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Haomian Zheng
Yi Lin
Huawei Technologies
Yang Zhao
China Mobile
Yunbin Xu
CAICT
Dieter Beller
Nokia

Interworking of GMPLS Control and Centralized Controller Systems

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Abstract

Generalized Multi-Protocol Label Switching (GMPLS) control allows each network element (NE) to perform local resource discovery, routing and signaling in a distributed manner.

On the other hand, with the development of software-defined transport networking technology, a set of NEs can be controlled via centralized controller hierarchies to address the issues from multi-domain, multi-vendor, and multi-technology. An example of such centralized architecture is Abstraction and Control of Traffic Engineered Networks (ACTN) controller hierarchy described in RFC 8453.

Instead of competing with each other, both the distributed and the centralized control plane have their own advantages, and should be complementary in the system. This document describes how the GMPLS distributed control plane can interwork with a centralized controller system in a transport network.

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1. Introduction

Generalized Multi-Protocol Label Switching (GMPLS) [RFC3945] extends MPLS to support different classes of interfaces and switching capabilities such as Time-Division Multiplex Capable (TDM), Lambda Switch Capable (LSC), and Fiber-Switch Capable (FSC). Each network element (NE) running a GMPLS control plane collects network information from other NEs and supports service provisioning through signaling in a distributed manner. A more generic description of Traffic-engineering networking information exchange can be found in [RFC7926].

On the other hand, Software-Defined Networking (SDN) technologies have been introduced to control the transport network in a centralized manner. Centralized controllers can collect network information from each node and provision services to corresponding nodes. One of the examples is the Abstraction and Control of Traffic Engineered Networks (ACTN) [RFC8453], which defines a hierarchical architecture with Provisioning Network Controller (PNC), Multi-domain Service Coordinator (MDSC) and Customer Network Controller (CNC) as centralized controllers for different network abstraction levels. A Path Computation Element (PCE) based approach has been proposed as Application-Based Network Operations (ABNO) in [RFC7491].

In such centralized controller architectures, GMPLS can be applied for the NE-level control. A centralized controller may support GMPLS enabled domains and may interact with a GMPLS enabled domain where the GMPLS control plane does the service provisioning from ingress to egress. In this case the centralized controller sends the request to the ingress node and does not have to configure all NEs along the path through the domain from ingress to egress thus leveraging the

GMPLS control plane. This document describes how GMPLS control interworks with a centralized controller system in a transport network.

2. Overview

In this section, overviews of GMPLS control plane and centralized controller system are discussed as well as the interactions between the GMPLS control plane and centralized controllers.

2.1. Overview of GMPLS Control Plane

GMPLS separates the control plane and the data plane to support time-division, wavelength, and spatial switching, which are significant in transport networks. For the NE level control in GMPLS, each node runs a GMPLS control plane instance. Functionalities such as service provisioning, protection, and restoration can be performed via GMPLS communication among multiple NEs. At the same time, the controller can also collect information about node and link resources in the network to construct the network topology and compute routing paths for serving service requests.

Several protocols have been designed for GMPLS control [RFC3945] including link management [RFC4204], signaling [RFC3471], and routing [RFC4202] protocols. The controllers applying these protocols communicate with each other to exchange resource information and establish Label Switched Paths (LSPs). In this way, controllers in different nodes in the network have the same view of the network topology and provision services based on local policies.

2.2. Overview of Centralized Controller System

With the development of SDN technologies, a centralized controller architecture has been introduced to transport networks. One example architecture can be found in ACTN [RFC8453]. In such systems, a controller is aware of the network topology and is responsible for provisioning incoming service requests.

Multiple hierarchies of controllers are designed at different levels implementing different functions. This kind of architecture enables multi-vendor, multi-domain, and multi-technology control. For example, a higher-level controller coordinates several lower-level controllers controlling different domains, for topology collection and service provisioning. Vendor-specific features can be abstracted between controllers, and a standard API (e.g., generated from RESTCONF/YANG) is used.

2.3. GMPLS Control Interworking with a Centralized Controller System

Besides GMPLS and the interactions among the controller hierarchies, it is also necessary for the controllers to communicate with the network elements. Within each domain, GMPLS control can be applied to each NE. The bottom-level centralized controller can act as an NE to collect network information and initiate LSPs. Figure 1 shows an example of GMPLS interworking with centralized controllers (ACTN terminologies are used in the figure).

```
                           +-------------------+
                           |    Orchestrator   |
                           |       (MDSC)      |
                           +-------------------+
                             ^       ^       ^
                             |       |       |
               +-------------+       |       +-------------+
               |                     |RESTCONF/YANG models |
               V                     V                     V
         +-------------+      +-------------+       +-------------+
         |Controller(N)|      |Controller(G)|       |Controller(G)|
         |    (PNC)    |      |    (PNC)    |       |    (PNC)    |
         +-------------+      +-------------+       +-------------+
              ^  ^                  ^  ^                  ^  ^
              |  |                  |  |                  |  |
       NETCONF|  |PCEP       NETCONF|  |PCEP       NETCONF|  |PCEP
        /YANG |  |            /YANG |  |            /YANG |  |
              V  V                  V  V                  V  V
          .----------.  Inter-  .----------.  Inter-  .----------.
         /            \ domain /            \ domain /            \
        |              | link |     LMP      | link |     LMP      |
        |              |======|   OSPF-TE    |======|   OSPF-TE    |
        |              |      |   RSVP-TE    |      |   RSVP-TE    |
         \            /        \            /        \            /
          `----------`          `----------`          `----------`
       Non-GMPLS domain 1      GMPLS domain 2        GMPLS domain 3
```

Figure 1: Example of GMPLS/non-GMPLS interworking with Controllers

Figure 1 shows the scenario with two GMPLS domains and one non-GMPLS domain. This system supports the interworking among non-GMPLS domain, GMPLS domain and the controller hierarchies. For domain 1, the network elements were not enabled with GMPLS so the control is purely from the controller, via NETCONF/YANG and/or PCEP. For domains 2 and 3, each domain has the GMPLS control plane enabled at the physical network level. The PNC can exploit GMPLS capabilities implemented in the domain to listen to the IGP routing protocol messages (OSPF LSAs, for example) that the GMPLS control plane instances are disseminating into the network and thus learn the network topology. For path computation in the domain with PNC implementing a PCE, PCCs (e.g. NEs, other controller/PCE) use PCEP to ask the PNC for a path and get replies. The MDSC communicates with PNCs using, for example REST/RESTCONF based on YANG data models. As a PNC has learned its domain topology, it can report the topology to the MDSC. When a service arrives, the MDSC computes the path and coordinates PNCs to establish the corresponding LSP segment.

Alternatively, the NETCONF protocol can be used to retrieve topology information utilizing the, e.g., [RFC8795] Yang model and the technology-specific YANG model augmentations required for the specific network technology. The PNC can retrieve topology information from any NE (the GMPLS control plane instance of each NE in the domain has the same topological view), construct the topology of the domain, and export an abstracted view to the MDSC. Based on the topology retrieved from multiple PNCs, the MDSC can create a topology graph of the multi-domain network, and can use it for path computation. To set up a service, the MDSC can exploit, e.g., [TE-Tunnel] Yang model together with the technology-specific YANG model augmentations.

This document focuses on the interworking between GMPLS and the centralized controller system, including:

- The interworking between the GMPLS domains and the centralized controllers (including the orchestrator, if it exists) controlling the GMPLS domains.

- The interworking between a non-GMPLS domain (which is controlled by a centralized controller system) and a GMPLS domain, through the controller hierarchy architecture.

For convenience, this document uses the following terminologies for the controller and the orchestrator:

- Controller(G): A domain controller controlling a GMPLS domain (the controller(G) of the GMPLS domains 2 and 3 in Figure 1);

- Controller(N): A domain controller controlling a non-GMPLS domain (the controller(N) of the non-GMPLS domain 1 in Figure 1);

- H-Controller(G): A domain controller controlling the higher-layer GMPLS domain, in the context of multi-layer networks;

- L-Controller(G): A domain controller controlling the lower-layer GMPLS domain, in the context of multi-layer networks;

- H-Controller(N): A domain controller controlling the higher-layer non-GMPLS domain, in the context of multi-layer networks;

- L-Controller(N): A domain controller controlling the lower-layer non-GMPLS domain, in the context of multi-layer networks;

- Orchestrator(MD): An orchestrator used to orchestrate the multi-domain networks;

- Orchestrator(ML): An orchestrator used to orchestrate the multi-layer networks.

3. Discovery Options

In GMPLS control, the link connectivity needs to be verified between each pair of nodes. In this way, link resources, which are fundamental resources in the network, are discovered by both ends of the link.

3.1. LMP

Link management protocol (LMP) [RFC4204] runs between a pair of nodes and is used to manage TE links. In addition to the setup and maintenance of control channels, LMP can be used to verify the data link connectivity and correlate the link properties.

4. Routing Options

In GMPLS control, link state information is flooded within the network as defined in [RFC4202]. Each node in the network can build the network topology according to the flooded link state information. Routing protocols such as OSPF-TE [RFC4203] and ISIS-TE [RFC5307] have been extended to support different interfaces in GMPLS.

In a centralized controller system, the centralized controller can be placed in the GMPLS network and passively receive the information flooded in the network. In this way, the centralized controller can construct and update the network topology.

4.1. OSPF-TE

OSPF-TE is introduced for TE networks in [RFC3630]. OSPF extensions have been defined in [RFC4203] to enable the capability of link state information for GMPLS network. Based on this work, OSPF has been extended to support technology-specific routing. The routing protocol for OTN, WSON and optical flexi-grid networks are defined in [RFC7138], [RFC7688] and [RFC8363], respectively.

4.2. ISIS-TE

ISIS-TE is introduced for TE networks in [RFC5305] and is extended to support GMPLS routing functions [RFC5307], and has been updated to [RFC7074] to support the latest GMPLS switching capability and Types fields.

4.3. NETCONF/RESTCONF

NETCONF [RFC6241] and RESTCONF [RFC8040] protocols are originally used for network configuration. These protocols can also be used for topology retrieval by using topology-related YANG models, such as [RFC8345] and [RFC8795]. These protocols provide a powerful mechanism for notification that permits to notify the client about topology changes.

5. Path Computation

5.1. Controller-based Path Computation

Once a controller learns the network topology, it can utilize the available resources to serve service requests by performing path computation. Due to abstraction, the controllers may not have sufficient information to compute the optimal path. In this case, the controller can interact with other controllers by sending Yang Path Computation requests [PAT-COMP] to compute a set of potential optimal paths and then, based on its own constraints, policy and specific knowledge (e.g. cost of access link) can choose the more feasible path for service e2e path setup.

Path computation is one of the key objectives in various types of controllers. In the given architecture, it is possible for different components that have the capability to compute the path.

5.2. Constraint-based Path Computing in GMPLS Control

In GMPLS control, a routing path may be computed by the ingress node ([RFC3473]) based on the ingress node TED. In this case, constraint-based path computation is performed according to the local policy of the ingress node.

5.3. Path Computation Element (PCE)

PCE has been introduced in [RFC4655] as a functional component that provides services to compute paths in a network. In [RFC5440], the path computation is accomplished by using the Traffic Engineering Database (TED), which maintains a view of the link resources in the network. The emergence of PCE efficiently improves the quality of network planning and offline computation, but there is a risk that the computed path may be infeasible if there is a diversity requirement, because stateless PCE has no knowledge about the former computed paths.

To address this issue, stateful PCE has been proposed in [RFC8231]. Besides the TED, an additional LSP Database (LSP-DB) is introduced to archive each LSP computed by the PCE. In this way, PCE can easily figure out the relationship between the computing path and former computed paths. In this approach, PCE provides computed paths to PCC, and then PCC decides which path is deployed and when to be established.

With PCE-Initiated LSPs [RFC8281], PCE is allowed to trigger the PCC to perform setup, maintenance, and teardown of the PCE-initiated LSP under the stateful PCE model. This would allow a dynamic network that is centrally controlled and deployed.

In a centralized controller system, the PCE can be implemented in a centralized controller, and the centralized controller performs path computation according to its local policies. On the other hand, the PCE can also be placed outside of the centralized controller. In this case, the centralized controller acts as a PCC to request path computation to the PCE through PCEP. One of the reference architecture can be found in [RFC7491].

6. Signaling Options

Signaling mechanisms are used to set up LSPs in GMPLS control. Messages are sent hop by hop between the ingress node and the egress node of the LSP to allocate labels. Once the labels are allocated along the path, the LSP setup is accomplished. Signaling protocols such as RSVP-TE [RFC3473] have been extended to support different interfaces in GMPLS.

6.1. RSVP-TE

RSVP-TE is introduced in [RFC3209] and extended to support GMPLS signaling in [RFC3473]. Several label formats are defined for a generalized label request, a generalized label, suggested label and label sets. Based on [RFC3473], RSVP-TE has been extended to support technology-specific signaling. The RSVP-TE extensions for OTN, WSON, optical flexi-grid network are defined in [RFC7139], [RFC7689], and [RFC7792], respectively.

7. Interworking Scenarios

7.1. Topology Collection & Synchronization

Topology information is necessary on both network elements and controllers. The topology on network element is usually raw information, while the topology on the controller can be either raw or abstracted. Three different abstraction methods have been described in [RFC8453], and different controllers can select the corresponding method depending on application.

When there are changes in the network topology, the impacted network elements need to report changes to all the other network elements, together with the controller, to sync up the topology information. The inter-NE synchronization can be achieved via protocols mentioned in Sections 3 and 4. The topology synchronization between NEs and controllers can either be achieved by routing protocols OSPF-TE/PCEP-LS in [PCEP-LS] or NETCONF protocol notifications with YANG model.

7.2. Multi-domain Service Provisioning

Based on the topology information on controllers and network elements, service provisioning can be deployed. Plenty of methods have been specified for single domain service provisioning, such as using PCEP and RSVP-TE.

Multi-domain service provisioning would require coordination among the controller hierarchies. Given the service request, the end-to-end delivery procedure may include interactions at any level (i.e. interface) in the hierachy of the controllers (e.g. MPI and SBI for ACTN). The computation for a cross-domain path is usually completed by controllers who have a global view of the topologies. Then the configuration is decomposed into lower-level controllers, to configure the network elements to set up the path.

A combination of the centralized and distributed protocols may be necessary for the interaction between network elements and controller. Several methods can be used to create the inter-domain path:

1) With end-to-end RSVP-TE session:

In this method, all the domains need to support the RSVP-TE protocol and thus need to be GMPLS domains. The Controller(G) of the source domain triggers the source node to create the end-to-end RSVP-TE session, and the assignment and distribution of the labels on the inter-domain links are done by the border nodes of each domain, using RSVP-TE protocol. Therefore, this method requires the interworking of RSVP-TE protocols between different domains.

There are two possible methods:

1.1) One single end-to-end RSVP-TE session

In this method, an end-to-end RSVP-TE session from the source node to the destination node will be used to create the inter-domain path. A typical example would be the PCE Initiation scenario, in which a PCE message (PCInitiate) is sent from the controller(G) to the source node, and then trigger an RSVP procedure along the path.

Similarly, the interaction between the controller and the source node of the source domain can be achieved by NETCONF protocol with corresponding YANG models, and then completed by running RSVP among the network elements.

1.2) LSP Stitching

The LSP stitching method defined in [RFC5150] can also be used to create the end-to-end LSP. I.e., when the source node receives an end-to-end path creation request (e.g., using PCEP or NETCONF protocol), the source node starts an end-to-end RSVP-TE session along the end points of each LSP segment (refers to S-LSP in [RFC5150]) of each domain, to assign the labels on the inter-domain links between each pair of neighbor S-LSPs, and stitch the end-to-end LSP to each S-LSP. See Figure 2 as an example. Note that the S-LSP in each domain can be either created by its Controller(G) in advance, or created dynamically triggered by the end-to-end RSVP-TE session.

```
                    +-------------------------+
                    |    Orchestrator(MD)     |
                    +-----------+-------------+
                                |
   +---------------+     +------V-------+     +---------------+
   | Controller(G) |     | Controller(G)|     | Controller(G) |
   +-------+-------+     +------+-------+     +-------+-------+
           |                    |                     |
  +--------V--------+   +-------V--------+   +--------V--------+
  |Client           |   |                |   |           Client|
  |Signal   Domain 1|   |    Domain 2    |   |Domain 3   Signal|
  |  |              |   |                |   |              |  |
  |+-+-+            |   |                |   |            +-+-+|
  || | |  +--+  +--+|   |+--+  +--+  +--+|   |+--+  +--+  | | ||
  || | |  |  |  |  ||   ||  |  |  |  |  ||   ||  |  |  |  | | ||
  || ******************************************************** ||
  ||   |  |  |  |  ||   ||  |  |  |  |  ||   ||  |  |  |  |   ||
  |+---+  +--+  +--+|   |+--+  +--+  +--+|   |+--+  +--+  +---+|
  +-----------------+   +----------------+   +-----------------+
   |   .           .     .              .     .           .   |
   |   .<-S-LSP 1->.     .<- S-LSP 2 -->.     .<-S-LSP 3->.   |
   |               .     .              .     .               |
   |-------------->.---->.------------->.---->.-------------->|
   |<--------------.<----.<-------------.<----.<--------------|
   |       End-to-end RSVP-TE session for LSP stitching       |
```

Figure 2: LSP stitching

2) Without end-to-end RSVP-TE session:

In this method, each domain can be a GMPLS domain or a non-GMPLS domain. Each controller (may be a Controller(G) or a Controller(N)) is responsible to create the path segment within its domain. The border node does not need to communicate with other border nodes in other domains for the distribution of labels on inter-domain links, so end-to-end RSVP-TE session through multiple domains is not required, and the interworking of RSVP-TE protocol between different domains is not needed.

Note that path segments in the source domain and the destination domain are "asymmetrical" segments, because the configuration of client signal mapping into server layer tunnel is needed at only one end of the segment, while configuration of server layer cross-connect is needed at the other end of the segment. See the example in Figure 3.

```
                    +-------------------------+
                    |    Orchestrator(MD)     |
                    +-----------+-------------+
                                |
   +---------------+     +------V-------+     +---------------+
   |  Controller   |     |  Controller  |     |  Controller   |
   +-------+-------+     +------+-------+     +-------+-------+
           |                    |                     |
  +--------V--------+   +-------V--------+   +--------V--------+
  |Client   Domain 1|   |    Domain 2    |   | Domain 3  Client|
  |Signal           |   |                |   |           Signal|
  |  |  Server layer|   |                |   |              |  |
  |  |     tunnel   |   |                |   |              |  |
  |+-+-+       ^    |   |                |   |            +-+-+|
  || | |  +--+ |+--+|   |+--+  +--+  +--+|   |+--+  +--+  | | ||
  || | |  |  | ||  ||   ||  |  |  |  |  ||   ||  |  |  |  | | ||
  || ******************************************************** ||
  ||   |  |  |  |  || . ||  |  |  |  |  || . ||  |  |  |  |   ||
  |+---+  +--+  +--+| . |+--+  +--+  +--+| . |+--+  +--+  +---+|
  +-----------------+ . +----------------+ . +-----------------+
   .                  .                    .                  .
   .<-Path Segment 1->.<--Path Segment 2-->.<-Path Segment 3->.
```

Figure 3: Example of asymmetrical path segment

The PCEP / GMPLS protocols should support creation of such asymmetrical segments.

Note also that mechanisms to assign the labels in the inter-domain links also need to be considered. There are two possible methods:

2.1) Inter-domain labels assigned by NEs:

The concept of Stitching Label that allows stitching local path segments was introduced in [RFC5150] and [sPCE-ID], in order to form the inter-domain path crossing several different domains. It also describes the Backward-Recursive PCE-Based Computation (BRPC) and Hierarchical Path Computation Element (H-PCE) PCInitiate procedure, i.e., the ingress node of each downstream domain assigns the stitching label for the inter-domain link between the downstream domain and its upstream neighbor domain, and this stitching label will be passed to the upstream neighbor domain by PCE protocol, which will be used for the path segment creation in the upstream neighbor domain.

2.2) Inter-domain labels assigned by controller:

If the resources of inter-domain links are managed by the orchestrator(MD), each domain controller can provide to the orchestrator(MD) the list of available labels (e.g. timeslots if OTN is the scenario) using the IETF Topology YANG model and related technology specific extension. Once the orchestrator(MD) has computed the E2E path, RSVP-TE or PCEP can be used in the different domains to setup related segment tunnel consisting with label inter-domain information, e.g. for PCEP the label Explicit Route Object (ERO) can be included in the PCInitiate message to indicate the inter-domain labels, so that each border node of each domain can configure the correct cross-connect within itself.

7.3. Multi-layer Service Provisioning

GMPLS can interwork with centralized controller system in multi-layer networks.

```
+----------------+
|Orchestrator(ML)|
+------+--+------+
       |  |                            Higher-layer Network
       |  |                           .--------------------.
       |  |                          /                      \
       |  |   +---------------+      |   +--+   Link   +--+   |
       |  +-->| H-Controller +----->|   |  |**********|  |   |
       |      +---------------+      |   +--+          +--+   |
       |                             \     .            .    /
       |                              `--.------------.---`
       |                                 .            .
       |                              .---.------------.---.
       |                             /     .            .    \
       |      +---------------+      |   +--+   +--+   +--+   |
       +----->| L-Controller +----->|   | ============== |   |
              +---------------+      |   +--+   +--+   +--+   |
                                     \         H-LSP        /
                                      `-------------------`
                                        Lower-layer Network
```

Figure 4: GMPLS-controller interworking in multi-layer networks

An example with two layers of network is shown in Figure 4. In this example, the GMPLS control plane is enabled in at least one layer network (otherwise it is out of scope of this document), and interworks with the controller of its domain (H-Controller and L-Controller, respectively). The Orchestrator(ML) is used to coordinate the control of the multi-layer network.

7.3.1. Multi-layer Path Computation

[RFC5623] describes three inter-layer path computation models and four inter-layer path control models:

- 3 Path computation:

  - Single PCE path computation model

  - Multiple PCE path computation with inter-PCE communication model

  - Multiple PCE path computation without inter-PCE communication model

- 4 Path control:

  - PCE-VNTM cooperation model

  - Higher-layer signaling trigger model

  - NMS-VNTM cooperation model (integrated flavor)

  - NMS-VNTM cooperation model (separate flavor)

Section 4.2.4 of [RFC5623] also provides all the possible combinations of inter-layer path computation and inter-layer path control models.

To apply [RFC5623] in multi-layer network with GMPLS-controller interworking, the H-Controller and the L-Controller can act as the PCE Hi and PCE Lo respectively, and typically, the Orchestrator(ML) can act as a Virtual Network Topology Manager (VNTM) because it has the abstracted view of both the higher-layer and lower-layer networks.

Table 1 shows all possible combinations of path computation and path control models in multi-layer network with GMPLS-controller interworking:

Table 1: Combinations of path computation and path control models

```
         ---------------------------------------------------------
        | Path computation    |Single PCE | Multiple  | Multiple  |
        |      \              |   (Not    | PCE with  | PCE w/o   |
        | Path control        |applicable)| inter-PCE | inter-PCE |
        |---------------------+-----------+-----------+-----------|
        | PCE-VNTM            |  ......   |           |           |
        | cooperation         |  . -- .   |   Yes     |   Yes     |
        |                     |  .    .   |           |           |
        |---------------------+--.----.---+-----------+-----------|
        | Higher-layer        |  .    .   |           |           |
        | signaling trigger   |  . -- .   |   Yes     |   Yes     |
        |                     |  .    .   |           |           |
        |---------------------+--.----.---+-----------+-----------|
        | NMS-VNTM            |  .    .   |  .........|.......    |
        | cooperation         |  . -- .   |  .Yes     |   No .    |
        | (integrated flavor) |  .    .   |  .        |      .    |
        |---------------------+--.----.---+--.--------+------.----|
        | NMS-VNTM            |  .    .   |  .        |      .    |
        | cooperation         |  . -- .   |  .No      |   Yes.    |
        | (separate flavor)   |  ......   |  .........|.......    |
         ---------------------+----|------+--------|--+-----------
                                   V               V
                 Not applicable because   Typical models to be used
                 there are multiple PCEs
```

Note that:

- Since there is one PCE in each layer network, the path computation model "Single PCE path computation" is not applicable.

- For the other two path computation models "Multiple PCE with inter-PCE" and "Multiple PCE w/o inter-PCE", the possible combinations are the same as defined in [RFC5623]. More specifically:

  o The path control models "NMS-VNTM cooperation (integrated flavor)" and "NMS-VNTM cooperation (separate flavor)" are the typical models to be used in multi-layer network with GMPLS-controller interworking. This is because in these two models, the path computation is triggered by the Network Management System (NMS) or VNTM. And in the centralized controller system, the path computation requests are typically from the Orchestrator(ML) (acts as VNTM).

  o For the other two path control models "PCE-VNTM cooperation" and "Higher-layer signaling trigger", the path computation is triggered by the NEs, i.e., NE performs PCC functions. These two models are still possible to be used, although they are not the main methods.

7.3.2. Cross-layer Path Creation

In a multi-layer network, a lower-layer LSP in the lower-layer network can be created, which will construct a new link in the higher-layer network. Such lower-layer LSP is called Hierarchical LSP, or H-LSP for short, see [RFC6107].

The new link constructed by the H-LSP can then be used by the higher-layer network to create new LSPs.

As described in [RFC5212], two methods are introduced to create the H-LSP: the static (pre-provisioned) method and the dynamic (triggered) method.

1) Static (pre-provisioned) method

In this method, the H-LSP in the lower-layer network is created in advance. After that, the higher-layer network can create LSPs using the resource of the link constructed by the H-LSP.

The Orchestrator(ML) is responsible to decide the creation of H-LSP in the lower-layer network if it acts as a VNTM. It then requests the L-Controller to create the H-LSP via, for example, MPI interface under the ACTN architecture. See Section 3.3.2 of [TE-Tunnel].

If the lower-layer network is a GMPLS domain, the L-Controller(G) can trigger the GMPLS control plane to create the H-LSP. As a typical example, the PCInitiate message can be used for the communication between the L-Controller and the source node of the H-LSP. And the source node of the H-LSP can trigger the RSVP-TE signaling procedure to create the H-LSP, as described in [RFC6107].

If the lower-layer network is a non-GMPLS domain, other methods may be used by the L-Controller(N) to create the H-LSP, which is out of scope of this document.

2) Dynamic (triggered) method

In this method, the signaling of LSP creation in the higher-layer network will trigger the creation of H-LSP in the lower-layer network dynamically, if it is necessary. Therefore, both the higher-layer and lower-layer networks need to support the RSVP-TE protocol and thus need to be GMPLS domains.

In this case, after the cross-layer path is computed, the Orchestrator(ML) requests the H-Controller(G) for the cross-layer

LSP creation. As a typical example, the MPI interface under the ACTN architecture could be used.

The H-Controller(G) can trigger the GMPLS control plane to create the LSP in the higher-layer network. As a typical example, the PCInitiate message can be used for the communication between the H-Controller(G) and the source node of the Higher-layer LSP, as described in Section 4.3 of [RFC8282]. At least two sets of ERO information should be included to indicate the routes of higher-layer LSP and lower-layer H-LSP.

The source node of the Higher-layer LSP follows the procedure defined in Section 4 of [RFC6001], to trigger the GMPLS control plane in both higher-layer network and lower-layer network to create the higher-layer LSP and the lower-layer H-LSP.

On success, the source node of the H-LSP should report the information of the H-LSP to the L-Controller(G) via, for example, PCRpt message.

7.3.3. Link Discovery

If the higher-layer network and the lower-layer network are under the same GMPLS control plane instance, the H-LSP can be a Forwarding Adjacency LSP (FA-LSP). Then the information of the link constructed by this FA-LSP, called Forwarding Adjacency (FA), can be advertised in the routing instance, so that the H-Controller can be aware of this new FA. [RFC4206] and the following updates to it (including [RFC6001] and [RFC6107]) describe the detail extensions to support advertisement of an FA.

If the higher-layer network and the lower-layer network are under separate GMPLS control plane instances, or one of the layer networks is a non-GMPLS domain, after an H-LSP is created in the lower-layer network, the link discovery procedure will be triggered in the higher-layer network to discover the information of the link constructed by the H-LSP. LMP protocol defined in [RFC4204] can be used if the higher-layer network supports GMPLS. The information of this new link will be advertised to the H-Controller.

7.4. Recovery

The GMPLS recovery functions are described in [RFC4426]. Span protection, end-to-end protection and restoration, are discussed with different protection schemes and message exchange requirements. Related RSVP-TE extensions to support end-to-end recovery is described in [RFC4872]. The extensions in [RFC4872] include protection, restoration, preemption, and rerouting mechanisms for an end-to-end LSP. Besides end-to-end recovery, a GMPLS segment recovery mechanism is defined in [RFC4873], which also intends to be compatible with Fast Reroute (FRR) (see [RFC4090] which defines RSVP-TE extensions for the FRR mechanism, and [RFC8271] which described the updates of GMPLS RSVP-TE protocol for FRR of GMPLS TE-LSPs).

7.4.1. Span Protection

Span protection refers to the protection of the link between two neighboring switches. The main protocol requirements include:

- Link management: Link property correlation on the link protection type;

- Routing: announcement of the link protection type;

- Signaling: indication of link protection requirement for that LSP.

GMPLS already supports the above requirements, and there are no new requirements in the scenario of interworking between GMPLS and centralized controller system.

7.4.2. LSP Protection

The LSP protection includes end-to-end and segment LSP protection. For both cases:

- In the provisioning phase:

  In both single-domain and multi-domain scenarios, the disjoint path computation can be done by the centralized controller system, as it has the global topology and resource view. And the path creation can be done by the procedure described in Section 7.2.

- In the protection switchover phase:

  In both single-domain and multi-domain scenarios, the existing standards provide the distributed way to trigger the protection switchover. For example, data plane Automatic Protection Switching (APS) mechanism described in [G.808.1], [RFC7271] and [RFC8234], or GMPLS Notify mechanism described in [RFC4872] and [RFC4873]. In the scenario of interworking between GMPLS and centralized controller system, using these distributed mechanisms rather than centralized mechanism (i.e., the controller triggers the protection switchover) can significantly shorten the protection switching time.

7.4.3. Single-domain LSP Restoration

- Pre-planned LSP protection (including shared-mesh restoration):

In pre-planned protection, the protecting LSP is established only in the control plane in the provisioning phase, and will be activated in the data plane once failure occurs.

In the scenario of interworking between GMPLS and centralized controller system, the route of protecting LSP can be computed by the centralized controller system. This takes the advantage of making better use of network resource, especially for the resource sharing in shared-mesh restoration.

- Full LSP rerouting:

  In full LSP rerouting, the normal traffic will be switched to an alternate LSP that is fully established only after failure occurrence.

  As described in [RFC4872] and [RFC4873], the alternate route can be computed on demand when failure occurrence, or pre-computed and stored before failure occurrence.

  In a fully distributed scenario, the pre-computation method offers faster restoration time, but has the risk that the pre-computed alternate route may become out of date due to the changes of the network.

  In the scenario of interworking between GMPLS and centralized controller system, the pre-computation of the alternate route could be taken place in the centralized controller (and may be stored in the controller or the head-end node of the LSP). In this way, any changes in the network can trigger the refreshment of the alternate route by the centralized controller. This makes sure that the alternate route will not become out of date.

7.4.4. Multi-domain LSP Restoration

A working LSP may traverse multiple domains, each of which may or may not support GMPLS distributed control plane.

In the case that all the domains support GMPLS, both the end-to-end rerouting method and the domain segment rerouting method could be used.

In the case that only some of the domains support GMPLS, the domain segment rerouting method could be used in those GMPLS domains. For other domains which do not support GMPLS, other mechanisms may be used to protect the LSP segments, which are out of scope of this document.

1) End-to-end rerouting:

In this case, failure occurs on the working LSP inside any domain or on the inter-domain links will trigger the end-to-end restoration.

In both pre-planned and full LSP rerouting, the end-to-end protecting LSP could be computed by the centralized controller system, and could be created by the procedure described in Section 7.2. Note that the end-to-end protecting LSP may traverse different domains from the working LSP, depending on the result of multi-domain path computation for the protecting LSP.

```
                       +----------------+
                       |Orchestrator(MD)|
                       +-------.--------+
          ............................................
          .             .              .             .
     +----V-----+  +----V-----+   +----V-----+  +----V-----+
     |Controller|  |Controller|   |Controller|  |Controller|
     |  (G) 1   |  |  (G) 2   |   |  (G) 3   |  |  (G) 4   |
     +----.-----+  +-------.--+   +-------.--+  +----.-----+
          .                .              .          .
     +----V--------+     +-V-----------+  .  +-------V-----+
     |  Domain 1   |     |  Domain 2   |  .  |  Domain 4   |
     |+---+   +---+|     |+---+   +---+|  .  |+---+   +---+|
     || ===/~/======/~~~/================================ ||
     |+-*-+   +---+|     |+---+   +---+|  .  |+---+   +-*-+|
     |  *          |     +-------------+  .  |          *  |
     |  *          |                      .  |          *  |
     |  *          |     +-------------+  .  |          *  |
     |  *          |     |  Domain 3   <...  |          *  |
     |+-*-+   +---+|     |+---+   +---+|     |+---+   +-*-+|
     || ************************************************* ||
     |+---+   +---+|     |+---+   +---+|     |+---+   +---+|
     +-------------+     +-------------+     +-------------+

     ====: Working LSP   ****: Protecting LSP   /~/: Failure
```

Figure 5: End-to-end restoration

2) Domain segment rerouting:

2.1) Intra-domain rerouting:

If failure occurs on the working LSP segment in a GMPLS domain, the segment rerouting ([RFC4873]) could be used for the working LSP segment in that GMPLS domain. Figure 6 shows an example of intra-domain rerouting.

The intra-domain rerouting of a non-GMPLS domain is out of scope of this document.

```
                       +----------------+
                       |Orchestrator(MD)|
                       +-------.--------+
          ............................................
          .             .              .             .
     +----V-----+  +----V-----+   +----V-----+  +----V-----+
     |Controller|  |Controller|   |Controller|  |Controller|
     |  (G) 1   |  |(G)/(N) 2 |   |(G)/(N) 3 |  |(G)/(N) 4 |
     +----.-----+  +-------.--+   +-------.--+  +----.-----+
          .                .              .          .
     +----V--------+     +-V-----------+  .  +-------V-----+
     |  Domain 1   |     |  Domain 2   |  .  |  Domain 4   |
     |+---+   +---+|     |+---+   +---+|  .  |+---+   +---+|
     || ===/~/=========================================== ||
     |+-*-+   +-*-+|     |+---+   +---+|  .  |+---+   +---+|
     |  *       *  |     +-------------+  .  |             |
     |  *       *  |                      .  |             |
     |  *       *  |     +-------------+  .  |             |
     |  *       *  |     |  Domain 3   <...  |             |
     |+-*-+   +-*-+|     |+---+   +---+|     |+---+   +---+|
     || ********* ||     ||   |   |   ||     ||   |   |   ||
     |+---+   +---+|     |+---+   +---+|     |+---+   +---+|
     +-------------+     +-------------+     +-------------+

     ====: Working LSP  ****: Rerouting LSP segment  /~/: Failure
```

Figure 6: Intra-domain segment rerouting

2.2) Inter-domain rerouting:

If intra-domain segment rerouting failed (e.g., due to lack of resource in that domain), or if failure occurs on the working LSP on an inter-domain link, the centralized controller system may coordinate with other domain(s), to find an alternative path or path segment to bypass the failure, and then trigger the inter-domain rerouting procedure. Note that the rerouting path or path segment may traverse different domains from the working LSP.

The domains involved in the inter-domain rerouting procedure need to be GMPLS domains, which support the RSVP-TE signaling for the creation of rerouting LSP segment.

For inter-domain rerouting, the interaction between GMPLS and centralized controller system is needed:

- Report of the result of intra-domain segment rerouting to its Controller(G), and then to the Orchestrator(MD). The former one could be supported by the PCRpt message in [RFC8231], while the latter one could be supported by the MPI interface of ACTN.

- Report of inter-domain link failure to the two Controllers (e.g., Controller(G) 1 and Controller(G) 2 in Figure 7) by which the two ends of the inter-domain link are controlled respectively, and then to the Orchestrator(MD). The former one could be done as described in Section 7.1 of this document, while the latter one could be supported by the MPI interface of ACTN.

- Computation of rerouting path or path segment crossing multi-domains by the centralized controller system (see [PAT-COMP]);

- Creation of rerouting LSP segment in each related domain. The Orchestrator(MD) can send the LSP segment rerouting request to the source Controller(G) (e.g., Controller(G) 1 in Figure 7) via MPI interface, and then the Controller(G) can trigger the creation of rerouting LSP segment through multiple GMPLS domains using GMPLS rerouting signaling. Note that the rerouting LSP segment may traverse a new domain which the working LSP does not traverse (e.g., Domain 3 in Figure 7).

```
                            +----------------+
                            |Orchestrator(MD)|
                            +-------.--------+
           ..................................................
           .               .                .               .
     +-----V------+  +-----V------+   +-----V------+  +-----V------+
     | Controller |  | Controller |   | Controller |  | Controller |
     |   (G) 1    |  |   (G) 2    |   |   (G) 3    |  | (G)/(N) 4  |
     +-----.------+  +------.-----+   +-----.------+  +-----.------+
           .                .               .               .
     +-----V-------+   +----V--------+      .        +------V------+
     |  Domain 1   |   |  Domain 2   |      .        |  Domain 4   |
     |+---+   +---+|   |+---+   +---+|      .        |+---+   +---+|
     ||   |   |   ||   ||   |   |   ||      .        ||   |   |   ||
     || ============/~/========================================== ||
     || * |   |   ||   ||   |   | * ||      .        ||   |   |   ||
     |+-*-+   +---+|   |+---+   +-*-+|      .        |+---+   +---+|
     |  *          |   +----------*--+      .        |             |
     |  *          |              *****     .        |             |
     |  *          |       +----------*-----V----+   |             |
     |  *          |       |          *Domain 3  |   |             |
     |+-*-+   +---+|       |+---+   +-*-+   +---+|   |+---+   +---+|
     || * |   |   ||       ||   |   | * |   |   ||   ||   |   |   ||
     || ******************************* |   |   ||   ||   |   |   ||
     ||   |   |   ||       ||   |   |   |   |   ||   ||   |   |   ||
     |+---+   +---+|       |+---+   +---+   +---+|   |+---+   +---+|
     +-------------+       +---------------------+   +-------------+

      ====: Working LSP  ****: Rerouting LSP segment  /~/: Failure
```

Figure 7: Inter-domain segment rerouting

7.4.5. Fast Reroute

[RFC4090] defines two methods of fast reroute, the one-to-one backup method and the facility backup method. For both methods:

1) Path computation of protecting LSP:

In Section 6.2 of [RFC4090], the protecting LSP (detour LSP in one-to-one backup, or bypass tunnel in facility backup) could be computed by the Point of Local Repair (PLR) using, for example, Constraint-based Shortest Path First (CSPF) computation. In the scenario of interworking between GMPLS and centralized controller system, the protecting LSP could also be computed by the centralized controller system, as it has the global view of the network topology, resource and information of LSPs.

2) Protecting LSP creation:

In the scenario of interworking between GMPLS and centralized controller system, the Protecting LSP could still be created by the RSVP-TE signaling protocol as described in [RFC4090] and [RFC8271].

In addition, if the protecting LSP is computed by the centralized controller system, the Secondary Explicit Route Object defined in [RFC4873] could be used to explicitly indicate the route of the protecting LSP.

3) Failure detection and traffic switchover:

If a PLR detects that failure occurs, it may significantly shorten the protection switching time by using the distributed mechanisms described in [RFC4090] to switch the traffic to the related detour LSP or bypass tunnel, rather than in a centralized way.

7.5. Controller Reliability

Given the important role in the network, the reliability of controller is critical. If the controller is shut down or disconnected from the network, it is highly desirable that all of the services currently provisioned in the network continue to function and carry traffic. Furthermore, protection switching to pre-established paths should also function. Additionally, it is desirable to provide protection mechanisms, such as redundancy, so that full operational control can be maintained even when one instance of the controller fails. This can be either achieved by controller back up or functionality back up. There are several of controller backup or federation mechanisms in the literature. It is also more reliable to have some function back up in the network element, to guarantee the performance in the network.

8. Manageability Considerations

Each entity in the network, including both controllers and network elements, should be managed properly as it will interact with other entities. The manageability considerations in controller hierarchies and network elements still apply respectively. For the protocols applied in the network, manageability is also requested.

The responsibility of each entity should be clarified. The control of function and policy among different controllers should be consistent via proper negotiation process.

9. Security Considerations

This document provides the interwork between the GMPLS and controller hierarchies. The security requirements in both system still applies respectively. Protocols referenced in this document also have various security considerations, which is also expected to be satisfied.

Other considerations on the interface between the controller and the network element are also important. Such security includes the functions to authenticate and authorize the control access to the controller from multiple network elements. Security mechanisms on the controller are also required to safeguard the underlying network elements against attacks on the control plane and/or unauthorized usage of data transport resources.

10. IANA Considerations

This document requires no IANA actions.

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12. Contributors

Xianlong Luo
Huawei Technologies
G1, Huawei Xiliu Beipo Village, Songshan Lake
Dongguan
Guangdong, 523808 China
Email: luoxianlong@huawei.com

Sergio Belotti
Nokia
Email: sergio.belotti@nokia.com

13. Authors' Addresses

Haomian Zheng
Huawei Technologies
H1, Huawei Xiliu Beipo Village, Songshan Lake
Dongguan
Guangdong, 523808 China
Email: zhenghaomian@huawei.com

Yunbin Xu
CAICT
Email: xuyunbin@caict.ac.cn

Yang Zhao
China Mobile
Email: zhaoyangyjy@chinamobile.com

Dieter Beller
Nokia
Email: Dieter.Beller@nokia.com

Yi Lin
Huawei Technologies
H1, Huawei Xiliu Beipo Village, Songshan Lake
Dongguan
Guangdong, 523808 China
Email: yi.lin@huawei.com