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

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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 published in 2012.

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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 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 Multi-Protocol Label Switching (MPLS) to encompass time
   division multiplexing (TDM) networks (e.g., Synchronous Optical
   NETwork (SONET)/ Synchronous Digital Hierarchy (SDH), Plesiochronous
   Digital Hierarchy (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 Open Shortest Path First (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. Later revisions of the G.709 specification, i.e., [G709-2012], has included some new features; for example, various multiplexing structures, two types of Tributary Slots (TSs) (i.e., 1.25Gbps and 2.5Gbps), and extension of the Optical channel Data Unit-j (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 PCE [RFC4655].

For the purposes of the control plane the OTN can be considered as being comprised of ODU and wavelength (Optical Channel (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

OPU: Optical channel Payload Unit

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

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, [G872-2012] describes the functional architecture of optical transport networks providing optical signal transmission, multiplexing, routing, supervision, performance assessment, and network survivability. The legacy OTN referenced by [RFC4328] 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 [G709-2012].

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 [G709-2012].
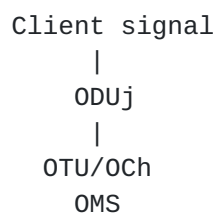
```
                Client signal
                     |
                   ODUj
                     |
                 OTU/OCh
                   OMS
```

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 OMS using Wavelength Division Multiplexing (WDM), and
this aggregated signal provides the link between the nodes.

3.1.1. **Client signal mapping**

The client signals are mapped into a LO ODUj. The current values of j
defined in [G709-2012] are: 0, 1, 2, 2e, 3, 4, Flex. The approximate
bit rates of these signals are defined in [G709-2012] and are
reproduced in Tables 1 and 2.

                    Table 1 - ODU types and bit rates

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 Constant Bit Rate (CBR) Client signals	239/238 x client signal bit rate
ODUflex for Generic Framing Procedure - Framed (GFP-F) Mapped client signal	Configured bit rate

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).

Table 2 - ODU types and tolerance

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

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). [G709-2012] 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 referenced by [RFC4328] only provided a single TS granularity and nominally 2.5Gb/s. [G709-2012] 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:

```
             Tributary Slot Granularity
               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 (Referring to Table 7-9 of [G709-2012]):

- 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 a specific
OTUk TSs is determined locally, and it can also be explicitly
controlled by a specific entity (e.g., head end, Network Management
System (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 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.

- 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
(Referring to [G798-V4]):

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

   - The expected MSI (ExMSI) information that is used to check the
      accepted MSI (AcMSI) information. The AcMSI information is the MSI
      valued received in-band, after a three-frame integration.

   As described in [[G798-V4](#)], the sink of the HO ODU trail checks the
   complete content of the AcMSI information against the ExMSI. If the
   AcMSI is different from the ExMSI, 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 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
   [[G872-2012](#)] 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.

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.

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,
as illustrated in Figure 2. In this layer there are ODU links with a
variety of TSs available, and nodes that are Optical Digital Cross
Connects (ODXCs). Lo ODU connections can be setup based on the
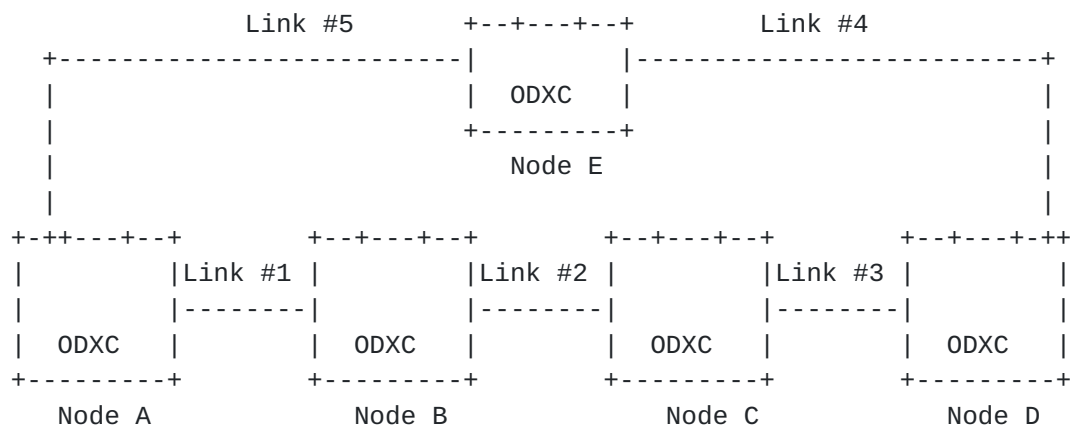network topology.

```
                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., Reconfiguration Optical Add/Drop Multiplexer (ROADM),

Optical Cross-Connect (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 Multi-Layer Networks (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 OCh
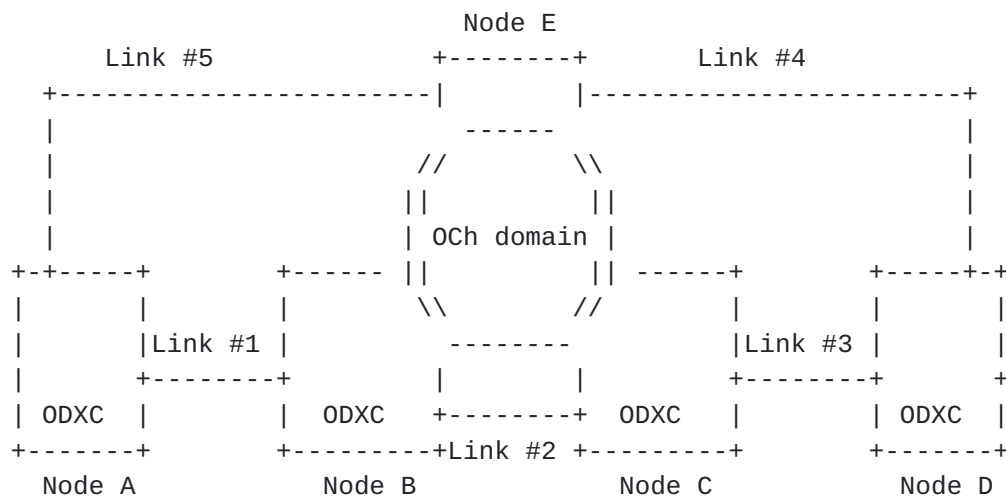layer network topology.

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

       Figure 3 - OCh 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
```
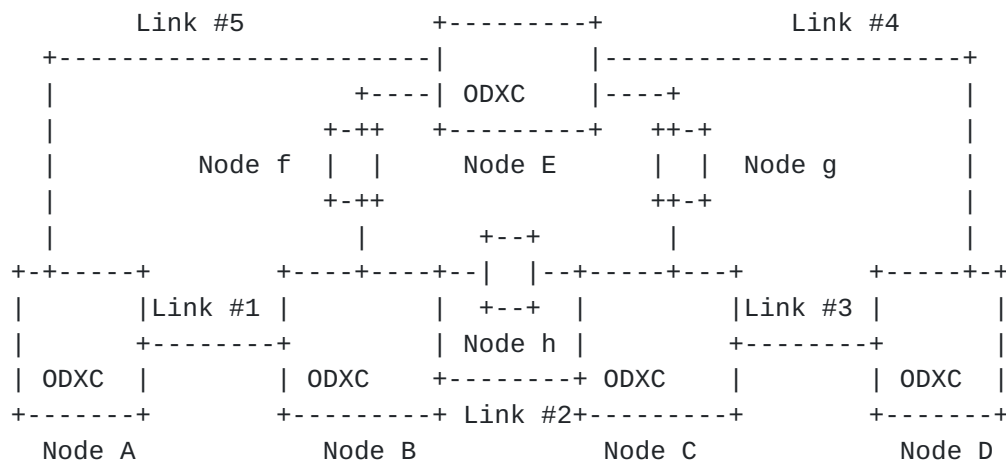
       Figure 4 - OCh Visible Topology for LO ODUj connection management

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 OCh 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 Label Switch Path (LSP) Hierarchy

The path computation for ODU connection request is based on the
topology of ODU layer.

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 Wavelength Switched Optical Network (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 [G709-2012] services (e.g., ODU0,
ODUflex) into a legacy network configuration (i.e., the legacy OTN
referenced by [RFC4328]). 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 the legacy

containers (ODU1, ODU2, ODU3), thus postponing the need to upgrade every network element to [G709-2012] 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 RSVP-TE extensions are described in [RFC3471] and [RFC3473]. For OTN-specific control, [RFC4328] defines signaling extensions to support control for the legacy G.709 Optical Transport Networks.

As described in Section 3, [G709-2012] 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 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 Hierarchical 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

  A new label format 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 TPN allocation and negotiation

  TPN 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 ([G7042]). [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)

  [G7044] 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 Shared Explicit
(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 sufficient
information to represent ODU Traffic Engineering (TE) topology.

Interface Switching Capability Descriptors defined in [RFC4202]
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-
2012] 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 restricted to
  switched (i.e. forwarded to switching matrix without
  multiplexing/demultiplexing actions), restricted to 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

  [G709-2012] 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

  As described in [RFC4201], 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

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.

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. User-
Network Interface (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 [G709-2012],
      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 was not allowed by the legacy OTN referenced by
      [RFC4328], 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 [G709-2012], there may be OTN networks
   composed of a mixture of nodes, some of which support the legacy OTN
   and run control plane protocols defined in [RFC4328], while others
   support [G709-2012] and new OTN control plane characterized in this
   document. Note that a third case, for the sake of completeness,
   consists on nodes supporting the legacy OTN referenced by [RFC4328]
   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 the legacy
   OTN, and the control plane procedures defined to support [G709-2012],
   as outlined by this document.

Compatibility needs to be considered only when controlling ODU1 or
ODU2 or ODU3 connection, because the legacy OTN only support these
three ODU signal types. In such cases, there are several possible
options including:

- A node supporting [G709-2012] could support only the [G709-2012]
  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 [G709-2012] could support both the [G709-2012]
  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 Path Computation Client (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, PCE
Communication Protocol (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
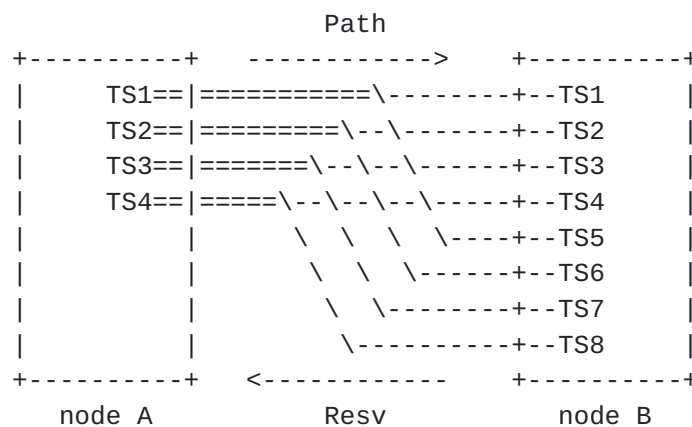support this TS combination.

```
                            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 opposite 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. Although, this is not greater than the risks presented by
the existing OTN control plane as defined by [RFC4203] and [RFC4328].

For further details of the specific security measures refer to the
documents that define the protocols ([RFC3473], [RFC4203], [RFC5307],
[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

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