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Expires: January 12, 2011 July 12, 2010

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

draft-ietf-ccamp-gmpls-g709-framework-02.txt

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]. No additional Switching Type and LSP Encoding Type are required to support the control of the evolved OTN, because the Switching Type and LSP Encoding Type defined in [RFC4328] are still applicable.

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 [WSON-Frame] 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	client signal bit rate tolerance, with a maximum of+-100 ppm
ODUflex for GFP-F Mapped client signal	+- 20 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 bit rate should be set to an integer multiplier of the High Order (HO) Optical Channel Physical Unit (OPU) OPUk TS rate, the tolerance should be +/- 20ppm, and the bit rate should be determined by the node that performs the mapping.

3.1.1.1. ODUj types and parameters

When ODUj connections are setup, two types of information should be conveyed in a connection request:

(a) End to end:
Client payload type (e.g. STM64; Ethernet etc.)

Bit rate and tolerance: Note for j = 0, 1, 2, 2e, 3, 4 this information may be carried as an enumerated type. For the ODUflex the actual bit rate and tolerance must be provided.

(b) Hop by hop:
TS assignment and port number carried by the Multiplex Structure Identifier (MSI) bytes as described in section 3.1.2.

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 OPU. 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 OTUk. 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. Link Parameters

Per [RFC4201], each OTU can be treated as a component link of a link bundle. The available capacity between nodes is the sum of the available capacity on the OTUs that interconnect the nodes. This total capacity is represented as the capacity of a link bundle.

Note that there will typically be more than one OTU between a pair of nodes so that the available capacity will typically be distributed across multiple OTUs. Thus, in order to be able to determine the maximum payload that can be carried on a bundled link, the link state advertisement must also provide the largest number of TSes available on any one component OTU.

In order to compute the lowest cost path for a ODUj connection request the critical parameters that need to be provided (for the purposes of routing) are:

- Number of TS

- Maximum number of TS available for a LSP (i.e., Maximum LSP Bandwidth)

- Bit rate of the TS. (Note: This may be efficiently encoded as a two integers representing the value of k and the granularity.)

3.1.2.2. Tributary Port Number Assignment

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 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.

The MSI information inserted in OPU3 overhead by the source of the HO ODUk trail is checked by the sink of the HO ODUk trail. G.709 default behavior requires that the multiplexing structure of the HO ODUk be provided by means of pre-provisioned MSI information, termed expectedMSI. The sink of the HO ODU trail checks the complete content of the MSI information (including the TPN) that was received in-band, termed acceptedMSI, against the expectedMSI. If the acceptedMSI is different from the expectedMSI, then the traffic is dropped and a payload mismatch alarm is generated.

Note that the values of the TPN MUST be either agreed between the source and the sink of the HO ODU trail either via control plane signaling or provisioning by the management plane.

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 [WSON-FRAME].

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 TSes 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 to 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 framework 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 [RFC4206bis] 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], [RFC4206bis] and related MLN drafts.

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

For the ODU layers, in order 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), it may be needed to consider introducing multi-stage multiplexing capability in specific network transition scenarios. One method for enabling multi-stage multiplexing 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 connection, which forms the LSP hierarchy in ODU layer. Here, [RFC4206], [RFC4206bis] and [MLN-EXT] (including related modifications, if needed) are relevant to connection set up.

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 2, [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.

5.2.1. Identifying OTN signals

[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 new signal types have been added since [RFC4328] was published:

(1) New signal types of sub-lambda layer

Optical Channel Data Unit (ODUj):

- ODU0
- ODU2e
- ODU4
- ODUflex

(2) A new TS granularity (i.e., 1.25 Gbps)

(3) Signal type with variable bandwidth:

ODUflex has a variable bandwidth/bit rate BR and a bit rate tolerance T. As described above the (node local) mapping process must 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 be carried in the Traffic Parameter in the signaling of connection setup request.

(4) Extended multiplexing hierarchy (For example, ODU0 into OTU2 multiplexing (with 1,25Gbps TS granularity).)

So the encoding provided in [RFC4328] needs to be extended to support all the signal types and related mapping and multiplexing with all kinds of TSs. Moreover, the extensions should consider the extensibility to match future evolvement of OTN.

For item (1) and (3), new traffic parameters may need to be extended in signaling message;

For item (2) and (4), new label should be defined to carry the exact TS allocation information related to the extended multiplexing hierarchy.

5.2.2. Tributary Port Number

The tributary port number may be assigned locally by the node at the (traffic) ingress end of the link and in this case as described above must be conveyed to the far end of the link as a "transparent" parameter i.e. the control plane does not need to understand this information. The TPN may also be assigned by the control plane when establishing LSP.

5.2.3. Support for constraint signaling

How an ODUk connection service is transported within an operator network is governed by operator policy. For example, the ODUk connection service might be transported over an ODUk path over an OTUk section, with the path and section being at the same rate as that of the connection service. In this case, an entire lambda of capacity is consumed in transporting the ODUk connection service. On the other hand, the operator might leverage sub-lambda multiplexing capabilities in the network to improve infrastructure efficiencies within any given networking domain. In this case, ODUk multiplexing may be performed prior to transport over various rate ODU servers over associated OTU sections.

The identification of constraints and associated encoding in the signaling for differentiating full lambda LSP or sub lambda LSP is for further study.

5.3. Implications for GMPLS Routing

The path computation process should select a suitable route for a ODUj connection request. In order to compute the lowest cost path it must evaluate the number (and availability) of TSs on each candidate link. The routing protocol should be extended to convey some information to represent ODU TE topology. As described above the number of TSs (on a link bundle), the bandwidth of the TS and the maximum number that are available to convey a single ODUj must be provided.

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

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. So routing protocol should be extended when TDM is ODU type to support representation of ODU switching information, especially 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 for carrying the TS granularity that the interface can support

  One type of ODUj can be multiplexed to an OTUk using different TS granularity. For example, ODU1 can be multiplexed into ODU2 with either 2.5Gbps TS granularity or 1.25G TS granularity. The routing protocol should be capable of carrying the TS granularity supported by the ODU interface.

- 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 must 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 link multiplexing capacity and link rate capacity

  When a network operator receives a request for a particular ODU connection service, the operator governs the manner in which the request is fulfilled in their network. Considerations include deployed network infrastructure capabilities, associated policies (e.g., at what link fill threshold should a particular higher-rate ODUk be utilized), etc. Thus, for example, an ODU2 connection service request could be supported by: OTU2 links (here the connection service rate is the same as the link rate), a combination of OTU2 and OTU3 links, OTU3 links, etc.

  Therefore, to allow the required flexibility, the routing protocol should be capable of differentiating between these two types of link capacity.

- 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 must be capable of supporting bundling multiple OTU links, at the same or different line rates, between a pair of nodes as a TE link. Note that link bundling is optional and is implementation dependent.

As mentioned in Section 5.1, one method of enabling multi-stage multiplexing 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.

5.4.1. 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 must 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 that both ends of the link advertise consistent capabilities (for routing) and ensures that viable connections are established.

5.4.2. Correlating the Supported LO ODU Signal Types

Many new ODU signal types have been introduced [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. If one end of a link can not support a certain LO ODU signal type, the link cannot be selected to carry such type of LO ODU connection.

Therefore, it is necessary for the two ends of an HO ODU link to correlate which types of LO ODU can be supported by the link. After correlating, the capability information can be flooded by IGP, so that the correct path for an ODU connection can be calculated.

5.5. 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. 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]). [GMPLS-SEC] provides an overview of security vulnerabilities and protection mechanisms for the GMPLS control plane.

7. IANA Considerations

This document makes not requests for IANA action.

8. Acknowledgments

We would like to thank Maarten Vissers for his 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 must first be created. 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 5 give an example of this kind of LO ODU connection.

In Figure 5, 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 5 - Connection of LO ODUj (1)

In the case of LO ODUj multiplexing into HO ODUk, Figure 6 gives an example of this kind of LO ODU connection.

In Figure 6, 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 6 - Connection of LO ODUj (2)

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