Network Working Group
Internet Draft
Category: Informational
Expires: February 25, 2013
August 25, 2012

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Framework for GMPLS and PCE Control of G.709 Optical Transport Networks

draft-ietf-ccamp-gmpls-g709-framework-09.txt

Status of this Memo

Abstract

This document provides a framework to allow the development of protocol extensions to support Generalized Multi-Protocol Label Switching (GMPLS) and Path Computation Element (PCE) control of

Optical Transport Networks (OTN) as specified in ITU-T Recommendation G.709 as consented in October 2009.

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1. Introduction

OTN has become a mainstream layer 1 technology for the transport network. Operators want to introduce control plane capabilities based on Generalized Multi-Protocol Label Switching (GMPLS) to OTN networks, to realize the benefits associated with a high-function control plane (e.g., improved network resiliency, resource usage efficiency, etc.).

GMPLS extends MPLS to encompass time division multiplexing (TDM) networks (e.g., SONET/SDH, PDH, and G.709 sub-lambda), lambda switching optical networks, and spatial switching (e.g., incoming

port or fiber to outgoing port or fiber). The GMPLS architecture is provided in [RFC3945], signaling function and Resource ReserVation Protocol-Traffic Engineering (RSVP-TE) extensions are described in [RFC3471] and [RFC3473], routing and OSPF extensions are described in [RFC4202] and [RFC4203], and the Link Management Protocol (LMP) is described in [RFC4204].

The GMPLS protocol suite including provision [RFC4328] provides the mechanisms for basic GMPLS control of OTN networks based on the 2001 revision of the G.709 specification [G709-V1]. Later revisions of the G.709 specification, including [G709-V3], have included some new features; for example, various multiplexing structures, two types of TSs (i.e., 1.25Gbps and 2.5Gbps), and extension of the Optical Data Unit (ODU) ODUj definition to include the ODUflex function.

This document reviews relevant aspects of OTN technology evolution that affect the GMPLS control plane protocols and examines why and how to update the mechanisms described in [RFC4328]. This document additionally provides a framework for the GMPLS control of OTN networks and includes a discussion of the implication for the use of the Path Computation Element (PCE) [RFC4655].

For the purposes of the control plane the OTN can be considered as being comprised of ODU and wavelength (OCh) layers. This document focuses on the control of the ODU layer, with control of the wavelength layer considered out of the scope. Please refer to [RFC6163] for further information about the wavelength layer.

2. Terminology

OTN: Optical Transport Network

ODU: Optical Channel Data Unit

OTU: Optical channel transport unit

OMS: Optical multiplex section

MSI: Multiplex Structure Identifier

TPN: Tributary Port Number

LO ODU: Lower Order ODU. The LO ODUj (j can be 0, 1, 2, 2e, 3, 4, flex.) represents the container transporting a client of the OTN that

is either directly mapped into an OTUk (k = j) or multiplexed into a server HO ODUk (k > j) container.

HO ODU: Higher Order ODU. The HO ODUk (k can be 1, 2, 2e, 3, 4.) represents the entity transporting a multiplex of LO ODUj tributary signals in its OPUk area.

ODUflex: Flexible ODU. A flexible ODUk can have any bit rate and a bit rate tolerance up to +/-100 ppm.

3. G.709 Optical Transport Network (OTN)

This section provides an informative overview of those aspects of the OTN impacting control plane protocols. This overview is based on the ITU-T Recommendations that contain the normative definition of the OTN. Technical details regarding OTN architecture and interfaces are provided in the relevant ITU-T Recommendations.

Specifically, [G872-2001] and [G872Am2] describe the functional architecture of optical transport networks providing optical signal transmission, multiplexing, routing, supervision, performance assessment, and network survivability. [G709-V1] defines the interfaces of the optical transport network to be used within and between subnetworks of the optical network. With the evolution and deployment of OTN technology many new features have been specified in ITU-T recommendations, including for example, new ODU0, ODU2e, ODU4 and ODUflex containers as described in [G709-V3].

3.1. OTN Layer Network

The simplified signal hierarchy of OTN is shown in Figure 1, which illustrates the layers that are of interest to the control plane. Other layers below OCh (e.g. Optical Transmission Section - OTS) are not included in this Figure. The full signal hierarchy is provided in [G709-V3].

```
Client signal
     |
    ODUj
     |
  OTU/OCh
    OMS
```

Figure 1 - Basic OTN signal hierarchy

Client signals are mapped into ODUj containers. These ODUj containers are multiplexed onto the OTU/OCh. The individual OTU/OCh signals are combined in the Optical Multiplex Section (OMS) using WDM multiplexing, and this aggregated signal provides the link between the nodes.

3.1.1. Client signal mapping

The client signals are mapped into a Low Order (LO) ODUj. Appendix A gives more information about LO ODU.

The current values of j defined in [G709-V3] are: 0, 1, 2, 2e, 3, 4, Flex. The approximate bit rates of these signals are defined in [G709-V3] and are reproduced in Tables 1 and 2.

ODU Type	ODU nominal bit rate
ODU0	1 244 160 kbits/s
ODU1	239/238 x 2 488 320 kbit/s
ODU2	239/237 x 9 953 280 kbit/s
ODU3	239/236 x 39 813 120 kbit/s
ODU4	239/227 x 99 532 800 kbit/s
ODU2e	239/237 x 10 312 500 kbit/s
ODUflex for CBR Client signals	239/238 x client signal bit rate
ODUflex for GFP-F Mapped client signal	Configured bit rate

Table 1 - ODU types and bit rates

NOTE - The nominal ODUk rates are approximately: 2 498 775.126 kbit/s (ODU1), 10 037 273.924 kbit/s (ODU2), 40 319 218.983 kbit/s (ODU3), 104 794 445.815 kbit/s (ODU4) and 10 399 525.316 kbit/s (ODU2e).

ODU Type	ODU bit-rate tolerance
ODU0	+- 20 ppm
ODU1	+- 20 ppm
ODU2	+- 20 ppm
ODU3	+- 20 ppm
ODU4	+- 20 ppm
ODU2e	+- 100 ppm
ODUflex for CBR Client signals	+- 100 ppm
ODUflex for GFP-F Mapped client signal	+- 100 ppm

Table 2 - ODU types and tolerance

One of two options is for mapping client signals into ODUflex depending on the client signal type:

- Circuit clients are proportionally wrapped. Thus the bit rate and tolerance are defined by the client signal.

- Packet clients are mapped using the Generic Framing Procedure (GFP). [G709-V3] recommends that the ODUflex(GFP) will fill an integral number of tributary slots of the smallest HO ODUk path over which the ODUflex(GFP) may be carried, and the tolerance should be +/-100ppm.

3.1.2. Multiplexing ODUj onto Links

The links between the switching nodes are provided by one or more wavelengths. Each wavelength carries one OCh, which carries one OTU, which carries one ODU. Since all of these signals have a 1:1:1 relationship, we only refer to the OTU for clarity. The ODUjs are mapped into the TS of the OPUk. Note that in the case where j=k the ODUj is mapped into the OTU/OCh without multiplexing.

The initial versions of G.709 [G709-V1] only provided a single TS granularity, nominally 2.5Gb/s. [G709-V3], approved in 2009, added an additional TS granularity, nominally 1.25Gb/s. The number and type of

TSs provided by each of the currently identified OTUk is provided below:

	2.5Gb/s	1.25Gb/s	Nominal Bit rate
OTU1	1	2	2.5Gb/s
OTU2	4	8	10Gb/s
OTU3	16	32	40Gb/s
OTU4	--	80	100Gb/s

To maintain backwards compatibility while providing the ability to interconnect nodes that support 1.25Gb/s TS at one end of a link and 2.5Gb/s TS at the other, the 'new' equipment will fall back to the use of a 2.5Gb/s TS if connected to legacy equipment. This information is carried in band by the payload type.

The actual bit rate of the TS in an OTUk depends on the value of k. Thus the number of TS occupied by an ODUj may vary depending on the values of j and k. For example an ODU2e uses 9 TS in an OTU3 but only 8 in an OTU4. Examples of the number of TS used for various cases are provided below:

- ODU0 into ODU1, ODU2, ODU3 or ODU4 multiplexing with 1,25Gbps TS granularity
  - o ODU0 occupies 1 of the 2, 8, 32 or 80 TS for ODU1, ODU2, ODU3 or ODU4
- ODU1 into ODU2, ODU3 or ODU4 multiplexing with 1,25Gbps TS granularity
  - o ODU1 occupies 2 of the 8, 32 or 80 TS for ODU2, ODU3 or ODU4

- ODU1 into ODU2, ODU3 multiplexing with 2.5Gbps TS granularity
  - o ODU1 occupies 1 of the 4 or 16 TS for ODU2 or ODU3

- ODU2 into ODU3 or ODU4 multiplexing with 1.25Gbps TS granularity
  - o ODU2 occupies 8 of the 32 or 80 TS for ODU3 or ODU4

- ODU2 into ODU3 multiplexing with 2.5Gbps TS granularity
  - o ODU2 occupies 4 of the 16 TS for ODU3

- ODU3 into ODU4 multiplexing with 1.25Gbps TS granularity
  - o ODU3 occupies 31 of the 80 TS for ODU4

- ODUflex into ODU2, ODU3 or ODU4 multiplexing with 1.25Gbps TS granularity o ODUflex occupies n of the 8, 32 or 80 TS for ODU2, ODU3 or ODU4 (n <= Total TS numbers of ODUk)

- ODU2e into ODU3 or ODU4 multiplexing with 1.25Gbps TS granularity
  o ODU2e occupies 9 of the 32 TS for ODU3 or 8 of the 80 TS for ODU4

In general the mapping of an ODUj (including ODUflex) into the OTUk TSs is determined locally, and it can also be explicitly controlled by a specific entity (e.g., head end, NMS) through Explicit Label Control [RFC3473].

3.1.2.1. Structure of MSI information

When multiplexing an ODUj into a HO ODUk (k>j), G.709 specifies the information that has to be transported in-band in order to allow for correct demultiplexing. This information, known as Multiplex Structure Information (MSI), is transported in the OPUk overhead and is local to each link. In case of bidirectional paths the association between TPN and TS must be the same in both directions.

The MSI information is organized as a set of entries, with one entry for each HO ODUj TS. The information carried by each entry is:

- Payload Type: the type of the transported payload.

- Tributary Port Number (TPN): the port number of the ODUj transported by the HO ODUk. The TPN is the same for all the TSs assigned to the transport of the same ODUj instance.

For example, an ODU2 carried by a HO ODU3 is described by 4 entries in the OPU3 overhead when the TS size is 2.5 Gbit/s, and by 8 entries when the TS size is 1.25 Gbit/s.

On each node and on every link, two MSI values have to be provisioned:

- The TxMSI information inserted in OPU (e.g., OPU3) overhead by the source of the HO ODUk trail.

- The expectedMSI information that is used to check the acceptedMSI information. The acceptedMSI information is the MSI valued received in-band, after a 3 frames integration.

The sink of the HO ODU trail checks the complete content of the acceptedMSI information against the expectedMSI.

If the acceptedMSI is different from the expectedMSI, then the traffic is dropped and a payload mismatch alarm is generated.

Provisioning of TPN can be performed either by network management system or control plane. In the last case, control plane is also responsible for negotiating the provisioned values on a link by link base.

4. Connection management in OTN

OTN-based connection management is concerned with controlling the connectivity of ODU paths and optical channels (OCh). This document focuses on the connection management of ODU paths. The management of OCh paths is described in [RFC6163].

While [G872-2001] considered the ODU as a set of layers in the same way as SDH has been modeled, recent ITU-T OTN architecture progress [G872-Am2] includes an agreement to model the ODU as a single layer network with the bit rate as a parameter of links and connections. This allows the links and nodes to be viewed in a single topology as a common set of resources that are available to provide ODUj connections independent of the value of j. Note that when the bit rate of ODUj is less than the server bit rate, ODUj connections are supported by HO-ODU (which has a one-to-one relationship with the OTU).

From an ITU-T perspective, the ODU connection topology is represented by that of the OTU link layer, which has the same topology as that of the OCh layer (independent of whether the OTU supports HO-ODU, where multiplexing is utilized, or LO-ODU in the case of direct mapping). Thus, the OTU and OCh layers should be visible in a single topological representation of the network, and from a logical perspective, the OTU and OCh may be considered as the same logical, switchable entity.

Note that the OTU link layer topology may be provided via various infrastructure alternatives, including point-to-point optical connections, flexible optical connections fully in the optical domain, flexible optical connections involving hybrid sub-lambda/lambda nodes involving 3R, etc.

The document will be updated to maintain consistency with G.872 progress when it is consented for publication.

4.1. Connection management of the ODU

LO ODUj can be either mapped into the OTUk signal (j = k), or multiplexed with other LO ODUjs into an OTUk (j < k), and the OTUk is mapped into an OCh. See Appendix A for more information.

From the perspective of control plane, there are two kinds of network topology to be considered.

(1) ODU layer

In this case, the ODU links are presented between adjacent OTN nodes, which is illustrated in Figure 2. In this layer there are ODU links with a variety of TSs available, and nodes that are ODXCs. Lo ODU connections can be setup based on the network topology.

```
                  Link #5       +--+---+--+        Link #4
     +--------------------------|         |--------------------------+
     |                          |  ODXC   |                          |
     |                          +---------+                          |
     |                             Node E                            |
     |                                                               |
   +-++---+--+        +--+---+--+        +--+---+--+        +--+---+-++
   |         |Link #1 |         |Link #2 |         |Link #3 |         |
   |         |--------|         |--------|         |--------|         |
   |  ODXC   |        |  ODXC   |        |  ODXC   |        |  ODXC   |
   +---------+        +---------+        +---------+        +---------+
      Node A             Node B              Node C            Node D
```

Figure 2 - Example Topology for LO ODU connection management

If an ODUj connection is requested between Node C and Node E routing/path computation must select a path that has the required number of TS available and that offers the lowest cost. Signaling is then invoked to set up the path and to provide the information (e.g., selected TS) required by each transit node to allow the configuration of the ODUj to OTUk mapping (j = k) or multiplexing (j < k), and demapping (j = k) or demultiplexing (j < k).

(2) ODU layer with OCh switching capability

In this case, the OTN nodes interconnect with wavelength switched node (e.g., ROADM, OXC) that are capable of OCh switching, which is illustrated in Figure 3 and Figure 4. There are ODU layer and OCh layer, so it is simply a MLN. OCh connections may be created on demand, which is described in section 5.1.

In this case, an operator may choose to allow the underlined OCh layer to be visible to the ODU routing/path computation process in which case the topology would be as shown in Figure 4. In Figure 3 below, instead, a cloud representing OCH capable switching nodes is represented. In Figure 3, the operator choice is to hide the real RWA network topology.

```
                             Node E
      Link #5              +--------+       Link #4
  +------------------------|        |------------------------+
  |                          ------                          |
  |                       //        \\                       |
  |                      ||          ||                      |
  |                      | RWA domain |                      |
+-+-----+        +------ ||          || ------+        +-----+-+
|       |        |        \\        //        |        |       |
|       |Link #1 |          --------          |Link #3 |       |
|       +--------+         |        |         +--------+       +
| ODXC  |        |  ODXC   +--------+  ODXC   |        | ODXC  |
+-------+        +---------+Link #2 +---------+        +-------+
  Node A            Node B             Node C            Node D
```

Figure 3 - RWA Hidden Topology for LO ODU connection management

```
        Link #5            +---------+            Link #4
  +------------------------|         |-----------------------+
  |                   +----| ODXC    |----+                  |
  |                 +-++   +---------+   ++-+                |
  |         Node f  |  |     Node E      |  |  Node g        |
  |                 +-++                 ++-+                |
  |                   |       +--+        |                  |
+-+-----+        +----+----+--|  |--+-----+---+        +-----+-+
|       |Link #1 |         |  +--+  |         |Link #3 |       |
|       +--------+         | Node h |         +--------+       |
| ODXC  |        | ODXC    +--------+ ODXC    |        | ODXC  |
+-------+        +---------+ Link #2+---------+        +-------+
  Node A            Node B            Node C             Node D
```

Figure 4 - RWA Visible Topology for LO ODUj connection management

In Figure 4, the cloud of previous figure is substitute by the real topology. The nodes f, g, h are nodes with OCH switching capability.

In the examples (i.e., Figure 3 and Figure 4), we have considered the case in which LO-ODUj connections are supported by OCh connection, and the case in which the supporting underlying connection can be also made by a combination of HO-ODU/OCh connections.

In this case, the ODU routing/path selection process will request an HO-ODU/OCh connection between node C and node E from the RWA domain. The connection will appear at ODU level as a Forwarding Adjacency, which will be used to create the ODU connection.

5. GMPLS/PCE Implications

The purpose of this section is to provide a set of requirements to be evaluated for extensions of the current GMPLS protocol suite and the PCE applications and protocols to encompass OTN enhancements and connection management.

5.1. Implications for LSP Hierarchy with GMPLS TE

The path computation for ODU connection request is based on the topology of ODU layer, including OCh layer visibility.

The OTN path computation can be divided into two layers. One layer is OCh/OTUk, the other is ODUj. [RFC4206] and [RFC6107] define the mechanisms to accomplish creating the hierarchy of LSPs. The LSP management of multiple layers in OTN can follow the procedures defined in [RFC4206], [RFC6107] and related MLN drafts.

As discussed in section 4, the route path computation for OCh is in the scope of WSON [RFC6163]. Therefore, this document only considers ODU layer for ODU connection request.

LSP hierarchy can also be applied within the ODU layers. One of the typical scenarios for ODU layer hierarchy is to maintain compatibility with introducing new [G709-V3] services (e.g., ODU0, ODUflex) into a legacy network configuration (containing [G709-V1] or [G709-V2] OTN equipment). In this scenario, it may be needed to consider introducing hierarchical multiplexing capability in specific network transition scenarios. One method for enabling multiplexing hierarchy is by introducing dedicated boards in a few specific places in the network and tunneling these new services through [G709-V1] or [G709-V2] containers (ODU1, ODU2, ODU3), thus postponing the need to upgrade every network element to [G709-V3] capabilities.

In such case, one ODUj connection can be nested into another ODUk (j<k) connection, which forms the LSP hierarchy in ODU layer. The creation of the outer ODUk connection can be triggered via network planning, or by the signaling of the inner ODUj connection. For the former case, the outer ODUk connection can be created in advance based on network planning. For the latter case, the multi-layer network signaling described in [RFC4206], [RFC6107] and [RFC6001] (including related modifications, if needed) are relevant to create the ODU connections with multiplexing hierarchy. In both cases, the outer ODUk connection is advertised as a Forwarding Adjacency (FA).

5.2. Implications for GMPLS Signaling

The signaling function and Resource reSerVation Protocol-Traffic Engineering (RSVP-TE) extensions are described in [RFC3471] and [RFC 3473]. For OTN-specific control, [RFC4328] defines signaling extensions to support G.709 Optical Transport Networks Control as defined in [G709-V1].

As described in Section 3, [G709-V3] introduced some new features that include the ODU0, ODU2e, ODU4 and ODUflex containers. The mechanisms defined in [RFC4328] do not support such new OTN features, and protocol extensions will be necessary to allow them to be controlled by a GMPLS control plane.

[RFC4328] defines the LSP Encoding Type, the Switching Type and the Generalized Protocol Identifier (Generalized-PID) constituting the common part of the Generalized Label Request. The G.709 Traffic Parameters are also defined in [RFC4328]. The following signaling aspects should be considered additionally since [RFC4328] was published:

- Support for specifying the new signal types and the related traffic information

  The traffic parameters should be extended in signaling message to support the new optical Channel Data Unit (ODUj) including:

  - ODU0
  - ODU2e
  - ODU4
  - ODUflex

  For ODUflex, since it has a variable bandwidth/bit rate BR and a bit rate tolerance T, the (node local) mapping process should be aware of the bit rate and tolerance of the ODUj being multiplexed in order to select the correct number of TS and the fixed/variable

stuffing bytes. Therefore, bit rate and bit rate tolerance should also be carried in the Traffic Parameter in the signaling of connection setup request.

For other ODU signal types, the bit rates and tolerances of them are fixed and can be deduced from the signal types.

- Support for LSP setup using different Tributary Slot Granularity (TSG)

  The signaling protocol should be able to identify the type of TS (i.e., the 2.5 Gbps TS granularity and the new 1.25 Gbps TS granularity) to be used for establishing an H-LSP which will be used to carry service LSP(s) requiring specific TS type.

- Support for LSP setup of new ODUk/ODUflex containers with related mapping and multiplexing capabilities

  New label must be defined to carry the exact TS allocation information related to the extended mapping and multiplexing hierarchy (For example, ODU0 into ODU2 multiplexing (with 1.25Gbps TS granularity)), in order to setting up the ODU connection.

- Support for Tributary Port Number allocation and negotiation

  Tributary Port Number needs to be configured as part of the MSI information (See more information in Section 3.1.2.1). A new extension object has to be defined to carry TPN information if control plane is used to configure MSI information.

- Support for ODU Virtual Concatenation (VCAT) and Link Capacity Adjustment Scheme (LCAS)

  GMPLS signaling should support the creation of Virtual Concatenation of ODUk signal with k=1, 2, 3. The signaling should also support the control of dynamic capacity changing of a VCAT container using LCAS ([G.7042]). [RFC6344] has a clear description of VCAT and LCAS control in SONET/SDH and OTN networks.

- Support for Control of Hitless Adjustment of ODUflex (GFP)

  [G.7044] has been created in ITU-T to specify hitless adjustment of ODUflex (GFP) (HAO) that is used to increase or decrease the bandwidth of an ODUflex (GFP) that is transported in an OTN network.

The procedure of ODUflex (GFP) adjustment requires the participation of every node along the path. Therefore, it is recommended to use the control plane signaling to initiate the adjustment procedure in order to avoid the manual configuration at each node along the path.

From the perspective of control plane, the control of ODUflex resizing is similar to control of bandwidth increasing and decreasing described in [RFC3209]. Therefore, the SE style can be used for control of HAO.

All the extensions above should consider the extensibility to match future evolvement of OTN.

5.3. Implications for GMPLS Routing

The path computation process needs to select a suitable route for an ODUj connection request. In order to perform the path computation, it needs to evaluate the available bandwidth on each candidate link. The routing protocol should be extended to convey some information to represent ODU TE topology.

GMPLS Routing [RFC4202] defines Interface Switching Capability Descriptor of TDM which can be used for ODU. However, some issues discussed below, should also be considered.

Interface Switching Capability Descriptors present a new constraint for LSP path computation. [RFC4203] defines the switching capability and related Maximum LSP Bandwidth and the Switching Capability specific information. When the Switching Capability field is TDM the Switching Capability Specific Information field includes Minimum LSP Bandwidth, an indication whether the interface supports Standard or Arbitrary SONET/SDH, and padding. Hence a new Switching Capability value needs to be defined for [G709-V3] ODU switching in order to allow the definition of a new Switching Capability Specific Information field definition. The following requirements should be considered:

- Support for carrying the link multiplexing capability

  As discussed in section 3.1.2, many different types of ODUj can be multiplexed into the same OTUk. For example, both ODU0 and ODU1 may be multiplexed into ODU2. An OTU link may support one or more types of ODUj signals. The routing protocol should be capable of carrying this multiplexing capability.

- Support any ODU and ODUflex

The bit rate (i.e., bandwidth) of TS is dependent on the TS granularity and the signal type of the link. For example, the bandwidth of a 1.25G TS in an OTU2 is about 1.249409620 Gbps, while the bandwidth of a 1.25G TS in an OTU3 is about 1.254703729 Gbps.

One LO ODU may need different number of TSs when multiplexed into different HO ODUs. For example, for ODU2e, 9 TSs are needed when multiplexed into an ODU3, while only 8 TSs are needed when multiplexed into an ODU4. For ODUflex, the total number of TSs to be reserved in a HO ODU equals the maximum of [bandwidth of ODUflex / bandwidth of TS of the HO ODU].

Therefore, the routing protocol should be capable of carrying the necessary and sufficient link bandwidth information for performing accurate route computation for any of the fixed rate ODUs as well as ODUflex.

- Support for differentiating between terminating and switching capability

  Due to internal constraints and/or limitations, the type of signal being advertised by an interface could be just switched (i.e. forwarded to switching matrix without multiplexing/demultiplexing actions), just terminated (demuxed) or both of them. The capability advertised by an interface needs further distinction in order to separate termination and switching capabilities.

  Therefore, to allow the required flexibility, the routing protocol should clearly distinguish the terminating and switching capability.

- Support for Tributary Slot Granularity advertisement

  [G709-V3] defines two types of TS but each link can only support a single type at a given time. In order to perform a correct path computation (i.e. the LSP end points have matching Tributary Slot Granularity values) the Tributary Slot Granularity needs to be advertised.

- Support different priorities for resource reservation

  How many priorities levels should be supported depends on the operator's policy. Therefore, the routing protocol should be capable of supporting either no priorities or up to 8 priority levels as defined in [RFC4202].

- Support link bundling

  Link bundling can improve routing scalability by reducing the amount of TE links that has to be handled by routing protocol. The routing protocol should be capable of supporting bundling multiple OTU links, at the same line rate and muxing hierarchy, between a pair of nodes as a TE link. Note that link bundling is optional and is implementation dependent.

- Support for Control of Hitless Adjustment of ODUflex (GFP)

  The control plane should support hitless adjustment of ODUflex, so the routing protocol should be capable of differentiating whether an ODU link can support hitless adjustment of ODUflex (GFP) or not, and how much resource can be used for resizing. This can be achieved by introducing a new signal type "ODUflex(GFP-F), resizable" that implies the support for hitless adjustment of ODUflex (GFP) by that link.

As mentioned in Section 5.1, one method of enabling multiplexing hierarchy is via usage of dedicated boards to allow tunneling of new services through legacy ODU1, ODU2, ODU3 containers. Such dedicated boards may have some constraints with respect to switching matrix access; detection and representation of such constraints is for further study.

5.4. Implications for Link Management Protocol (LMP)

As discussed in section 5.3, Path computation needs to know the interface switching capability of links. The switching capability of two ends of the link may be different, so the link capability of two ends should be correlated.

The Link Management Protocol (LMP) [RFC4204] provides a control plane protocol for exchanging and correlating link capabilities.

It is not necessary to use LMP to correlate link-end capabilities if the information is available from another source such as management configuration or automatic discovery/negotiation within the data plane.

Note that LO ODU type information can be, in principle, discovered by routing. Since in certain case, routing is not present (e.g. UNI case) we need to extend link management protocol capabilities to cover this aspect. In case of routing presence, the discovering procedure by LMP could also be optional.

- Correlating the granularity of the TS

  As discussed in section 3.1.2, the two ends of a link may support different TS granularity. In order to allow interconnection the node with 1.25Gb/s granularity should fall back to 2.5Gb/s granularity.

  Therefore, it is necessary for the two ends of a link to correlate the granularity of the TS. This ensures the correct use and of the TE link.

- Correlating the supported LO ODU signal types and multiplexing hierarchy capability

  Many new ODU signal types have been introduced in [G709-V3], such as ODU0, ODU4, ODU2e and ODUflex. It is possible that equipment does not support all the LO ODU signal types introduced by those new standards or drafts. Furthermore, since multiplexing hierarchy is not allowed before [G709-V3], it is possible that only one end of an ODU link can support multiplexing hierarchy capability, or the two ends of the link support different multiplexing hierarchy capabilities (e.g., one end of the link supports ODU0 into ODU1 into ODU3 multiplexing while the other end supports ODU0 into ODU2 into ODU3 multiplexing).

  For the control and management consideration, it is necessary for the two ends of an HO ODU link to correlate which types of LO ODU can be supported and what multiplexing hierarchy capabilities can be provided by the other end.

5.5. Implications for Control Plane Backward Compatibility

With the introduction of G709-v3, there may be OTN networks composed of a mixture of nodes, some of which support [G709-V1] and run control plane protocols defined in [RFC4328], while others support [G709-V3] and new OTN control plane characterized in this document. Note that a third case, for the sake of completeness, consists on G709-V1 nodes with a new OTN control plane, but such nodes can be considered as new nodes with limited capabilities.

This section discusses the compatibility of nodes implementing the control plane procedures defined [RFC4328], in support of [G709-V1], and the control plane procedures defined to support [G709-V3], as outlined by this document.

Compatibility needs to be considered only when controlling ODU1 or ODU2 or ODU3 connection, because [G709-V1] only support these three

ODU signal types. In such cases, there are several possible options including:

- A node supporting [G709-V3] could support only the [G709-V3] related control plane procedures, in which case both types of nodes would be unable to jointly control an LSP for an ODU type that both nodes support in the data plane. Note that this case is supported by the procedures defined in [RFC3473] as a different Switching Capability/Type value is used for the different control plane versions.

- A node supporting [G709-V3] could support both the [G709-V3] related control plane and the control plane defined in [RFC4328].

    o Such a node could identify which set of procedure to follow when initiating an LSP based on the Switching Capability value advertised in routing.

    o Such a node could follow the set of procedures based on the Switching Type received in signaling messages from an upstream node.

    o Such a node, when processing a transit LSP, could select which signaling procedures to follow based on the Switching Capability value advertised in routing by the next hop node.

5.6. Implications for Path Computation Elements

[PCE-APS] describes the requirements for GMPLS applications of PCE in order to establish GMPLS LSP. PCE needs to consider the GMPLS TE attributes appropriately once a PCC or another PCE requests a path computation. The TE attributes which can be contained in the path calculation request message from the PCC or the PCE defined in [RFC5440] includes switching capability, encoding type, signal type, etc.

As described in section 5.2.1, new signal types and new signals with variable bandwidth information need to be carried in the extended signaling message of path setup. For the same consideration, PCECP also has a desire to be extended to carry the new signal type and related variable bandwidth information when a PCC requests a path computation.

6. Data Plane Backward Compatibility Considerations

If TS auto-negotiation is supported, a node supporting 1.25Gbps TS can interwork with the other nodes that supporting 2.5Gbps TS by combining Specific TSs together in data plane. The control plane must support this TS combination.

```
                         Path
  +----------+   ------------>    +----------+
  |     TS1==|===========\--------+--TS1     |
  |     TS2==|=========\--\-------+--TS2     |
  |     TS3==|=======\--\--\------+--TS3     |
  |     TS4==|=====\--\--\--\-----+--TS4     |
  |          |      \  \  \  \----+--TS5     |
  |          |       \  \  \------+--TS6     |
  |          |        \  \--------+--TS7     |
  |          |         \----------+--TS8     |
  +----------+   <------------    +----------+
     node A          Resv            node B
```

Figure 5 - Interworking between 1.25Gbps TS and 2.5Gbps TS

Take Figure 5 as an example. Assume that there is an ODU2 link between node A and B, where node A only supports the 2.5Gbps TS while node B supports the 1.25Gbps TS. In this case, the TS#i and TS#i+4 (where i<=4) of node B are combined together. When creating an ODU1 service in this ODU2 link, node B reserves the TS#i and TS#i+4 with the granularity of 1.25Gbps. But in the label sent from B to A, it is indicated that the TS#i with the granularity of 2.5Gbps is reserved.

In the contrary direction, when receiving a label from node A indicating that the TS#i with the granularity of 2.5Gbps is reserved, node B will reserved the TS#i and TS#i+4 with the granularity of 1.25Gbps in its data plane.

7. Security Considerations

The use of control plane protocols for signaling, routing, and path computation opens an OTN to security threats through attacks on those protocols. The data plane technology for an OTN does not introduce any specific vulnerabilities, and so the control plane may be secured using the mechanisms defined for the protocols discussed.

For further details of the specific security measures refer to the documents that define the protocols ([RFC3473], [RFC4203], [RFC4205],

[RFC4204], and [RFC5440]). [RFC5920] provides an overview of security vulnerabilities and protection mechanisms for the GMPLS control plane.

8. IANA Considerations

This document makes not requests for IANA action.

9. Acknowledgments

We would like to thank Maarten Vissers and Lou Berger for their review and useful comments.

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APPENDIX A: ODU connection examples

This appendix provides a description of ODU terminology and connection examples. This section is not normative, and is just intended to facilitate understanding.

In order to transmit a client signal, an ODU connection needs to be created first. From the perspective of [G709-V3] and [G872-Am2], some types of ODUs (i.e., ODU1, ODU2, ODU3, ODU4) may assume either a client or server role within the context of a particular networking domain:

(1) An ODUj client that is mapped into an OTUk server. For example, if a STM-16 signal is encapsulated into ODU1, and then the ODU1 is mapped into OTU1, the ODU1 is a LO ODU (from a multiplexing perspective).

(2) An ODUj client that is mapped into an ODUk (j < k) server occupying several TSs. For example, if ODU1 is multiplexed into ODU2, and ODU2 is mapped into OTU2, the ODU1 is a LO ODU and the ODU2 is a HO ODU (from a multiplexing perspective).

Thus, a LO ODUj represents the container transporting a client of the OTN that is either directly mapped into an OTUk (k = j) or multiplexed into a server HO ODUk (k > j) container. Consequently, the HO ODUk represents the entity transporting a multiplex of LO ODUj tributary signals in its OPUk area.

In the case of LO ODUj mapped into an OTUk (k = j) directly, Figure 6 give an example of this kind of LO ODU connection.

In Figure 6, The LO ODUj is switched at the intermediate ODXC node. OCh and OTUk are associated with each other. From the viewpoint of connection management, the management of OTUk is similar with OCh. LO ODUj and OCh/OTUk have client/server relationships.

For example, one LO ODU1 connection can be setup between Node A and Node C. This LO ODU1 connection is to be supported by OCh/OTU1 connections, which are to be set up between Node A and Node B and between Node B and Node C. LO ODU1 can be mapped into OTU1 at Node A, demapped from it in Node B, switched at Node B, and then mapped into the next OTU1 and demapped from this OTU1 at Node C.

```
   |                            LO ODUj                         |
   +-----------------------------(b)--------------------------+
   |      |      OCh/OTUk      |     |    OCh/OTUk       |     |
   |      +---------(a)---------+     +---------(a)---------+     |
   |      |                    |     |                   |     |
  +------++-+                 +--+---+--+               +-++------+
  |      |EO|                 |OE|   |EO|               |OE|      |
  |      +--+-----------------+--+   +--+----------------+--+      |
  |  ODXC   |                 |  ODXC   |               |  ODXC   |
  +---------+                 +---------+               +---------+
   Node A                      Node B                    Node C
```

Figure 6 - Connection of LO ODUj (1)

In the case of LO ODUj multiplexing into HO ODUk, Figure 7 gives an example of this kind of LO ODU connection.

In Figure 7, OCh, OTUk, HO ODUk are associated with each other. The LO ODUj is multiplexed/de-multiplexed into/from the HO ODU at each ODXC node and switched at each ODXC node (i.e. trib port to line port, line card to line port, line port to trib port). From the viewpoint of connection management, the management of these HO ODUk and OTUk are similar to OCh. LO ODUj and OCh/OTUk/HO ODUk have client/server relationships. When a LO ODU connection is setup, it will be using the existing HO ODUk (/OTUk/OCh) connections which have been set up. Those HO ODUk connections provide LO ODU links, of which the LO ODU connection manager requests a link connection to support the LO ODU connection.

For example, one HO ODU2 (/OTU2/OCh) connection can be setup between Node A and Node B, another HO ODU3 (/OTU3/OCh) connection can be

setup between Node B and Node C. LO ODU1 can be generated at Node A, switched to one of the 10G line ports and multiplexed into a HO ODU2 at Node A, demultiplexed from the HO ODU2 at Node B, switched at Node B to one of the 40G line ports and multiplexed into HO ODU3 at Node B, demultiplexed from HO ODU3 at Node C and switched to its LO ODU1 terminating port at Node C.

```
    |                         LO ODUj                         |
    +----------------------------(b)----------------------------+
    |      |  OCh/OTUk/HO ODUk  |     | OCh/OTUk/HO ODUk   |     |
    |      +---------(c)---------+     +----------(c)--------+     |
    |      |                    |     |                     |     |
   +------++-+                +--+---+--+              +-++------+
   |      |EO|                |OE|   |EO|              |OE|      |
   |      +--+----------------+--+   +--+----------------+--+      |
   |  ODXC   |                |  ODXC   |              |  ODXC   |
   +---------+                +---------+              +---------+
     Node A                     Node B                   Node C
```

Figure 7 - Connection of LO ODUj (2)

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