namely signaling, routing and link management, has been already standardized, and has been shown to be stable and functional through several years of testing and early deployments. Now carriers are looking at how they can leverage the protocols to realize revenue and activate advanced services. Accordingly, discussion in the IETF has shifted to how to apply GMPLS protocols to support various scenarios and use cases. After briefly reviewing GMPLS basics, this paper presents the latest trends in GMPLS standardization, with a focus on deployment strategies, service aspects, and operation and management.
key words: *GMPLS, optical network, standard, IETF*

1. Introduction

[NOTE: This section changed for Reviewer 1's comment (1)(2)(18)]
With the growth of broadband access lines, such as Asymmetric Digital Subscriber Line (ADSL) and Fiber To The Home (FTTH), and with the introduction of broadband content delivery services, such as IP-TV and video communications, it is expected that the amount of traffic will continue to grow rapidly over the next few years. At the same time, carriers are continuously facing demand for cost reduction. Therefore, carrier networks need to be enhanced to be able to support high volumes of traffic for various services with low cost.

Currently, various activities are under way to develop new technologies to comply with such challenges. The optical network is certainly one major topic, including how to provide control and management plane technologies. Here, GMPLS is expected to be a key enabler. GMPLS is a suite of IP-based protocols that can be applied to control and manage optical networks [1]. GMPLS offers opportunities to realize new features, such as multi-vendor interoperability, multi-layer interoperability (interworking of different network layers), fast service delivery and resiliency, which have never been satisfactorily achieved in optical networks.

Standardization plays an important role here, since many of advantages brought by GMPLS are due to the nature of standardization. There are several standardization organizations and forums in the area of GMPLS, and the IETF is in charge of specifying the protocols. The basic suite of GMPLS protocols, namely signaling, routing and link management, has been already standardized [2], [3], [5], and has been shown to be stable and functional through several years of testing and early deployments [6]. Now carriers are looking at how they can leverage the protocols to realize revenue and activate advanced services. Accordingly, it appears that the discussion in the IETF has shifted to how to apply GMPLS protocols to support various scenarios and use cases in order to provide solutions, rather than to provide protocol pieces. Note that GMPLS covers wide range of technologies including ones intended for packet networks, but this paper focuses on GMPLS as a tool to control and manage optical networks, and presents the latest trends in GMPLS standardization in this area.

The rest of paper is organized as follows. Section 2 briefly introduces GMPLS basics and emerging work areas in GMPLS standardization. Recent activities in emerging work areas are expanded in Sects. 3, 4 and 5, in terms of deployment strategies, service aspects, and operation and management, respectively. The conclusion is given in Sect. 6.

2. GMPLS Basics and Emerging Work Areas

2.1 GMPLS Concepts and Drivers

[NOTE: This section changed for Editors' comment and Reviewer 1's comment (4) and 2's comment (1)]
Figure 1 shows the GMPLS concept. The origin of GMPLS is MPLS, which offers a mechanism for the use of connections in packet, cell or frame-based networks.

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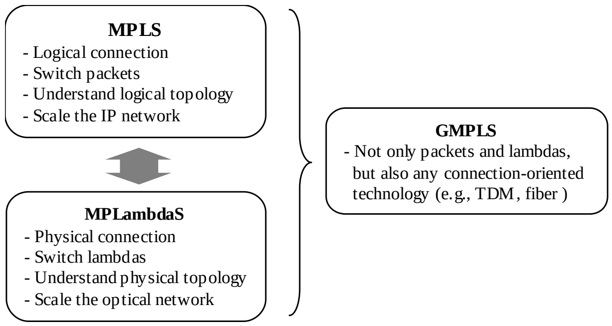


Fig. 1 GMPLS concept.

MPLS defines the data plane packet format as well as IP-based control plane protocols. MPLS standardization started late 1990s in the IETF, and today, MPLS is widely deployed in various networks to provide Traffic Engineering (TE), Virtual Private Network (VPN) services and pseudo-wire services.

Around year 2000, an attempt to extend MPLS control plane protocols to control optical networks began, as it was believed that traffic growth would necessitate combination of packet and optical technologies. Since the primary focus was on controlling the lambda (or wavelength), such attempt is called Multi-Protocol Lambda Switching (MPλS) [7].

Later on, this attempt has expanded to include not only lambdas, but also any connection-oriented technology, such as packets (or MPLS), TDM and fibers. Because of this generalization, such technology is called Generalized MPLS (GMPLS).

As shown in Fig. 2, GMPLS enables enhancement of carrier networks, which are often composed on packet-based service networks supported by the common transport network. GMPLS adds the concept of a control plane to the transport network, in addition to the data plane and the management plane. This network transition helps reducing the reliance on proprietary management systems and interfaces, and enables additional capabilities such as fast service delivery and intelligent failure recovery at the network equipment level. This also helps constructing common (IP-based) network operation across network layers, and easier integration of control and management across network layers. GMPLS is also future-proven in a sense that it is applicable to emerging data plane technologies, such as Optical Cross Connects (OXCs) and Reconfigurable Optical Add/Drop Multiplexers (ROADMs).

2.2 GMPLS Standards

[NOTE: This section changed for Editors' comment and Reviewer 1's comment (19) and 2's comment (1)]

There are three main standardization organizations and forums in the area of GMPLS, that is, IETF, International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) and Optical Internetworking Forum (OIF). Figure 3 shows how they are related. Roughly speaking,

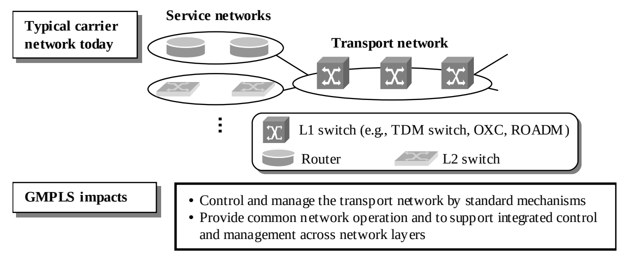


Fig. 2 Impact of GMPLS on carrier networks.

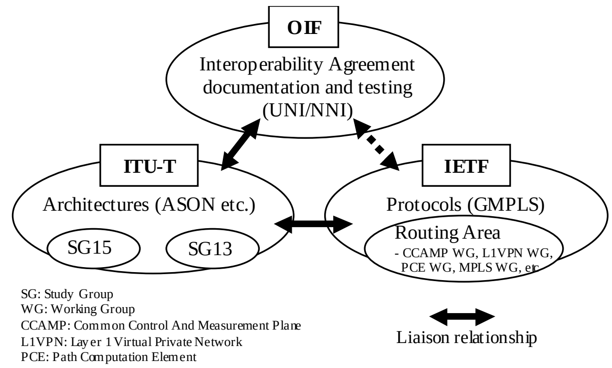


Fig. 3 Relationship of IETF, ITU-T and OIF.

- The IETF is focusing on protocols that were originated in the IETF.
- The ITU-T is focusing on the architecture, called Automatically Switched Optical Network (ASON) [10].
- The OIF is focusing on documenting Interoperability Agreements (IAs) and testing.

Initially, their standpoints were slightly different, and they communicated less. However, as technologies evolve, their relationship is becoming closer. An example is that the IETF is now standardizing protocols that meet the requirements of ITU-T ASON architecture.

There are three basic GMPLS protocols being defined in the IETF as follows.

- Signaling:
  Signaling is a function to setup, delete or modify a connection. A connection is called Label Switched Path (LSP) in GMPLS context. The GMPLS signaling protocol is Resource ReserVation Protocol-TE (RSVP-TE) [2].
- Routing:
  Routing is a function to distribute and collect network-wide link state information with TE parameters, such as bandwidth, cost, switching capability and link encoding. Such protocols in GMPLS are Open Shortest Path First-TE (OSPF-TE) [3] and Intermediate System to Intermediate System-TE (ISIS-TE) [4].

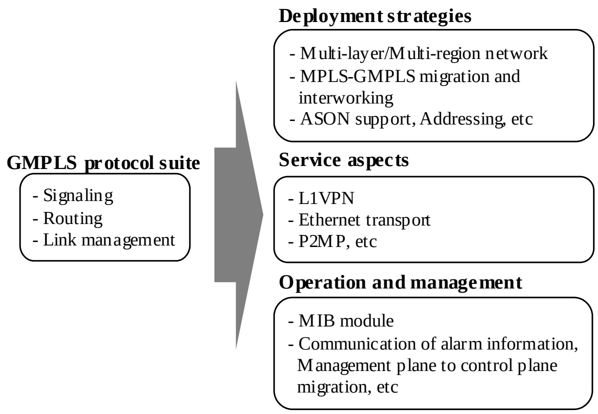


Fig. 4 GMPLS standardization emerging work areas.

- Link management:
  Link management is a function to maintain and synchronize link status and parameters between neighboring nodes. Such protocol in GMPLS is called Link Management Protocol (LMP) [5].

In addition, protocol extensions to recover LSPs from failures are almost standardized [8], [9]. More details on each protocol can be found in existing documents such as [11], [12].

2.3 Emerging Work Areas

[NOTE: This section changed for Editors' comment and Reviewer 2's comment (1)]

Standardization activities within the IETF are now shifting to how to apply GMPLS protocols to support various scenarios and use cases. In this context, GMPLS protocols are analyzed to be extended, including to work with other mechanisms where necessary.

As shown in Fig. 4, there are three major emerging work areas as follows.

- Deployment strategies:
  As described previously, one objective of GMPLS is to support integrated control and management across network layers. Such work item is called multi-layer/multi-region network.
  Furthermore, migration strategies need to be considered when deploying GMPLS into existing MPLS networks. In the course of migration, MPLS and GMPLS may co-exist, thus interworking between MPLS and GMPLS is necessary. Such work item is called MPLS-GMPLS migration and interworking.
  There are several other work items. As described in Sect. 2.2, the work is going on around how to apply GMPLS protocols to satisfy ASON requirements. In addition, further interoperability would be required for deployment, and the work is going on to complement GMPLS addressing rules.
- Service aspects:
  GMPLS offers capabilities not only to enhance operations but also to provide new services. One of such new services being discussed is Layer 1 VPNs (L1VPNs). L1VPNs offer L1 connections (i.e., TDM or optical connections) to customers flexibly, yet separating the control of the transport network.
  Furthermore, with the progress of data plane technologies, GMPLS is being extended to be able to offer Ethernet transport with capabilities such as dynamic bandwidth modification.
  There are several other work items, such as establishing Point-to-MultiPoint (P2MP) LSPs.
- Operation and management:
  Operation and management is an important work area for deployment, since GMPLS changes network operation, for example from semi-automatic (management) provisioning to distributed automatic provisioning, and from network planning based on point-to-point topology to network planning based on mesh topology. Gradually more work is going on in this area.
  Management Information Base (MIB) modules are being standardized, which would be necessary to develop management systems to control and manage GMPLS-based networks.
  There are several other works items. One is communication of alarm information for diagnosing the status of LSPs. Another is how to migrate from a management plane oriented network to a control plane oriented network, and on the way, how to transfer connection ownership from the management plane to the control plane.

In the following sections, more details on each emerging work area are presented.

3. Deployment Strategies

3.1 Multi-Layer/Multi-Region Network

[NOTE: This section changed for Reviewer 1's comment (6)(7)(8)]

Figure 5 shows an example of multi-layer/multi-region network. Two optical connections are established between nodes A and F, and nodes F and C respectively. These optical connections provide logical links in the packet layer. A network topology composed of such logical links is called Virtual Network Topology (VNT) [13]. Logical links in the VNT provide IP/MPLS links in the packet layer so that packets are forward over them. A connection in the packet layer (i.e., MPLS LSP) may be established between nodes A and C, by utilizing logical links.

Multi-layer/multi-region networks exist in carrier networks today, and the focus in the context of GMPLS is how to apply GMPLS to control the VNT in accor-

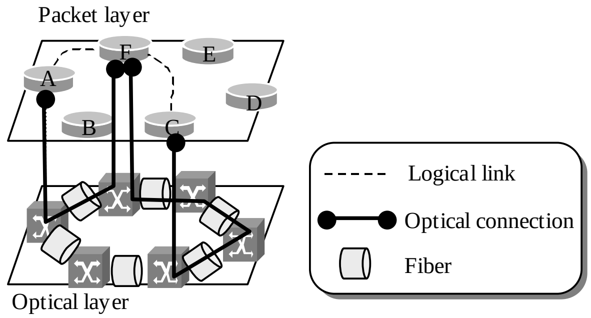


Fig. 5 Multi-layer/multi-region network.

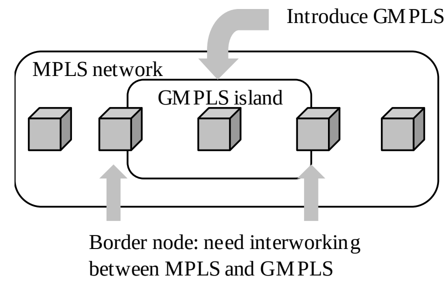


Fig. 6 Island model for MPLS to GMLS migration.

dance with traffic change or failures. GMPLS protocols allow simplified operation across network layers, thus it would be possible to control the VNT more flexibly. Currently, requirements of multi-layer/multi-region networks, and protocol evaluation for multi-layer/multi-region networks are discussed [13], [14], followed by protocol extensions. One of identified protocol extensions needed is to support advertisement of a logical link in routing, where an actual connection in the lower layer is not established yet. Such a link is called virtual TE link, and represents the possibility of an underlining lower layer connection establishment [13]. The underlining connection must be established when there is an actual need to use the virtual TE link.

Recently, a new approach to the operation of the VNT has been discussed. The approach applies the Path Computation Element (PCE) architecture [15], with one or more PCEs responsible for computing paths across network layers, and combines this with the GMPLS protocols to establish connections of multiple network layers [16]. A PCE may be implemented within a network element or at a server.

3.2 MPLS-GMPLS Migration and Interworking

[NOTE: This section changed for Reviewer 1's comment (9)(10)(11)]

In order to deploy GMPLS to the network where MPLS is already deployed, migration strategies need to be considered. Note that the migration applies how to migrate from MPLS to GMPLS in packet networks. An objective to deploy GMPLS in packet networks is to utilize new features by GMPLS, such as ability to interwork with GMPLS-capable optical networks. In the course of migration, MPLS and GMPLS may co-exist in packet networks, which necessitates interworking between MPLS and GMPLS. That is, MPLS-GMPLS interworking is required on the way to migrate from MPLS to GMPLS. Currently, the framework describing migration models and interworking issues is discussed [17].

There are three migration models, that is, island model, integrated model and phased model. In the island model, GMPLS-capable nodes are introduced as an island, as shown in Fig. 6. The border node may need to perform interworking functions. As time progresses, such GMPLS island is expanded to cover the whole network. In the integrated model, some nodes within the network supports both of MPLS and GMPLS. MPLS-capable nodes and MPLS/GMPLS-capable nodes co-exist within the network for some time. As time progresses, all nodes within the network are upgraded to support GMPLS. In the phased model, some features of GMPLS are added to MPLS-capable nodes. As time progresses, all nodes become GMPLS-capable by supporting all features of GMPLS.

In some migration models, MPLS and GMPLS co-exist and interworking is required. For example, how to treat GMPLS specific parameters in signaling and routing needs some analysis [17].

Note that for some carriers, it may not necessarily be needed to migrate from MPLS to GMPLS on the whole network. That is, MPLS-GMPLS interworking may be required as an ultimate solution, not as a transient solution. Client-server model is considered as a reference model of MPLS-GMPLS interworking in [18], which corresponds to the island model mentioned above. Specific requirements on MPLS and GMPLS interworking, such as triggered establishment of GMPLS LSPs, diverse MPLS LSP establishment over GMPLS, interworking of MPLS and GMPLS recovery mechanisms, are described [18].

The choice of migration model depends on each network policy, but it is important that impact on existing MPLS networks are minimized, such as configuration change and operation change, yet utilizing new features by GMPLS.

3.3 Other Areas

Support of ASON is another possible deployment scenario of GMPLS. As described previously, the work is going on within the IETF to extend GMPLS protocols to satisfy requirements of ASON in terms of signaling and routing [19], [20].

Yet another work item is complementing GMPLS addressing rules for the sake of interoperability [21]. In GMPLS, it is possible that different kinds of net-

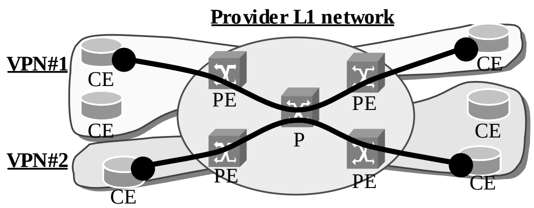


Fig. 7 Concept of L1VPNs.

work equipments are deployed. This includes router from one equipment vendor and OXC from another equipment vendor. GMPLS addressing rules govern addresses to be used in protocol messages and are fundamental pieces for interoperability among different kinds of network equipments.

4. Service Aspects

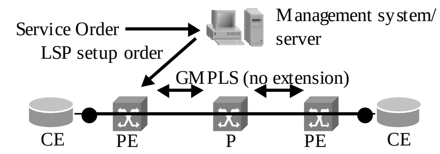
4.1 L1VPNs

[NOTE: This section changed for Reviewer 1's comment (12)(18) and 3's comment (2)]

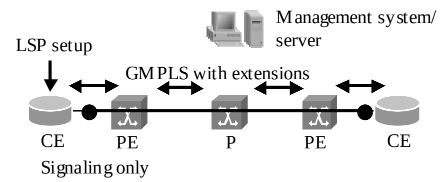
Figure 7 shows the concept of L1VPNs. The provider network consists of Provider Edge (PE) devices and Provider (P) devices, which are L1 switches such as OXCs. A Customer Edge (CE) device is connected to at least one PE. A set of CEs is grouped, which forms a VPN. What is unique in L1VPNs is that customers are granted to request L1 connection setup/deletion/modification between CEs within the same VPN. L1VPNs allow support of multiple service networks over a common transport network. In addition, L1VPNs offer new services such as switching services and scheduling services.

The L1VPN standardization work has started in the ITU-T Study Group (SG) 13 specifying requirements and architectures [22], [23]. Later, discussion has moved to the IETF to extend GMPLS protocols to support L1VPNs.

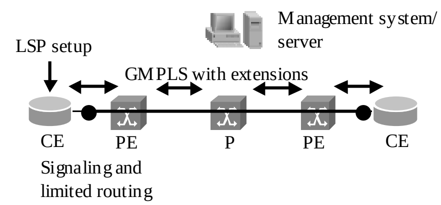
The framework defines three service models [24], as shown in Fig. 8. In the management-based service model, the provider receives a service order via the management plane. The management system or server indicates the PE to initiate connection establishment. In the signaling-based service model (referred as basic mode) and the signaling and routing service model (referred as enhanced mode), the provider receives a service order via signaling from the CE. In the basic mode, there is no routing between a CE and a PE, while in the enhanced mode, there is limited routing between a CE and a PE. Although the detailed routing model of the enhanced mode is still open, it is expected that the enhanced mode provides more service features for customers, such as avoidance of N-square routing adjacencies and ability to setup diverse LSPs between CEs.



(a) Management-based service model



(b) Signaling-based service model (basic mode)



(c) Signaling and routing service model (enhanced mode)

Fig. 8 L1VPN service models.

Currently the work is around specifying protocols in support of the basic mode. In the basic mode, a PE-PE part of a CE-CE connection is controlled and computed by the provider. On the other hand, how to connect various CEs is controlled by the customer. Signaling mechanisms are specified in [25], based on GMPLS UNI [26]. The ingress CE sends a connection setup request to the PE by specifying the egress CE. Here, the ingress CE is not allowed to specifying the path within the provider network. The PE-PE part of a connection is computed within the provider network.

The PE that receives a connection setup request from a CE needs to identify the remote PE connected to the egress CE. This requires CE-PE mapping information associated with a VPN. To obtain such information from remote PEs, manual configuration or auto-discovery mechanisms are used. Currently, two alternative auto-discovery mechanisms are specified, based on Border Gateway Protocol (BGP) and OSPF respectively [27], [28].

4.2 Ethernet transport

[NOTE: This section changed for Editors' comment and Reviewer 1's comment (13)(14)(20) and 2's comment (1) and 3's comment (1)]

With the progress of Ethernet traffic, it is becoming important to offer Ethernet transport services. Recently, more efficient bandwidth usage of Synchronous Optical NETwork/Synchronous Digital Hierarchy (SONET/SDH) networks for Ethernet transport is becoming possible with the progress of data plane technologies, such as Generic Frame Protocol (GFP) [30], Virtual Concatenation (VCAT) [31] and Link Capacity Adjustment Scheme (LCAS) [32]. Now the question is how to apply GMPLS to support Ethernet transport with additional capabilities such as dynamic bandwidth modification.

GFP allows mapping Ethernet frames onto a TDM connection. VCAT allows efficient bandwidth usage without following the strict hierarchy. For example, it allows grouping VC3 (50M) $\times$ 10 members into a Virtual Concatenation Group (VCG) to be allocated for a client interface. Furthermore, VCAT allows grouping of members over multiple paths. LCAS allows hitless bandwidth modification in combination with VCAT, by adding/deleting a member to/from the VCG.

By controlling these data plane features by GMPLS, it is possible to offer flexible Ethernet line services over the SONET/SDH network, where the Ethernet line bandwidth can be hitlessly modified with fine granularity. This requires that the client must be able to specify Ethernet traffic parameters by the use of GMPLS, and that GMPLS must be able to control dynamic bandwidth modification over the SONET/SDH network. For the former functionality, GMPLS allows requests for end-to-end Ethernet services through the definition of Ethernet traffic parameters [33]. For the latter functionality, GMPLS allows not only to modify bandwidth of a single TDM connection, but also to setup/delete a TDM connection and trigger LCAS to bundle it into a VCG that is mapped to client Ethernet signals [34]. In order to specify to which VCG a TDM connection is to be bundled, information associated with a VCG is included in the signaling messages of the newly established connection. An example scenario is shown in Fig. 9.

Note that Ethernet transport is also discussed in the OIF, and experimental implementation and interoperability testing was conducted [35]. Also note that recently, effort on introducing the concept of Ethernet connection to Ethernet switches, as well as applying GMPLS to control such Ethernet switches is being proposed [36].

4.3 Other Areas

[NOTE: This section changed for Editors' comment and Reviewer 2's comment (1)]

Requirements and protocol extensions for establishing P2MP LSPs are another emerging work item [29]. Although the initial target was packet networks (i.e., MPLS), protocol extensions are well applicable to optical networks (i.e., GMPLS). Currently, basic protocol specifications are almost standardized, and considerations on operation and management are under way.

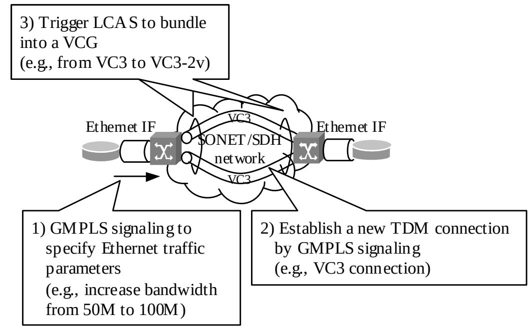


Fig. 9 Flexible Ethernet line service.

5. Operation and Management

5.1 MIB Module

In the IETF, Simple Network Management Protocol (SNMP) is a de-facto protocol to control and manage the network equipment from management systems. It allows get/set/trap operations. MIB modules define the semantics of information exchanged by SNMP.

In traditional transport networks, management systems play an important role for control and management. SNMP support is not yet common in transport networks, but in order to develop management systems to control and manage GMPLS-based networks, SNMP support may become important.

Currently, MIB modules for RSVP-TE and LMP are mostly standardized [37]–[39]. In addition, the work is going on for specifying OSPF-TE MIB modules [40].

5.2 Other Areas

[NOTE: This section changed for Editors' comment and Reviewer 2's comment (1)]

Communication of alarm information is an important feature in order to display and diagnose the status of LSPs. Currently, protocol extensions are almost stable [41], but some considerations would be needed whether this could be applied in wider context (e.g., to gracefully reroute LSPs before node/link planned outage).

Another emerging work item is how to deploy GMPLS in the transport network which is originally controlled and managed by management systems. In such a scenario, it may be required to transfer the management system initiated connection into the control plane maintained connection without traffic disruption. This means transferring connection ownership from the management plane to the control plane, as shown in Fig. 10. In order to address such issues, requirements are being discussed [42]. Solution work may follow.

Note that as mentioned in Sect. 2.3, operation and

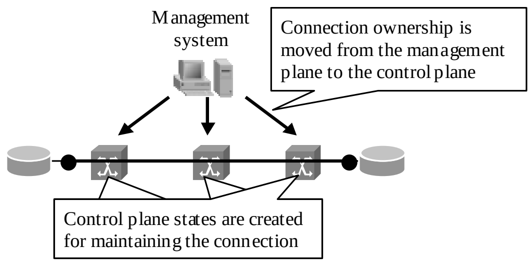


Fig. 10 Transfer of connection ownership.

management is still at the early stage for GMPLS. When GMPLS is deployed in the transport network, several considerations are needed, such as

- How to associate control plane database and management plane database (e.g., in terms of resource management and fault management)
- How the management system monitors control plane initiated connections (e.g., in the case of restoration)
- How to build and monitor the control plane network itself

These issues certainly impact operational policies and implementation of management systems. These issues may further impact protocols between management systems (e.g., SNMP MIB modules) and/or GMPLS protocols themselves, which would require standardization effort. Some work is under way (e.g., [43]), but more detailed analysis would be required to be able to manage and operate GMPLS-based networks.

6. Conclusion

[NOTE: This section changed for Reviewer 1's comment (15)]

This paper presented the latest trends in GMPLS standardization. GMPLS is expected to be a key enabler for carrier network enhancement. It offers standardized mechanisms to control and manage optical networks. Furthermore, it offers common control and management plane protocols to support any connection-oriented technology, such as packets (or MPLS), TDM, optical and fibers.

There are three major relevant standardization organizations and forums in the area of GMPLS, that is, IETF, ITU-T and OIF. The IETF is responsible for standardizing GMPLS protocols. The basic suite of GMPLS protocols is already standardized. Now the standardization work within the IETF is moving toward to how to apply GMPLS protocols to support various scenarios and use cases. Three major emerging work areas are deployment strategies, service aspects, and operation and management.

As presented in this paper, there are several possible GMPLS deployment scenarios, and GMPLS standards are evolving to address such scenarios. In one scenario, GMPLS may be deployed to offer operational enhancement of the existing networks, such as integrated control and management. In order to tackle this scenario, the standardization work is going on, such as multi-region/multi-layer networks, migration from MPLS to GMPLS, and migration from management plane oriented networks to control plane oriented networks. In another scenario, GMPLS may be deployed as a tool to offer new services, such as L1VPNs and Ethernet transport. The standardization work is going on for such use cases as well.

One area that requires more effort would be operation and management. This may be particularly interesting when a GMPLS-based network is deployed as a replacement of today's transport network, rather than as a brand-new network. Since GMPLS would change network operation from today, but is still a new technology, additional consideration would be required in the area of operation and management. Further standardization effort may be required to address such issues.

References

[1] E. Mannie (Editor), "Generalized multi-protocol label switching architecture," IETF RFC 3945, Oct. 2004.
[2] L. Berger (Editor), "Generalized multi-protocol label switching (GMPLS) signaling resource reservation protocol-traffic engineering (RSVP-TE) extensions," IETF RFC 3473, Jan. 2003.
[3] K. Kompella and Y. Rekhter (Editors), "OSPF extensions in support of generalized multi-protocol label switching," IETF RFC 4203, Oct. 2005.
[4] K. Kompella and Y. Rekhter (Editors), "Intermediate System to Intermediate System (IS-IS) Extensions in Support of Generalized Multi-Protocol Label Switching (GMPLS)," IETF RFC 4205, Oct. 2005.
[5] J. Lang (Editor), "Link management protocol (LMP)," IETF RFC 4204, Oct. 2005.
[6] R. Papneja, E. Oki and K. Ogaki, "MPLS to GMPLS migration: from concept to validation," iPOP2006, June 2006.
[7] D. Awduche and Y. Rekhter, "Multiprotocol lambda switching: combining MPLS traffic engineering control with optical crossconnects," IEEE Commun. Mag., vol. 39, no.3, pp.111-116, March 2001.
[8] J.P. Lang, Y. Rekhter and D. Papadimitriou (Editors), "RSVP-TE extensions in support of end-to-end generalized multi-protocol label switching (GMPLS)-based recovery," IETF Internet draft, work in progress.
[9] L. Berger, I. Bryskin, D. Papadimitriou and A. Farrel, "GMPLS based segment recovery," IETF Internet draft, work in progress.
[10] ITU-T Recommendation G.8080/Y.1304, "Architecture for the automatically switched optical networks (ASON)," Nov. 2001.
[11] A. Banerjee, J. Drake, J.P. Lang, B. Turner, K. Kompella, and Y. Rekhter, "Generalized multiprotocol label switching: an overview of routing and management enhancements," IEEE Commun. Mag., vol.39, no.1, pp.144-150, Jan. 2001.
[12] A. Banerjee, J. Drake, J.P. Lang, B. Turner, D. Awduche, L. Berger, K. Kompella and Y. Rekhter, "Generalized multiprotocol label switching: an overview of signaling enhancements and recovery techniques," IEEE Commun.

Mag., vol. 39, no.7, pp.144-51, July 2001.
[13] K. Shiomoto, D. Papadimitriou, J.L. Le Roux, M. Vigoureux and D. Brungard, "Requirements for GMPLS-based multi-region and multi-layer networks (MRN/MLN)," IETF Internet draft, work in progress.
[14] J.L. Le Roux, D. Brungard, E. Oki, D. Papadimitriou, K. Shiomoto and M. Vigoureux, "Evaluation of existing GMPLS protocols against multi layer and multi region networks (MLN/MRN)," IETF Internet draft, work in progress.
[15] A. Farrel, J.P. Vasseur and J. Ash, "A path computation element (PCE)-based architecture," IETF RFC 4655, Aug. 2006.
[16] E. Oki, J.L. Le Roux and A. Farrel, "Framework for PCE-based inter-layer MPLS and GMPLS traffic engineering," IETF Internet draft, work in progress.
[17] K. Shiomoto, D. Papadimitriou, J.L. Le Roux, D. Brungard, K. Kumaki, E. Oki, I. Inoue and T. Otani, "Framework for IP/MPLS-GMPLS interworking in support of IP/MPLS to GMPLS migration," IETF Internet draft, work in progress.
[18] K. Kumaki, T. Otani, S. Okamoto, K. Fujihara, Y. Ikejiri, "Interworking requirements to support operation of MPLS-TE over GMPLS networks," IETF Internet draft, work in progress.
[19] D. Papadimitriou and A. Farrel (Editors), "Generalized MPLS (GMPLS) RSVP-TE signaling extensions in support of calls," IETF Internet draft, work in progress.
[20] D. Papadimitriou, "OSPFv2 routing protocol extensions for ASON routing," IETF Internet draft, work in progress.
[21] K. Shiomoto, R. Papneja and R. Rabbat, "Use of addresses in generalized multi-protocol label switching (GMPLS) networks," IETF Internet draft, work in progress.
[22] ITU-T Recommendation Y.1312, "Layer 1 virtual private network generic requirements and architecture elements," Sept. 2003.
[23] ITU-T Recommendation Y.1313, "Layer 1 virtual private network service and network architectures," July 2004.
[24] T. Takeda (Editor), "Framework and requirements for layer 1 virtual private networks," IETF Internet draft, work in progress.
[25] D. Fedyk and Y. Rekhter (Editors), "Layer 1 VPN basic mode," IETF Internet draft, work in progress.
[26] G. Swallow, J. Drake, H. Ishimatsu and Y. Rekhter, "Generalized multiprotocol label switching (GMPLS) user-network interface (UNI): resource reservation protocol-traffic engineering (RSVP-TE) support for the overlay model," IETF RFC 4208, Oct. 2005.
[27] H. Ould-Brahim, D. Fedyk and Y. Rekhter, "BGP-based auto-discovery for L1VPNs," IETF Internet draft, work in progress.
[28] I. Bryskin and L. Berger, "OSPF based L1VPN auto-discovery," IETF Internet draft, work in progress.
[29] R. Aggarwal, D. Papadimitriou and S. Yasukawa (Editors), "Extensions to RSVP-TE for point-to-multipoint TE LSPs," IETF Internet draft, work in progress.
[30] ITU-T Recommendation G.7041/Y.1303, "Generic framing procedure (GFP)," Aug. 2005.
[31] ITU-T Recommendation G.707/Y.1322, "Network node interface for the synchronous digital hierarchy (SDH)," Dec. 2003.
[32] ITU-T Recommendation G.7042/Y.1305, "Link capacity adjustment scheme (LCAS) for virtual concatenated signals," Feb. 2004.
[33] D. Papadimitriou, "MEF Ethernet traffic parameters," IETF Internet draft, work in progress.
[34] R. Rabbat (Editor), "Operating virtual concatenation (VCAT) and the link capacity adjustment scheme (LCAS) with generalized multi-protocol label switching (GMPLS)," IETF Internet draft, work in progress.
[35] J.D. Jones, L. Ong, M. Lazer, "Interoperability update: dynamic ethernet services via intelligent optical networks," IEEE Commun. Mag., vol.43, no.11, pp.4-10, Nov. 2005.
[36] D. Fedyk, D. Allan, G. Sunderwood, H. Shah, N. Bitar, A .Takacs, D. Caviglia, "GMPLS control of Ethernet," IETF Internet draft, work in progress.
[37] T.D. Nadeau and A. Farrel (Editors), "Generalized multi-protocol label switching (GMPLS) traffic engineering management information base," IETF Internet draft, work in progress.
[38] T.D. Nadeau and A. Farrel (Editors), "Generalized multiprotocol label switching (GMPLS) label switching router (LSR) management information base," IETF Internet draft, work in progress.
[39] M. Dubuc, T. Nadeau, J. Lang and E. McGinnis, "Link Management Protocol (LMP) Management Information Base (MIB)," IETF RFC 4327, Jan. 2006.
[40] M. Miyazawa, T. Otani, T.D. Nadeau and K. Kumaki, "Extensions to the OSPF management information base in support of GMPLS," IETF Internet draft, work in progress.
[41] L. Berger, "GMPLS - communication of alarm information," IETF Internet draft, work in progress.
[42] D. Caviglia, D. Bramanti and D. Li, "Requirements for the conversion between permanent connections and switched connections in a generalized multiprotocol label switching (GMPLS) network," IETF Internet draft, work in progress.
[43] T.D. Nadeau and H. Rakotoranto, "GMPLS operations and management: today's challenges and solutions for tomorrow," IEEE Commun. Mag., vol 43, no. 7, pp.68-74, July 2005.