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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 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
```
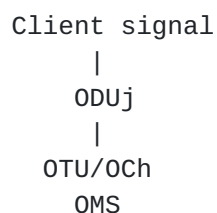
                  Figure 1 - Basic OTN signal hierarchy

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
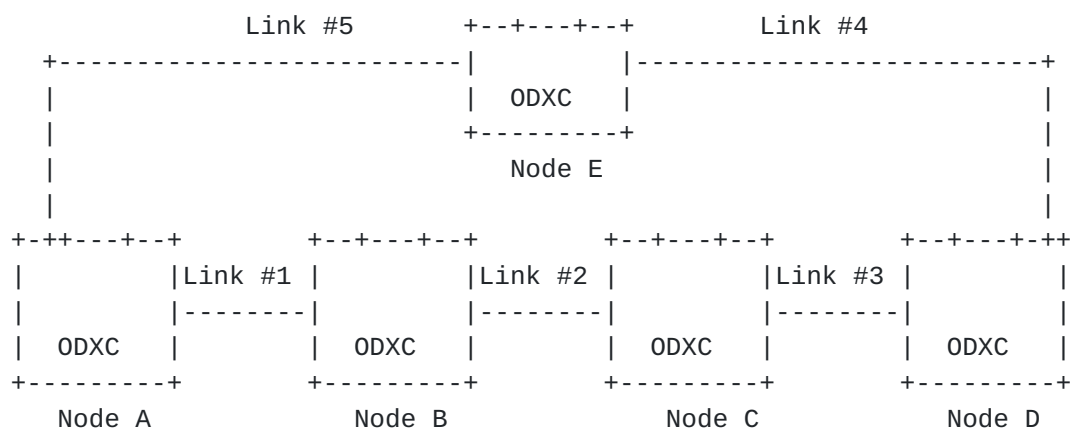   connections can be setup based on the network topology.

```
            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
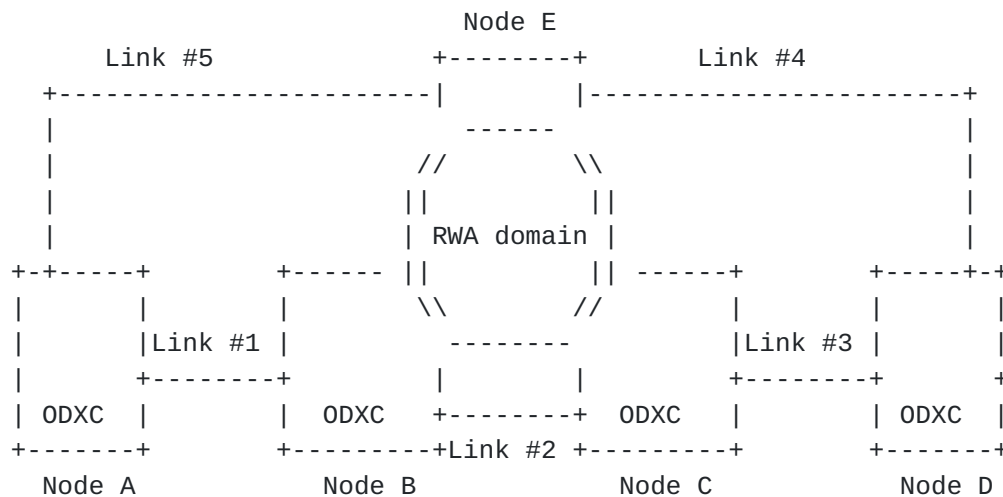network topology.

```
                             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
```
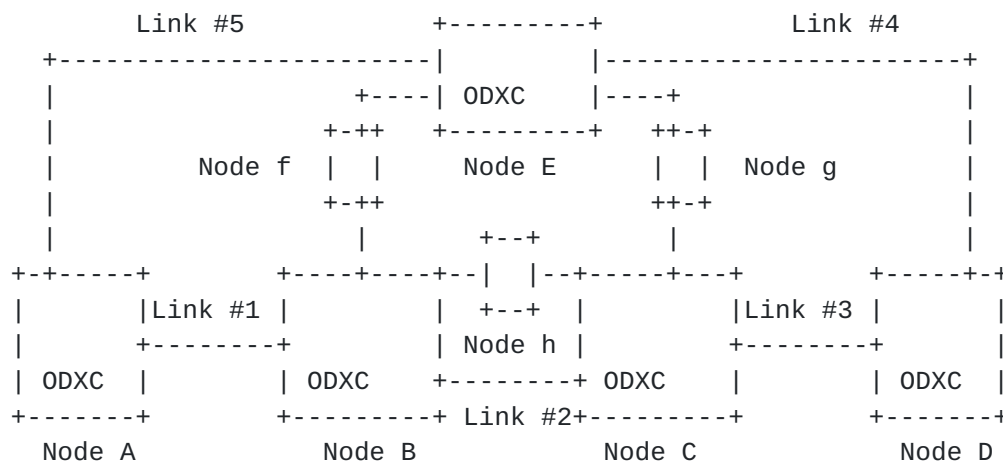
        Figure 4 - RWA Visible Topology for LO ODUj connection management

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 ODU layer multiplexing hierarchy signaling

  ODU layer multiplexing hierarchy has been supported by [G709-V3],
  i.e., a client ODUj connection can be nested into server layer

ODUk (j<k) connection. Control plane should provide mechanisms to
support creation of such ODU hierarchy.

When creating server layer ODU LSP for carrying one specific
client LSP, the first and last hop of the server LSP should be
capable of selecting the correct link to make sure that both ends
of the server LSP can support multiplexing/demultiplexing client
signal into / from server LSP.

Therefore, the adaption information (e.g., hierarchical
information and TSG) should be carried in the signaling to make
the penultimate node of the FA-LSP to select the correct link for
carrying the specific client signal.

- 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] (referred to as legacy
nodes), while others support [G709-V3] and new OTN control plane
characterized in this document (referred to as new nodes). In such
case, control plane backward compatibility needs to be taken into
consideration (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).

In order to provide backward compatibility, a new Switching
Capability type is required for the control of [G709-V3] both in
routing and signaling.

From a routing perspective, the advertisement of LSAs carrying new
Switching Capability type implies the support of new OTN control
plane protocols. A new node must support both legacy routing (i.e.,
the procedures defined in [RFC4203] with the switching capabilities
defined in [RFC4328]) and new routing (i.e., the procedures defined
for [G709-V3]), and should use new routing by default. When detecting
the presence of a legacy node in the administrative domain (i.e.,
receiving LSAs carrying legacy Switching Capability type), the new
node should advertise its links information by both the new and
legacy routing approach, so that the legacy node can obtain the link
resource information advertised by the new node.

On the other hand, from a signaling perspective, a new node must
support both the legacy signaling procedures defined in [RFC4328] and
the new procedures for control of [G709-V3]. Based on the routing
information, a new node can determine whether its neighbor node is a
legacy one or new one, so that it can determine which signaling
procedure (new or legacy signaling procedure) needs to be performed.
In case the new node has not enough information to know which
signaling procedure its neighbor can support, it can use the new
signaling procedure with the new Switching Capability type by default.

Since a legacy node receiving such message will respond with an error
message indicating an unsupported Switching Capability type, the new
node can perform the signaling again with a procedure [RFC4328]
compliant.


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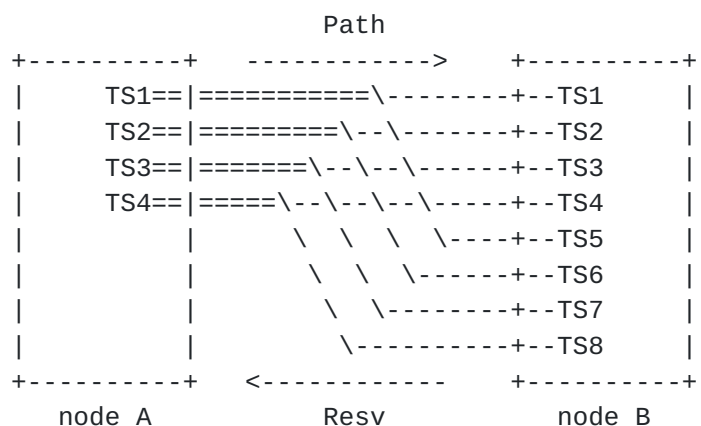
           Figure 5 - Interworking between 1.25Gbps TS and 2.5Gbps TS

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

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10. References

10.1. Normative References

   [RFC4328]   D. Papadimitriou, Ed. "Generalized Multi-Protocol
               LabelSwitching (GMPLS) Signaling Extensions for G.709
               Optical Transport Networks Control", RFC 4328, Jan 2006.

   [RFC3471]   Berger, L., Editor, "Generalized Multi-Protocol Label
               Switching (GMPLS) Signaling Functional Description", RFC
               3471, January 2003.

   [RFC3473]   L. Berger, Ed., "Generalized Multi-Protocol Label
               Switching (GMPLS) Signaling Resource ReserVation
               Protocol-Traffic Engineering (RSVP-TE) Extensions", RFC
               3473, January 2003.

   [RFC4201]   K. Kompella, Y. Rekhter, Ed., "Link Bundling in MPLS
               Traffic Engineering (TE)", RFC 4201, October 2005.

   [RFC4202]   K. Kompella, Y. Rekhter, Ed., "Routing Extensions in
               Support of Generalized Multi-Protocol Label Switching
               (GMPLS)", RFC 4202, October 2005.

   [RFC4203]   K. Kompella, Y. Rekhter, Ed., "OSPF Extensions in Support
               of Generalized Multi-Protocol Label Switching (GMPLS)",
               RFC 4203, October 2005.

   [RFC4205]   K. Kompella, Y. Rekhter, Ed., "Intermediate System to
               Intermediate System (IS-IS) Extensions in Support of
               Generalized Multi-Protocol Label Switching (GMPLS)", RFC
               4205, October 2005.

   [RFC4204]   Lang, J., Ed., "Link Management Protocol (LMP)", RFC 4204,
               October 2005.

   [RFC4206]   K. Kompella, Y. Rekhter, Ed., " Label Switched Paths (LSP)
               Hierarchy with Generalized Multi-Protocol Label Switching
               (GMPLS) Traffic Engineering (TE)", RFC 4206, October 2005.

   [RFC6107]   K. Shiomoto, A. Farrel, "Procedures for Dynamically
               Signaled Hierarchical Label Switched Paths", RFC6107,
               February 2011.

   [RFC6001]    Dimitri Papadimitriou et al, "Generalized Multi-Protocol
                Label Switching (GMPLS) Protocol Extensions for Multi-
                Layer and Multi-Region Networks (MLN/MRN)", RFC6001,
                February 21, 2010.

   [RFC5440]    JP. Vasseur, JL. Le Roux, Ed.," Path Computation Element
                (PCE) Communication Protocol (PCEP)", RFC 5440, March
                2009.

   [RFC6344]    G. Bernstein et al, "Operating Virtual Concatenation
                (VCAT) and the Link Capacity Adjustment Scheme (LCAS)
                with Generalized Multi-Protocol Label Switching (GMPLS)",
                RFC6344, August, 2011.

   [G709-V3]    ITU-T, "Interfaces for the Optical Transport Network
                (OTN)", G.709 Recommendation and Amendment2, April 2011.

## 10.2. Informative References

   [G709-V1]    ITU-T, "Interface for the Optical Transport Network
                (OTN)," G.709 Recommendation and Amendment1, November
                2001.

   [G709-V2]    ITU-T, "Interface for the Optical Transport Network
                (OTN)," G.709 Recommendation, March 2003.

   [G7042]      ITU-T, "Link capacity adjustment scheme (LCAS) for
                virtual concatenated signals", G.7042/Y.1305, March 2006.

   [G872-2001] ITU-T, "Architecture of optical transport networks",
                G.872 Recommendation, November 2001.

   [G872-Am2]  ITU-T, "Architecture of optical transport networks",
                G.872 Recommendation and Amendment 2, July 2010.

   [G.7044]     ITU-T, "Hitless adjustment of ODUflex", G.7044 (and
                Amendment 1), February 2012.

   [HZang00]    H. Zang, J. Jue and B. Mukherjeee, "A review of routing
                and wavelength assignment approaches for wavelength-
                routed optical WDM networks", Optical Networks Magazine,
                January 2000.

   [RFC6163]    Y. Lee, G. Bernstein, W. Imajuku, "Framework for GMPLS
                and PCE Control of Wavelength Switched Optical Networks
                (WSON)", RFC6163, April 2011.

    [PCE-APS]    Tomohiro Otani, Kenichi Ogaki, Diego Caviglia, and Fatai
                 Zhang, "Requirements for GMPLS applications of PCE",
                 draft-ietf-pce-gmpls-aps-req, Work in Progress.

    [RFC5920]    Fang, L., Ed., "Security Framework for MPLS and GMPLS
                 Networks", July 2010.

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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
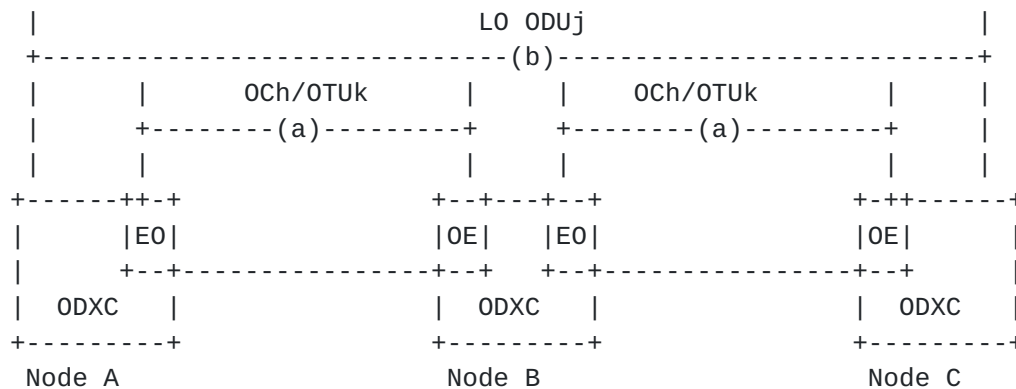   the next OTU1 and demapped from this OTU1 at Node C.

```
    |                            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
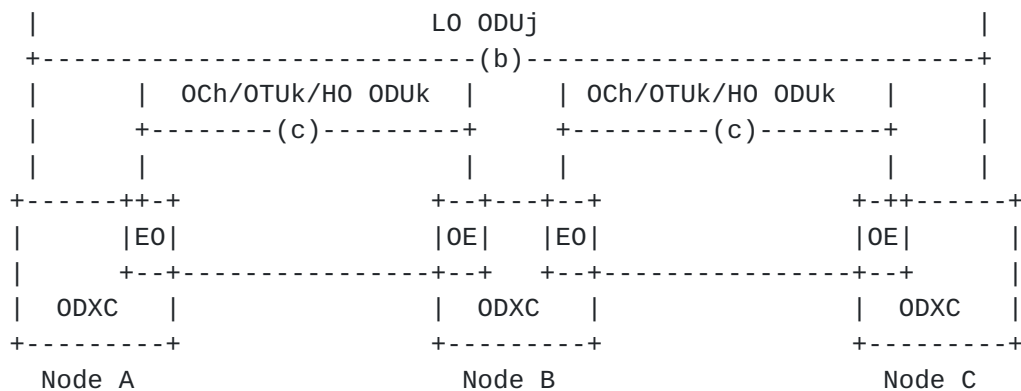terminating port at Node C.

```
     |                          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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