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Generalized Multi-Protocol Label Switching (GMPLS) Signaling Extensions for the evolving G.709 Optical Transport Networks Control

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Abstract

ITU-T Recommendation G.709 [G709-2012] has introduced new Optical channel Data Unit (ODU) containers (ODU0, ODU4, ODU2e and ODUflex)

and enhanced Optical Transport Networking (OTN) flexibility.

This document updates RFC4328 to provide the extensions to the Generalized Multi-Protocol Label Switching (GMPLS) signaling to control the evolving OTN addressing ODUk multiplexing and new features including ODU0, ODU4, ODU2e and ODUflex.

Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

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1. Introduction

With the evolution and deployment of OTN technology, it is necessary that appropriate enhanced control technology support be provided for [G709-2012].

[OTN-FWK] provides a framework to allow the development of protocol extensions to support GMPLS and Path Computation Element (PCE) control of OTN as specified in [G709-2012]. Based on this framework, [OTN-INFO] evaluates the information needed by the routing and signaling process in OTNs to support GMPLS control of OTN.

[RFC4328] describes the control technology details that are specific to the 2001 revision of the G.709 specification. This document updates [RFC4328] to provide Resource ReserVation Protocol-Traffic Engineering (RSVP-TE) extensions to support of control for [G709-2012].

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. GMPLS Extensions for the Evolving G.709 - Overview

New features for the evolving OTN, for example, new ODU0, ODU2e, ODU4 and ODUflex containers are specified in [G709-2012]. The corresponding new signal types are summarized below:

- Optical Channel Transport Unit (OTUk):
  . OTU4

- Optical Channel Data Unit (ODUk):
  . ODU0
  . ODU2e
  . ODU4
  . ODUflex

A new Tributary Slot Granularity (TS Granularity, TSG) (i.e., 1.25 Gbps) is also described in [G709-2012]. Thus, there are now two TS granularities for the foundation OTN ODU1, ODU2 and ODU3 containers.

The TS granularity at 2.5 Gbps is used on legacy interfaces while the new 1.25 Gbps is used on the new interfaces.

In addition to the support of ODUk mapping into OTUk (k = 1, 2, 3, 4), the evolving OTN [G.709-V3] encompasses the multiplexing of ODUj (j = 0, 1, 2, 2e, 3, flex) into an ODUk (k > j), as described in Section 3.1.2 of [OTN-FWK].

Virtual Concatenation (VCAT) of Optical channel Payload Unit-k (OPUk) (OPUk-Xv, k = 1/2/3, X = 1...256) is also supported by [G709-2012]. Note that VCAT of OPU0 / OPU2e / OPU4 / OPUflex is not supported per [G709-2012].

[RFC4328] describes GMPLS signaling extensions to support the control for the 2001 revision of the G.709 specification. However, [RFC4328] needs to be updated because it does not provide the means to signal all the new signal types and related mapping and multiplexing functionalities. Moreover, it supports only the deprecated auto-Multiframe Structure Identifier (MSI) mode which assumes that the Tributary Port Number (TPN) is automatically assigned in the transmit direction and not checked in the receive direction.

This document extends the G.709 traffic parameters described in [RFC4328] and presents a new flexible and scalable OTN label format. Additionally, procedures about Tributary Port Number assignment through control plane are also provided in this document.

4. Generalized Label Request

The Generalized Label Request, as described in [RFC3471], carries the Label Switched Path (LSP) Encoding Type, the Switching Type and the Generalized Protocol Identifier (G-PID).

[RFC4328] extends the Generalized Label Request, introducing two new code-points for the LSP Encoding Type (i.e., G.709 ODUk (Digital Path) and G.709 Optical Channel) and adding a list of G-PID values in order to accommodate the 2001 revision of the G.709 specification.

This document follows these extensions and a new Switching Type is introduced to indicate the ODUk switching capability [G709-2012] in order to support backward compatibility with [RFC4328], as described in [OTN-FWK]. The new Switching Type (101, TBA by IANA) is defined in [OTN-OSPF].

This document also updates the G-PID values defined in [RFC4328]:

Value	G-PID Type	
47	ODU-2.5G:	transport of Digital Paths (e.g., at 2.5, 10 and 40 Gbps) via 2.5Gbps TSG
49	CBRa:	asynchronous Constant Bit Rate (CBR) (e.g., mapping of CBR2G5, CBR10G and CBR40G)
50	CBRb:	bit synchronous Constant Bit Rate (e.g., mapping of CBR2G5, CBR10G, CBR40G, CBR10G3 and supra-2.488 CBR Gbit/s signal (carried by OPUflex))
32	ATM:	mapping of Asynchronous Transfer Mode (ATM) cell stream (e.g., at 1.25, 2.5, 10 and 40 Gbps)
51	BSOT:	non-specific client Bit Stream with Octet Timing (e.g., Mapping of 1.25, 2.5, 10, 40 and 100 Gbps Bit Stream)
52	BSNT:	non-specific client Bit Stream without Octet Timing (e.g., Mapping of 1.25, 2.5, 10, 40 and 100 Gbps Bit Stream)

Note: Values 32, 47, 49 and 50 include mapping of Synchronous Digital Hierarchy (SDH).

In the case of ODU multiplexing, the Lower Order ODU (LO ODU) (i.e., the client signal) may be multiplexed into Higher Order ODU (HO ODU) via 1.25G TSG, 2.5G TSG or any one of them (i.e., TSG Auto_Negotiation is enabled). Since the G-PID type "ODUk" defined in [RFC4328] is only used for 2.5Gbps TSG, two new G-PID types are defined as follows:

- ODU-1.25G: transport of Digital Paths at 1.25, 2.5, 10, 40 and 100 Gbps via 1.25Gbps TSG

- ODU-any: transport of Digital Paths at 1.25, 2.5, 10, 40 and 100 Gbps via 1.25 or 2.5Gbps TSG (i.e., the fallback procedure is enabled and the default value of 1.25Gbps TSG can be fallen back to 2.5Gbps if needed)

In addition, some other new G-PID types are defined to support other new client signals described in [G709-2012]:

- CBRc: Mapping of constant bit-rate signals with justification into OPUk (k = 0, 1, 2, 3, 4) via Generic Mapping Procedure (GMP) (i.e., mapping of sub-1.238, supra-

1.238 to sub-2.488, close-to 9.995, close-to 40.149
and close-to 104.134 Gbit/s CBR client signal)

- 1000BASE-X: Mapping of a 1000BASE-X signal via timing transparent transcoding into OPU0

- FC-1200: Mapping of a FC-1200 signal via timing transparent transcoding into OPU2e

The following table summarizes the new G-PID values with respect to the LSP Encoding Type:

Value	G-PID Type	LSP Encoding Type
59(TBA)	G.709 ODU-1.25G	G.709 ODUk
60(TBA)	G.709 ODU-any	G.709 ODUk
61(TBA)	CBRc	G.709 ODUk
62(TBA)	1000BASE-X	G.709 ODUk (k=0)
63(TBA)	FC-1200	G.709 ODUk (k=2e)

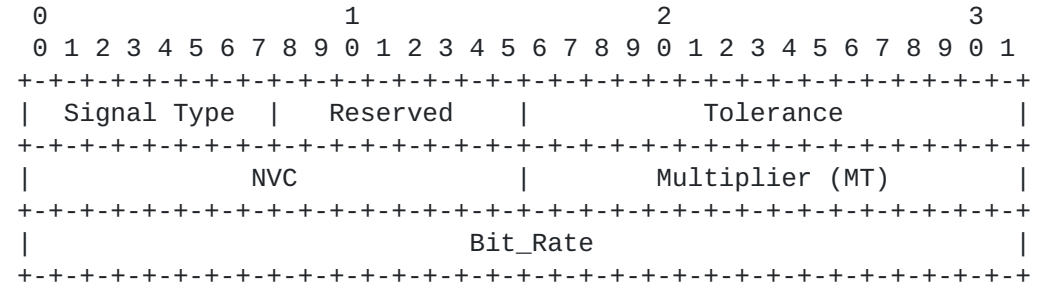
Note: Values 59 and 60 include mapping of SDH.

5. Extensions for Traffic Parameters for the Evolving G.709

The traffic parameters for OTN-TDM capable Switching Type are carried in the OTN-TDM SENDER_TSPEC and FLOWSPEC objects. The objects have the following class and type:

- OTN-TDM SENDER_TSPEC Object: Class = 12, C-Type = 7 (TBA)
- OTN-TDM FLOWSPEC Object: Class = 9, C-Type = 7 (TBA)

The format of traffic parameters in these two objects are defined as follows:



The valid Signal Type values defined in [RFC4328] are updated to be:

Value	Type
0	Not significant
1	ODU1 (i.e., 2.5 Gbps)
2	ODU2 (i.e., 10 Gbps)
3	ODU3 (i.e., 40 Gbps)
4	ODU4 (i.e., 100 Gbps)
5	Reserved (for future use)
6	Optical Channel (Och) at 2.5 Gbps
7	OCh at 10 Gbps
8	OCh at 40 Gbps
9	OCh at 100 Gbps
10	ODU0 (i.e., 1.25 Gbps)
11	ODU2e (i.e., 10Gbps for FC1200 and GE LAN)
12~19	Reserved (for future use)
20	ODUflex(CBR) (i.e., 1.25*N Gbps)
21	ODUflex(Generic Framing Procedure-Framed (GFP-F)), resizable (i.e., 1.25*N Gbps)
22	ODUflex(GFP-F), non resizable (i.e., 1.25*N Gbps)
23~255	Reserved (for future use)

In case of ODUflex(CBR), the Bit_Rate and Tolerance fields MUST be used together to represent the actual bandwidth of ODUflex, where:

- The Bit_Rate field indicates the nominal bit rate of ODUflex(CBR) expressed in bytes per second, encoded as a 32-bit IEEE single-precision floating-point number (referring to [RFC4506] and [IEEE]). The value contained in the Bit Rate field has to keep into account both 239/238 factor and the Transcoding factor.

- The Tolerance field indicates the bit rate tolerance (part per million, ppm) of the ODUflex(CBR) encoded as an unsigned integer, which MUST be bounded in 0~100ppm.

For example, for an ODUflex(CBR) service with Bit_Rate = 2.5Gbps and Tolerance = 100ppm, the actual bandwidth of the ODUflex is:

2.5Gbps * (1 +/- 100ppm)

In case of ODUflex(GFP), the Bit_Rate field is used to indicate the nominal bit rate of the ODUflex(GFP), which implies the number of tributary slots requested for the ODUflex(GFP). Since the tolerance of ODUflex(GFP) makes no sense on tributary slot resource

reservation, the Tolerance field for ODUflex(GFP) is not necessary and MUST be filled with 0.

In case of other ODUk signal types, the Bit_Rate and Tolerance fields are not necessary and MUST be set to 0.

The usage of the NVC and Multiplier (MT) fields are the same as [RFC4328].

Note that the error process on the traffic parameters MUST follow the rules defined in Section 6 of [RFC4328].

5.1. Usage of ODUflex(CBR) Traffic Parameters

In case of ODUflex(CBR), the information of Bit_Rate and Tolerance in the ODUflex traffic parameters MUST be used to determine the total number of tributary slots N in the HO ODUk link to be reserved. Here:

N = Ceiling of

ODUflex(CBR) nominal bit rate * (1 + ODUflex(CBR) bit rate tolerance)

ODTUk.ts nominal bit rate * (1 - HO OPUk bit rate tolerance)

In this formula, the ODUflex(CBR) nominal bit rate is the bit rate of the ODUflex(CBR) on the line side, i.e., the client signal bit rate after applying the 239/238 factor (according to Clause 7.3, Table 7-2 of [G709-2012]) and the transcoding factor T (if needed) on the CBR client. According to clauses 17.7.3, 17.7.4 and 17.7.5 of [G709-2012]:

ODUflex(CBR) nominal bit rate = CBR client bit rate * (239/238) / T

The ODTUk.ts (Optical channel Data Tributary Unit k with ts tributary slots) nominal bit rate is the nominal bit rate of the tributary slot of ODUk, as shown in Table 1 (referring to Table 7-7 of [G709-2012]).

Table 1 - Actual TS bit rate of ODUk (in Kbps)

ODUk.ts	Minimum	Nominal	Maximum
ODU2.ts	1,249,384.632	1,249,409.620	1,249,434.608
ODU3.ts	1,254,678.635	1,254,703.729	1,254,728.823
ODU4.ts	1,301.683.217	1,301,709.251	1,301,735.285

Note that:

Minimum bit rate of ODUTk.ts =
ODTUk.ts nominal bit rate * (1 - HO OPUk bit rate tolerance)

Maximum bit rate of ODTUk.ts =
ODTUk.ts nominal bit rate * (1 + HO OPUk bit rate tolerance)

Where: HO OPUk bit rate tolerance = 20ppm

Therefore, a node receiving a PATH message containing ODUflex(CBR) nominal bit rate and tolerance can allocate precise number of tributary slots and set up the cross-connection for the ODUflex service.

Note that for different ODUk, the bit rates of the tributary slots are different, and so the total number of tributary slots to be reserved for the ODUflex(CBR) MAY not be the same on different HO ODUk links.

An example is given below to illustrate the usage of ODUflex(CBR) traffic parameters.

As shown in Figure 1, assume there is an ODUflex(CBR) service requesting a bandwidth of (2.5Gbps, +/-100ppm) from node A to node C.
In other words, the ODUflex traffic parameters indicate that Signal Type is 20 (ODUflex(CBR)), Bit_Rate is 2.5Gbps and Tolerance is 100ppm.

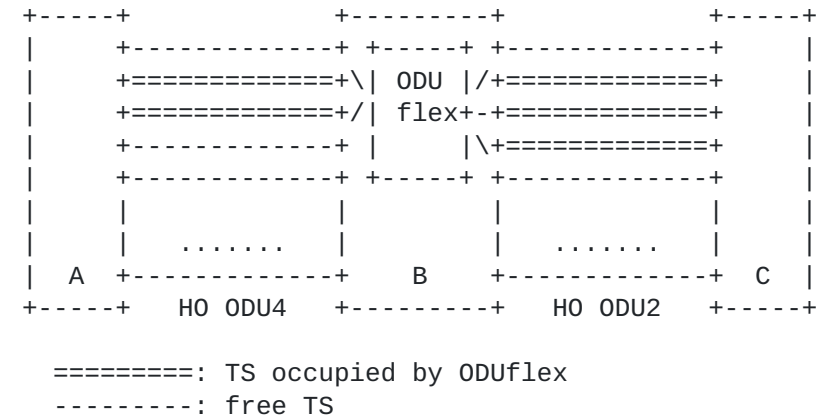


Figure 1 - Example of ODUflex(CBR) Traffic Parameters

- On the HO ODU4 link between node A and B:

  The maximum bit rate of the ODUflex(CBR) equals 2.5Gbps * (1 + 100ppm), and the minimum bit rate of the tributary slot of ODU4 equals 1,301,683.217 Kbps, so the total number of tributary slots N1 to be reserved on this link is:

  N1 = ceiling (2.5Gbps * (1 + 100ppm) / 1,301,683.217 Kbps) = 2

- On the HO ODU2 link between node B and C:

  The maximum bit rate of the ODUflex equals 2.5Gbps * (1 + 100ppm), and the minimum bit rate of the tributary slot of ODU2 equals 1,249,384.632 Kbps, so the total number of tributary slots N2 to be reserved on this link is:

  N2 = ceiling (2.5Gbps * (1 + 100ppm) / 1,249,384.632 Kbps) = 3

5.2. Usage of ODUflex(GFP) Traffic Parameters

[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, as shown in Table 2.

Table 2 - Recommended ODUflex(GFP) bit rates and tolerance

ODU type	Nominal bit-rate	Tolerance
ODUflex(GFP) of n TS, 1<=n<=8	n * ODU2.ts	+/-100 ppm
ODUflex(GFP) of n TS, 9<=n<=32	n * ODU3.ts	+/-100 ppm
ODUflex(GFP) of n TS, 33<=n<=80	n * ODU4.ts	+/-100 ppm

According to this table, the Bit_Rate field for ODUflex(GFP) MUST equal to one of the 80 values listed below:

1 * ODU2.ts; 2 * ODU2.ts; ...; 8 * ODU2.ts;
9 * ODU3.ts; 10 * ODU3.ts, ...; 32 * ODU3.ts;
33 * ODU4.ts; 34 * ODU4.ts; ...; 80 * ODU4.ts.

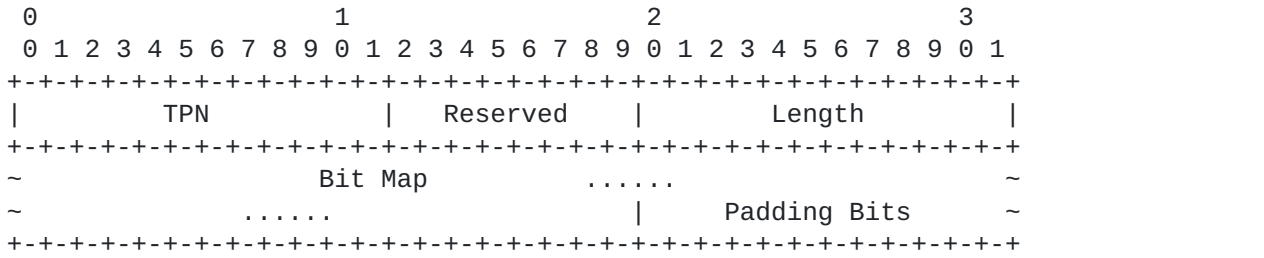
In this way, the number of required tributary slots for the ODUflex(GFP) (i.e., the value of "n" in Table 2) can be deduced from the Bit_Rate field.

6. Generalized Label

This section defines the format of the OTN-TDM Generalized Label.

6.1. OTN-TDM Switching Type Generalized Label

The following is the Generalized Label format for that MUST be used with the OTN-TDM Switching Type:



The OTN-TDM Generalized Label is used to indicate how the LO ODUj signal is multiplexed into the HO ODUk link. Note that the LO OUDj signal type is indicated by traffic parameters, while the type of HO ODUk link is identified by the selected interface carried in the IF_ID RSVP_HOP Object.

TPN (12 bits): indicates the TPN for the assigned Tributary Slot(s).

- In case of LO ODUj multiplexed into HO ODU1/ODU2/ODU3, only the lower 6 bits of TPN field are significant and the other bits of TPN MUST be set to 0.

- In case of LO ODUj multiplexed into HO ODU4, only the lower 7 bits of TPN field are significant and the other bits of TPN MUST be set to 0.

- In case of ODUj mapped into OTUk (j=k), the TPN is not needed and this field MUST be set to 0.

Per [G709-2012], The TPN is used to allow for correct demultiplexing in the data plane. When an LO ODUj is multiplexed into HO ODUk occupying one or more TSs, a new TPN value is configured at the two ends of the HO ODUk link and is put into the related MSI byte(s) in

the OPUk overhead at the (traffic) ingress end of the link, so that the other end of the link can learn which TS(s) is/are used by the LO ODUj in the data plane.

According to [G709-2012], the TPN field MUST be set as according to the following tables:

Table 3 - TPN Assignment Rules (2.5Gbps TS granularity)

HO ODUk	LO ODUj	TPN	TPN Assignment Rules
ODU2	ODU1	1~4	Fixed, = TS# occupied by ODU1
	ODU1	1~16	Fixed, = TS# occupied by ODU1
ODU3	ODU2	1~4	Flexible, != other existing LO ODU2s' TPNs

Table 4 - TPN Assignment Rules (1.25Gbps TS granularity)

HO ODUk	LO ODUj	TPN	TPN Assignment Rules
ODU1	ODU0	1~2	Fixed, = TS# occupied by ODU0
	ODU1	1~4	Flexible, != other existing LO ODU1s' TPNs
ODU2	ODU0 & ODUflex	1~8	Flexible, != other existing LO ODU0s and ODUflexes' TPNs
	ODU1	1~16	Flexible, != other existing LO ODU1s' TPNs

```
   |       +-------+----+-----------------------------------------------
+
   |       | ODU2  |1~4 |Flexible, != other existing LO ODU2s' TPNs
|
   | ODU3  +-------+----+-----------------------------------------------
+
   |       |ODU0 & |    |Flexible, != other existing LO ODU0s and
|
   |       |ODU2e &|1~32|ODU2es and ODUflexes' TPNs
|
   |       |ODUflex|    |
|
   +-------+-------+----+-----------------------------------------------
+
   | ODU4  |Any ODU|1~80|Flexible, != ANY other existing LO ODUs' TPNs
|
   +-------+-------+----+-----------------------------------------------
+
```

Note that in the case of "Flexible", the value of TPN MAY not be corresponding to the TS number as per [G709-2012].

Length (12 bits): indicates the number of bits of the Bit Map field, i.e., the total number of TS in the HO ODUk link. The valid values for this field are 0, 2, 4, 8, 16, 32 and 80.

In case of an ODUk mapped into OTUk, there is no need to indicate which tributary slots will be used, so the length field MUST be set to 0.

Bit Map (variable): indicates which tributary slots in HO ODUk that the LO ODUj will be multiplexed into. The sequence of the Bit Map is consistent with the sequence of the tributary slots in HO ODUk. Each bit in the bit map represents the corresponding tributary slot in HO ODUk with a value of 1 or 0 indicating whether the tributary slot will be used by LO ODUj or not.

Padding bits are added after the Bit Map to make the whole label a multiple of four bytes if necessary. Padding bits MUST be set to 0 and MUST be ignored.

6.2. Procedures

When a node receives a generalized label request for setting up an ODUj LSP from its upstream neighbor node, the node MUST generate an OTN-TDM label according to the signal type of the requested LSP and the free resources (i.e., free tributary slots of ODUk) that will be reserved for the LSP, and send the label to its upstream neighbor node.

In case of ODUj to ODUk multiplexing, the node MUST firstly determine the size of the Bit Map field according to the signal type and the tributary slot type of ODUk, and then set the bits to 1 in the Bit Map field corresponding to the reserved tributary slots. The node MUST also assign a valid TPN, which MUST NOT collide with other TPN value used by existing LO ODU connections in the selected HO ODU link, and configure the Expected MSI (ExMSI) using this TPN. Then, the assigned TPN MUST be filled into the label.

In case of ODUk to OTUk mapping, TPN field MUST be set to 0. Bit Map information is not REQUIRED and MUST NOT be included, so Length field MUST be set to 0 as well.

The node receiving a OTN-TDM generalized label MUST firstly identify which ODU signal type is multiplexed or mapped into which ODU signal type accordingly to the traffic parameters and the IF_ID RSVP_HOP Object in the received message.

In case of ODUj to ODUk multiplexing, the node MUST retrieve the reserved tributary slots in the ODUk by its downstream neighbor node according to the position of the bits that are set to 1 in the Bit Map field. The node determines the TS type (according to the total TS number of the ODUk, or pre-configured TS type), so that the node,

based on the TS type, can multiplex the ODUj into the ODUk. The node MUST also retrieve the TPN value assigned by its downstream neighbor node from the label, and fill the TPN into the related MSI byte(s) in the OPUk overhead in the data plane, so that the downstream neighbor node can check whether the TPN received from the data plane is consistent with the ExMSI and determine whether there is any mismatch defect.

Note that the Length field in the label format MAY be used to indicate the TS type of the HO ODUk (i.e., TS granularity at 1.25Gbps or 2.5Gbps) since the HO ODUk type can be known from IF_ID RSVP_HOP Object. In some cases when there is no Link Management Protocol (LMP) or routing to make the two end points of the link to know the TSG, the TSG information used by another end can be deduced from the label format. For example, for HO ODU2 link, the value of the length filed will be 4 or 8, which indicates the TS granularity is 2.5Gbps or 1.25Gbps, respectively.

In case of ODUk to OTUk mapping, the size of Bit Map field MUST be 0 and no additional procedure is needed.

In order to create bidirectional LSP, an upstream node MUST generate an Upstream Label on the out outgoing interface to indicate the reserved TSs of ODUk and the assigned TPN value in the upstream direction. This Upstream Label is sent to the downstream node via Path massage for upstream resource reservation.

The upstream node MAY generate Label Set to indicate which labels on the outgoing interface in the downstream direction are acceptable. The downstream node will restrict its choice of labels, i.e., TS resource and TPN value, to one which is in the Label Set.

The upstream node MAY also generate Suggested Label to indicate the preference of TS resource and TPN value on the outgoing interface in the downstream direction. The downstream node is not REQUIRED to use the Suggested Label and MAY use another label based on local decision and send it to the upstream node, as described in [RFC3473].

The ingress node of an LSP MAY include label ERO to indicate the label in each hops along the path. Note that the TPN in the label ERO (Explicit Route Object) subobject MAY not be assigned by the ingress node. In this case, the node MUST assign a valid TPN value and then put this value into TPN field of the label object when receiving a Path message.

6.2.1. Notification on Label Error

When receiving an OTN-TDM label from the neighbor node, the node MUST check whether the label is acceptable. An error message containing an "Unacceptable label value" indication ([RFC3209]) MUST be sent if one of the following cases occurs:

- Invalid value in the length field;
- The selected link only supports 2.5Gbps TS granularity while the Length field in the label along with ODUk signal type indicates the 1.25Gbps TS granularity;
- The label includes an invalid TPN value that breaks the TPN assignment rules;
- The indicated resources (i.e., the number of "1" in the Bit Map field) are inconsistent with the Traffic Parameters.

6.3. Supporting Virtual Concatenation and Multiplication

Per [RFC6344], the Virtual Concatenation Groups (VCGs) can be created using Co-Signaled style or Multiple LSPs style.

In case of Co-Signaled style, the explicit ordered list of all labels MUST reflect the order of VCG members, which is similar to [RFC4328].

In case of multiplexed virtually concatenated signals (NVC > 1), the first label MUST indicate the components of the first virtually concatenated signal; the second label MUST indicate the components of the second virtually concatenated signal; and so on. In case of multiplication of multiplexed virtually concatenated signals (MT > 1), the first label MUST indicate the components of the first multiplexed virtually concatenated signal; the second label MUST indicate components of the second multiplexed virtually concatenated signal; and so on.

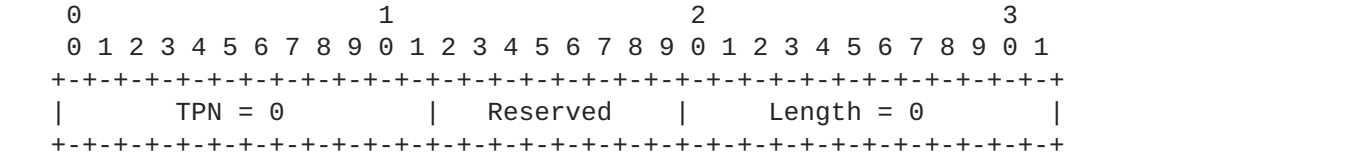
In case of Multiple LSPs style, multiple control plane LSPs are created with a single VCG and the VCAT Call SHOULD be used to associate the control plane LSPs. The procedures are similar to section 6 of [RFC6344].

6.4. Examples

The following examples are given in order to illustrate the label format described in Section 5.1 of this document.

(1) ODUk into OTUk mapping:

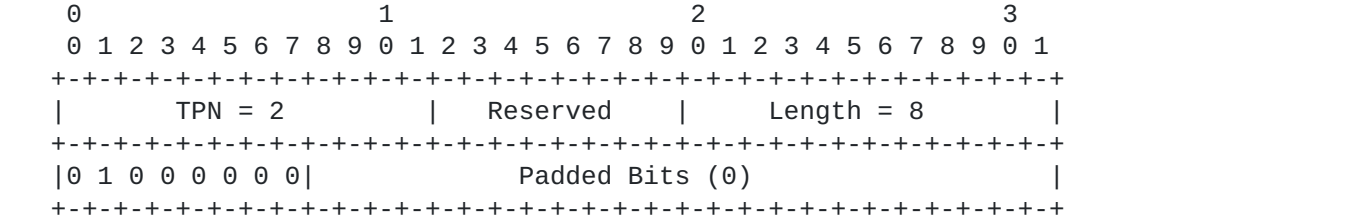
In such conditions, the downstream node along an LSP returns a label indicating that the ODUk (k=1, 2, 3, 4) is directly mapped into the corresponding OTUk. The following example label indicates an ODU1 mapped into OTU1.



(2) ODUj into ODUk multiplexing:

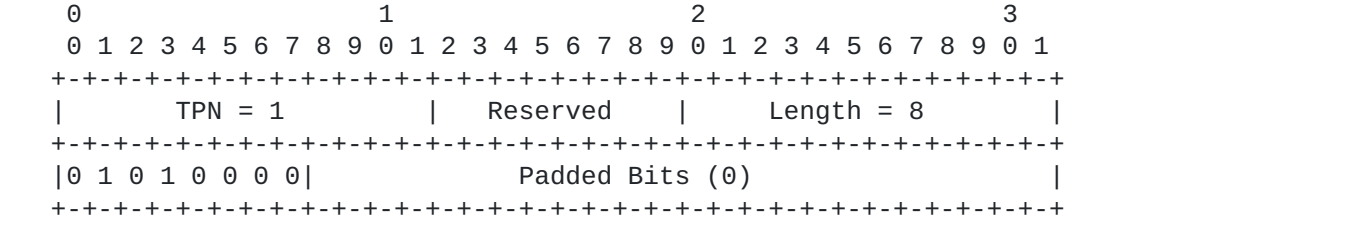
In such conditions, this label indicates that an ODUj is multiplexed into several tributary slots of OPUk and then mapped into OTUk. Some instances are shown as follow:

- ODU0 into ODU2 Multiplexing:



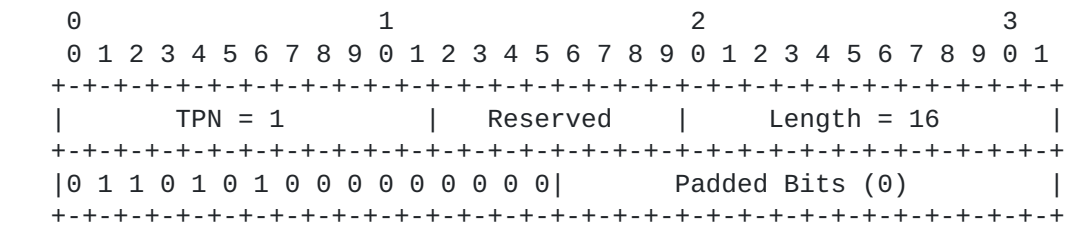
This above label indicates an ODU0 multiplexed into the second tributary slot of ODU2, wherein there are 8 TS in ODU2 (i.e., the type of the tributary slot is 1.25Gbps), and the TPN value is 2.

- ODU1 into ODU2 Multiplexing with 1.25Gbps TS granularity:



This above label indicates an ODU1 multiplexed into the 2nd and the 4th tributary slot of ODU2, wherein there are 8 TS in ODU2 (i.e., the type of the tributary slot is 1.25Gbps), and the TPN value is 1.

- ODU2 into ODU3 Multiplexing with 2.5Gbps TS granularity:



This above label indicates an ODU2 multiplexed into the 2nd, 3rd, 5th and 7th tributary slot of ODU3, wherein there are 16 TS in ODU3 (i.e., the type of the tributary slot is 2.5Gbps), and the TPN value is 1.

7. Supporting Hitless Adjustment of ODUflex (GFP)

[G7044] describes the procedure of ODUflex (GFP) hitless resizing using Link Connection Resize (LCR) and Bandwidth Resize (BWR) protocols in OTN data plane.

For the control plane, signaling messages are REQUIRED to initiate the adjustment procedure. Section 2.5 and Section 4.6.4 of [RFC3209] describe how the Shared Explicit (SE) style is used in Traffic Engineering (TE) network for bandwidth increasing and decreasing, which is still applicable for triggering the ODUflex (GFP) adjustment procedure in data plane.

Note that the SE style MUST be used at the beginning when creating a resizable ODUflex connection (Signal Type = 21). Otherwise an error with Error Code "Conflicting reservation style" MUST be generated when performing bandwidth adjustment.

- Bandwidth increasing

  In order to increase the bandwidth of an ODUflex (GFP) connection, a Path message with SE style (keeping Tunnel ID unchanged and assigning a new LSP ID) MUST be sent along the path.

  A downstream node compares the old Traffic Parameters (stored locally) with the new one carried in the Path message, to determine the number of TS to be added. After choosing and reserving new free TS, the downstream node MUST send back a Resv message carrying both the old and new LABEL Objects in the SE flow descriptor, so that its upstream neighbor can determine

which TS are added. And the LCR protocol between each pair of neighbor nodes MUST be triggered.

On the source node, the BWR protocol will be triggered by the successful completion of LCR protocols on every hop after Resv message is processed. On success of BWR, the source node MUST send a PathTear message to delete the old control state (i.e., the control state of the ODUflex (GFP) before resizing) on the control plane.

- Bandwidth decreasing

The SE style SHOULD also be used for ODUflex bandwidth decreasing. For each pair of neighbor nodes, the sending and receiving Resv message with old and new LABEL Objects will trigger the first step of LCR between them to perform LCR handshake. On the source node, the BWR protocol will be triggered by the successful completion of LCR handshake on every hop after Resv message is processed. On success of BWR, the second step of LCR, i.e., link connection decrease procedure will be started on every hop of the connection.

Similarly, after completion of bandwidth decreasing, a ResvErr message SHOULD be sent to tear down the old control state.

8. Control Plane Backward Compatibility Considerations

As described in [OTN-FWK], since the [RFC4328] has been deployed in the network for the nodes that support the 2001 revision of the G.709 specification, control plane backward compatibility SHOULD be taken into consideration. More specifically:

- Nodes supporting this document SHOULD support [OTN-OSPF].
- Nodes supporting this document MAY support [RFC4328] signaling.
- A node supporting both sets of procedures (i.e., [RFC4328] and this document) is not REQUIRED to signal an LSP using both procedures, i.e., to act as a signaling version translator.
- Ingress nodes that support both sets of procedures MAY select which set of procedures to follow based on routing information or local policy.

- Per [RFC3473], nodes that do not support this document will generate a PathErr message, with a "Routing problem/Switching Type" indication.

9. Security Considerations

This document introduces no new security considerations to the existing GMPLS signaling protocols. Referring to [RFC3473] and [RFC4328], further details of the specific security measures are provided. Additionally, [RFC5920] provides an overview of security vulnerabilities and protection mechanisms for the GMPLS control plane.

10. IANA Considerations

Three RSVP C-Types are defined for OTN-TDM Traffic Parameters and OTN-TDM Generalized Label in this document.

- OTN-TDM SENDER_TSPEC and FLOWSPEC objects:

  - OTN-TDM SENDER_TSPEC Object: Class = 12, C-Type = 7 (see Section 4)

  - OTN-TDM FLOWSPEC Object: Class = 9, C-Type = 7 (see Section 4)

- OTN-TDM Generalized Label Object:

  - OTN-TDM Generalized Label Object: Class = 16, C-Type = 2 (see Section 5.1)

IANA will also track the code-point spaces extended and/or updated by this document. The Generalized PID has been added in the newly requested registry entry:

- Generalized PID (G-PID):

  Name: G-PID

  Format: 16-bit number

  Values:

  [0..31, 36..46] defined in [RFC3471]

[32]	defined in [RFC3471] and updated by Section 3
[33..35]	defined in [RFC3471] and updated by [RFC4328]
[47, 49..52]	defined in [RFC4328] and updated by Section 3
[48, 53..58]	defined in [RFC4328]
[59..63]	defined in Section 3

Allocation Policy (as defined in [RFC4328]):

[0..31743]	Assigned by IANA via IETF Standards Track RFC Action.
[31744..32767]	Assigned temporarily for Experimental Usage
[32768..65535]	Not assigned. Before any assignments can be made in this range, there MUST be a Standards Track RFC that specifies IANA Considerations that covers the range being assigned.

11. References

11.1. Normative References

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Intellectual Property

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