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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

Recent progress in ITU-T Recommendation G.709 standardization has introduced new ODU containers (ODU0, ODU4, ODU2e and ODUflex) and

enhanced Optical Transport Networking (OTN) flexibility. Several recent documents have proposed ways to modify GMPLS signaling protocols to support these new OTN features.

It is important that a single solution is developed for use in GMPLS signaling and routing protocols. This solution must support ODUk multiplexing capabilities, address all of the new features, be acceptable to all equipment vendors, and be extensible considering continued OTN evolution.

This document describes the extensions to the Generalized Multi-Protocol Label Switching (GMPLS) signaling to control the evolving Optical Transport Networks (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

Generalized Multi-Protocol Label Switching (GMPLS) [RFC3945] extends MPLS to include Layer-2 Switching (L2SC), Time-Division Multiplex (e.g., SONET/SDH, PDH, and ODU), Wavelength (OCh, Lambdas) Switching, and Spatial Switching (e.g., incoming port or fiber to outgoing port or fiber). [RFC3471] presents a functional description of the extensions to Multi-Protocol Label Switching (MPLS) signaling required to support Generalized MPLS. RSVP-TE-specific formats and mechanisms and technology specific details are defined in [RFC3473].

With the evolution and deployment of G.709 technology, it is necessary that appropriate enhanced control technology support be provided for G.709. [RFC4328] describes the control technology details that are specific to foundation G.709 Optical Transport Networks (OTN), as specified in the ITU-T Recommendation G.709 [G709-V1], for ODUk deployments without multiplexing.

In addition to increasing need to support ODUk multiplexing, the evolution of OTN has introduced additional containers and new flexibility. For example, ODU0, ODU2e, ODU4 containers and ODUflex are developed in [G709-V3].

In addition, the following issues require consideration:

- Support for Hitless Adjustment of ODUflex (GFP) (HAO), which is defined in [G.7044].

- Support for Tributary Port Number. The Tributary Port Number has to be negotiated on each link for flexible assignment of tributary ports to tributary slots in case of LO-ODU over HO-ODU (e.g., ODU2 into ODU3).

Therefore, it is clear that [RFC4328] has to be updated or superceded in order to support ODUk multiplexing, as well as other ODU enhancements introduced by evolution of OTN standards.

This document updates [RFC4328] extending the G.709 ODUk traffic parameters and also presents a new OTN label format which is very flexible and scalable.

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-V3]. 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 (TSG) (i.e., 1.25 Gbps) is also described in [G709-V3]. 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 OPUk (OPUk-Xv, k = 1/2/3, X = 1...256) is also supported by [OTN-V3]. Note that VCAT of OPU0 / OPU2e / OPU4 / OPUflex is not supported per [OTN-V3].

[RFC4328] describes GMPLS signaling extensions to support the control for G.709 Optical Transport Networks (OTN) [G709-V1]. 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-MSI mode which assumes that the Tributary Port Number 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 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 [G709-v1].

This document follows these extensions and a new Switching Type is introduced to indicate the ODUk switching capability [G709-V3] 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 at 2.5, 10 and 40 Gbps via 2.5Gbps TSG
49	CBRa: asynchronous Constant Bit Rate (i.e., mapping of CBR2G5, CBR10G and CBR40G)
50	CBRb: bit synchronous Constant Bit Rate (i.e., mapping of CBR2G5, CBR10G, CBR40G, CBR10G3 and supra-2.488 CBR Gbit/s signal (carried by OPUflex))
32	ATM: mapping at 1.25, 2.5, 10 and 40 Gbps
51	BSOT: non-specific client Bit Stream with Octet Timing (i.e., Mapping of 1.25, 2.5, 10, 40 and 100 Gbps Bit Stream)
52	BSNT: non-specific client Bit Stream without Octet Timing (i.e., Mapping of 1.25, 2.5, 10, 40 and 100 Gbps Bit Stream)

Note: Values 32, 47, 49 and 50 include mapping of SDH.

In the case of ODU multiplexing, the LO ODU (i.e., the client signal)
may be multiplexed into 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 needed:

- 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-V3]:

- CBRc: Mapping of constant bit-rate signals with justification into OPUk (k = 0, 1, 2, 3, 4) via 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

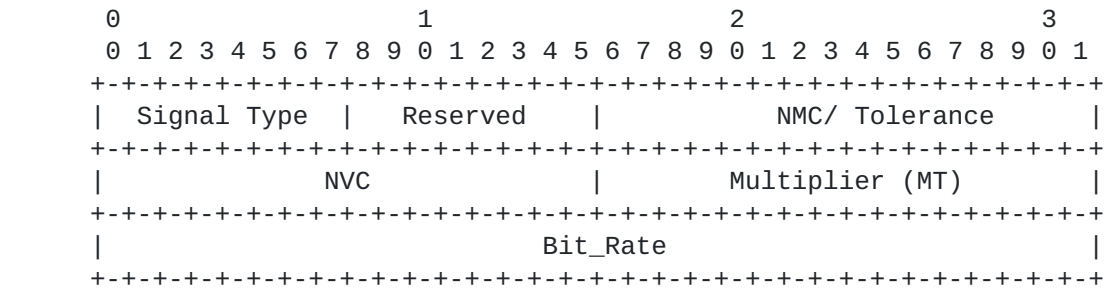
The following table summarizes the new G-PID values with respect to the LSP Encoding Type:

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 G.709 are defined as follows:



The Signal Type needs to be extended in order to cover the new Signal Type introduced by the evolving OTN. The new Signal Type values are extended as follows:

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	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(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)

NMC/Tolerance:

This field is redefined from the original definition in [RFC4328]. NMC field defined in [RFC4328] cannot be fixed value for an end-to-end circuit involving dissimilar OTN link types. For example, ODU2e requires 9 TS on ODU3 and 8 TS on ODU4. Usage of NMC field is deprecated and should be used only with [RFC4328] generalized label format for backwards compatibility reasons. For the new generalized label format as defined in this document this field is interpreted as Tolerance.

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 is 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].

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-V3]) 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-V3]:

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

The ODTUk.ts nominal bit rate is the nominal bit rate of the tributary slot of ODUk, as shown in Table 1 (referring to [G709-V3]).

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

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.

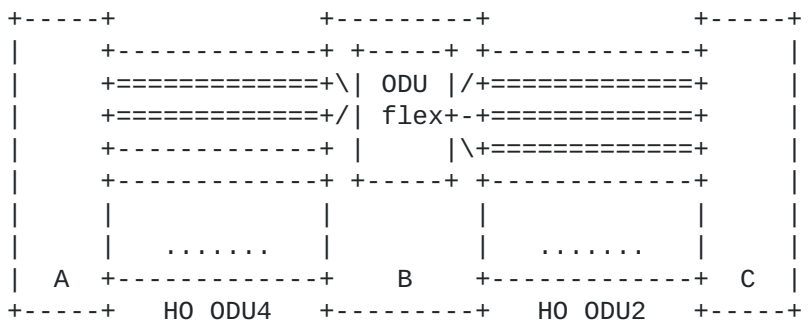


Figure 1 - Example of ODUflex(CBR) Traffic Parameters

- 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 217Gbps, so the total number of tributary slots N1 to be reserved on this link is:

  N1 = ceiling (2.5Gbps * (1 + 100ppm) / 1.301 683 217Gbps) = 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 632Gbps, so the total number of tributary slots N2 to be reserved on this link is:

  N2 = ceiling (2.5Gbps * (1 + 100ppm) / 1.249 384 632Gbps) = 3

5.2. Usage of ODUflex(GFP) Traffic Parameters

[G709-V3-A2] 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.

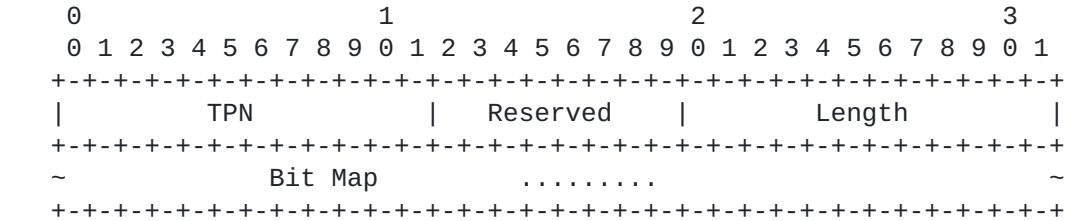
6. Generalized Label

[RFC3471] has defined the Generalized Label which extends the traditional label by allowing the representation of not only labels which are sent in-band with associated data packets, but also labels which identify time-slots, wavelengths, or space division multiplexed positions. The format of the corresponding RSVP-TE Generalized Label object is defined in the Section 2.3 of [RFC3473].

However, for different technologies, we usually need use specific label rather than the Generalized Label. For example, the label format described in [RFC4606] could be used for SDH/SONET, the label format in [RFC4328] for G.709.

6.1. New definition of ODU Generalized Label

In order to be compatible with new types of ODU signal and new types of tributary slot, the following new ODU label format MUST be used:



The ODU 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 can be figured out locally according to the identifier of the selected interface carried in the IF_ID RSVP_HOP Object.

TPN (12 bits): indicates the Tributary Port Number (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.

As per [G709-V3], 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-V3], 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

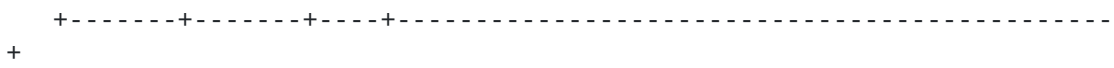


Table 4 - TPN Assignment Rules (1.25Gbps TS granularity)

HO ODUk	LO ODUj	TPN	TPN Assignment Rules
ODU1	ODU0	1~2	Fixed, = TS# occupied by ODU0
ODU2	ODU1	1~4	Flexible, != other existing LO ODU1s' TPNs
	ODU0 & ODUflex	1~8	Flexible, != other existing LO ODU0s and ODUflexes' TPNs
ODU3	ODU1	1~16	Flexible, != other existing LO ODU1s' TPNs
	ODU2	1~4	Flexible, != other existing LO ODU2s' TPNs
	ODU0 & ODU2e & ODUflex	1~32	Flexible, != other existing LO ODU0s and ODU2es and ODUflexes' TPNs
ODU4	Any ODU	1~80	Flexible, != ANY other existing LO ODUs' TPNs

Note that in the case of "Flexible", the value of TPN is not corresponding to the TS number as per [G709-V3].

Length (12 bits): indicates the number of bit of the Bit Map field, i.e., the total number of TS in the HO ODUk link.

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.

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

Note that the Length field in the label format can also 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 LMP (Link Management Protocol)

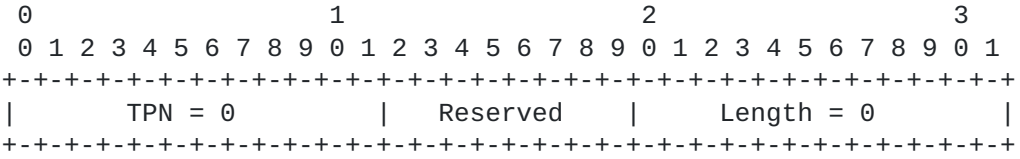
or routing to make the two end points of the link to know the TSG, the TSG information used by another end can be deduced from the label format. For example, for HO ODU2 link, the value of the length filed will be 4 or 8, which indicates the TS granularity is 2.5Gbps or 1.25Gbps, respectively.

6.2. Examples

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

(1) ODUk into OTUk mapping:

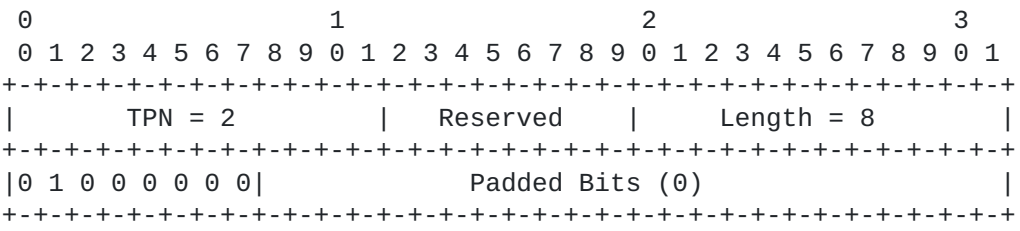
In such conditions, the downstream node along an LSP returns a label indicating that the ODUk (k=1, 2, 3, 4) is directly mapped into the corresponding OTUk. The following example label indicates an ODU1 mapped into OTU1.



(2) ODUj into ODUk multiplexing:

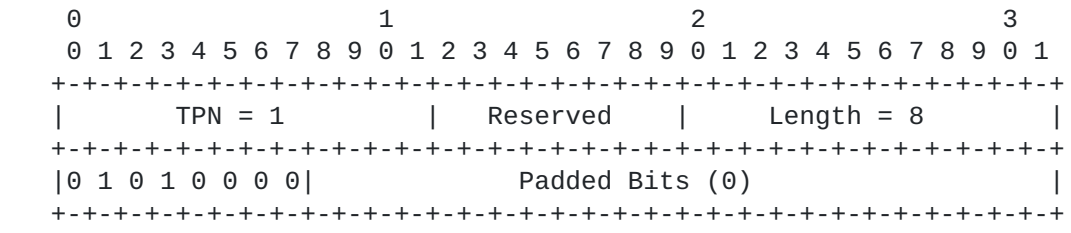
In such conditions, this label indicates that an ODUj is multiplexed into several tributary slots of OPUk and then mapped into OTUk. Some instances are shown as follow:

- ODU0 into ODU2 Multiplexing:



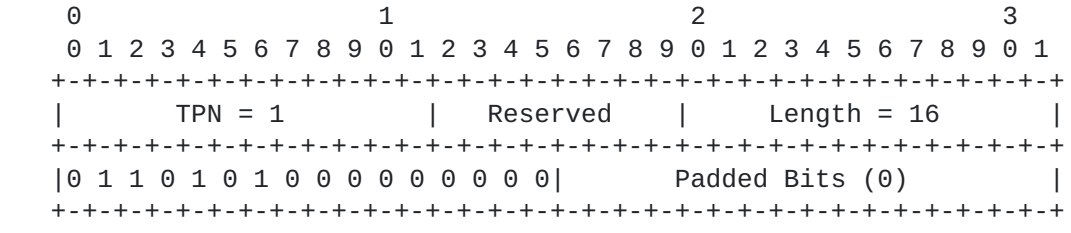
This above label indicates an ODU0 multiplexed into the second tributary slot of ODU2, wherein there are 8 TS in ODU2 (i.e., the type of the tributary slot is 1.25Gbps), and the TPN value is 2.

- 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.

6.3. Label Distribution Procedure

This document does not change the existing label distribution procedures [RFC4328] for GMPLS except that the new ODUk label MUST be processed as follows.

When a node receives a generalized label request for setting up an ODUj LSP from its upstream neighbor node, the node MUST generate an ODU 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 does not collide with other TPN value used by existing LO ODU connections in the selected HO ODU link, and configure the expected multiplex structure identifier (ExMSI) using this TPN. Then, the assigned TPN is filled into the label.

In case of ODUk to OTUk mapping, the node only needs to fill the ODUj and the ODUk fields with corresponding values in the label. Other bits are reserved and MUST be set to 0.

In order to process a received ODU label, the node MUST firstly learn 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.

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

Note that the procedures of other label related objects (e.g., Upstream Label, Label Set) are similar to the one described above.

Note also that the TPN in the label_ERO MAY not be assigned (i.e., TPN field = 0) if the TPN is requested to be assigned locally.

6.3.1. Notification on Label Error

When receiving an ODUk label from the neighbor node, the node SHOULD check the integrity of the label. An error message containing an "Unacceptable label value" indication ([RFC3209]) SHOULD 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 reserved resources (i.e., the number of "1" in the Bit Map field) do not match with the Traffic Parameters.

6.4. Supporting Virtual Concatenation and Multiplication

As per [RFC6344], the 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 reflects the order of VCG members, which is similar to [RFC4328]. In case of multiplexed virtually concatenated signals (NVC > 1), the first label indicates the components of the first virtually concatenated signal; the second label indicates 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 indicates the components of the first multiplexed virtually concatenated signal; the second label indicates 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 can be used to associate the control plane LSPs. The procedures are similar to section 6 of [RFC6344].

7. Supporting Multiplexing Hierarchy

As described in [OTN-FWK], one ODUj connection can be nested into another ODUk (j<k) connection, which forms the multiplexing hierarchy in the ODU layer. This is useful if there are some intermediate nodes in the network which only support ODUk but not ODUj switching.

For example, in Figure 2, assume that N3 is a legacy node which only supports [G709-V1] and does not support ODU0 switching. If an ODU0 connection between N1 and N5 is required, then we can create an ODU2 connection between N2 and N4 (or ODU1 / ODU3 connection, depending on policies and the capabilities of the two ends of the connection), and nest the ODU0 into the ODU2 connection. In this way, N3 only needs to perform ODU2 switching and does not need to be aware of the ODU0 connection.

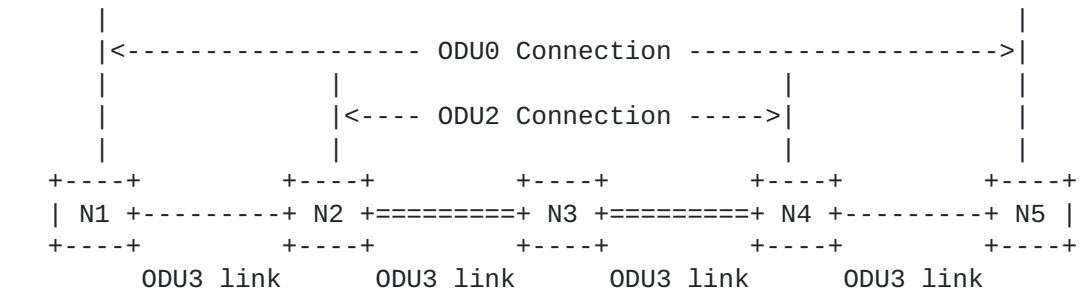


Figure 2 - Example of multiplexing hierarchy

The control plane signaling should support the provisioning of hierarchical multiplexing. Two methods are provided below (taking Figure 2 as example):

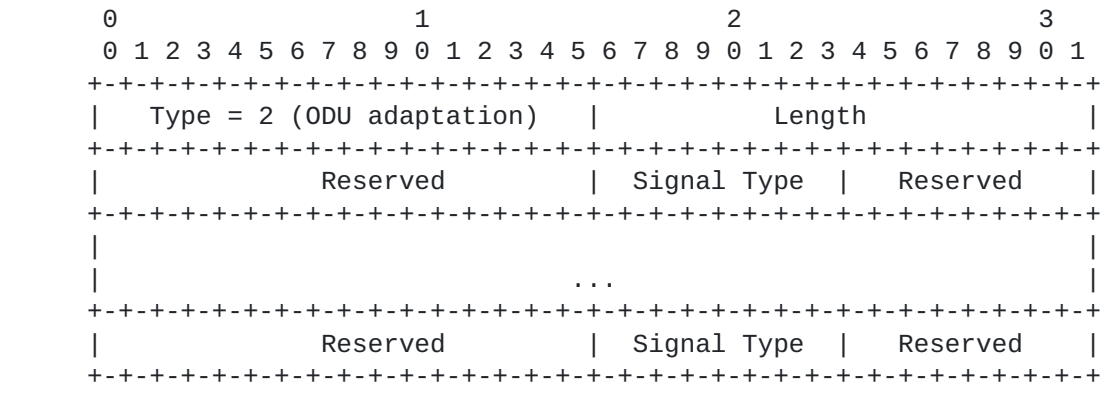
- Using the multi-layer network signaling described in [RFC4206], [RFC6107] and [RFC6001] (including related modifications, if needed). That is, when the signaling message for ODUO connection arrives at N2, a new RSVP session between N2 and N4 is triggered to create the ODU2 connection. This ODU2 connection is treated as a Forwarding Adjacency (FA) after it is created. And then the signaling procedure for the ODU0 connection can be continued using the resource of the ODU2 FA.

- The ODU2 FA-LSP is created in advance based on network planning, which is treated as an FA. Then the ODU0 connection can be created using the resource of the ODU2 FA. In this case, the ODU2 FA-LSP and inner ODU0 connections are created separately.

For both methods, when creating an FA-LSP(e.g., ODU2 FA-LSP), the penultimate hop needs to choose a correct outgoing interface for the ODU2 connection, so that the destination node can support multiplexing and de-multiplexing LO ODU signal(e.g., ODU0). In order to choose a correct outgoing interface for the penultimate hop of the FA-LSP, multiplexing capability (i.e., what client signal type that can be adapted directly to this FA-LSP) should be carried in the signaling to setup this FA-LSP. In addition, when Auto_Negotiation in the data plane is not enabled, TS granularity may also be needed.

7.1. Extension to LSP_ATTRIBUTES Object

In order to indicate the adaptation information for a requested FA-LSP (i.e., the server layer LSP) to carry the client LSP, a new type of Attributes TLV of the LSP_ATTRIBUTES Object (Class-Num = 197, C-Type = 1, defined in [RFC5420]) is defined:



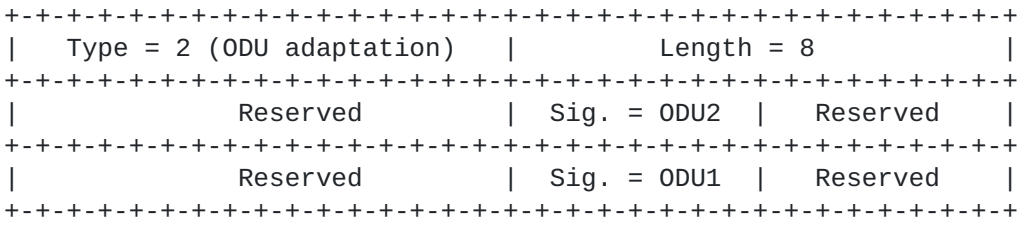
One or more ODU adaptation TLVs can be carried to indicate the desired adaptation capabilities. Each of an ODU adaptation TLV for each branch of the client signal multiplexing supported by the server LSP MUST be used. Inside each TLV a row for each stage of the hierarchy MUST be included.

A row for the server stage MUST NOT be included as it is already signaled via the Traffic Parameters.

The number of stages is implicitly inferred from the length value.

Signal Type: as defined in [RFC4328] and this document.

For example, in order to create ODU3 FA-LSP passing through a set of ODU4 links to perform ODU1->ODU2->ODU3 hierarchy, the ODU adaptation TLV can be used to indicate the ODU2 into ODU3 multiplexing and ODU1 into ODU2 multiplexing stages.



7.2. ODU FA-LSP Creation

When creating an ODU FA-LSP to carry lower ODU, the source node (e.g., node N2 in Figure 2) can include the LSP_ATTRIBUTES object to specify the desired ODU adaptation capabilities.

On receiving the Path message, the penultimate node on the FA-LSP (e.g., node N3 in Figure 2) MUST select an outgoing link which can support the TS granularity (indicated in the G-PID filed in Section 4)
and the multiplexing hierarchy (listed in the LSP_ATTRIBUTES object).
If no link supporting the specified hierarchy capabilities or TSG, a ParhErr message with Error Code = 38 (LSP Hierarchy Issue) and Error Value = y1(TBA) MUST be sent back to upstream.

Intermediate nodes (except end points and penultimate node) along the
FA-LSP don't need to process the ODU adaptation TLV, which SHOULD be forwarded to the next node in the Path message without any modification.

8. Supporting Hitless Adjustment of ODUflex (GFP)

[G.7044] describes the procedure of ODUflex (GFP) hitless resizing using LCR (Link Connection Resize) and BWR (Bandwidth Resize) 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 Share Explicit (SE) style is used in 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 SHOULD be used at the beginning when creating a resizable ODUflex connection (Signal Type = 21). Otherwise an error
with Error Code "Conflicting reservation style" will be generated when performing bandwidth adjustment.

If any node along the ODUflex connection doesn't support hitless resizing, a Notify message with Error Code = x2 and Error Value = y1 will be sent to the source node. The source node MAY keep the connection and treat it as a non resizable ODUflex connection, or MAY
tear it down, depending on the local policy.

- 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) is 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 sends 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 is 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 SHOULD 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 can 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.

9. Control Plane Backward Compatibility Considerations

Since the [RFC4328] has been deployed in the network for the nodes that support [G709-V1], control plane backward compatibility SHOULD be taken into consideration when the new nodes (supporting [G709-V3] and RSVP-TE extensions defined in this document) and the legacy nodes (supporting [G709-V1] and [RFC4328]) are interworking.

The backward compatibility needs to be considered only when controlling ODU1 or ODU2 or ODU3 connection, because legacy nodes can only support these three ODU signal types. In such case, new nodes can fall back to use signaling message defined in [RFC4328] when detecting legacy node on the path. More detailedly:

o When receiving Path message using [RFC4328] (i.e., Switching Type = 100), a new node SHOULD follow [RFC4328] to process and reply it.

o A source node of an ODU LSP can send Path message using new OTN control message (with new Switching Type = 101, TBA by IANA). If

there is legacy node on the LSP, it will fail to process the Generalized Label Request Object because of unknown of the new Switching Type, and reply a PathErr message indicating unknown of this object. The source node MAY re-signal the Path message using [RFC4328], depending on local policies.

o Alternatively, if a new node has known that its neighbor only supports [RFC4328] in advance (e.g., through manual configuration or auto discovery mechanism), the new node MAY act as an RSVP agent to translate new RSVP-TE message into old one before sending to its neighbor.

No special compatibility consideration needs to be taken if the legacy device has updated its control plane to support this document.

10. Security Considerations

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

11. IANA Considerations

- G.709 SENDER_TSPEC and FLOWSPEC objects:

  The traffic parameters, which are carried in the G.709 SENDER_TSPEC and FLOWSPEC objects, do not require any new object class and type based on [RFC4328]:

  o G.709 SENDER_TSPEC Object: Class = 12, C-Type = 5 [RFC4328]

  o G.709 FLOWSPEC Object: Class = 9, C-Type = 5 [RFC4328]

- Generalized Label Object:

  The new defined ODU label (Section 6) is a kind of generalized label. Therefore, the Class-Num and C-Type of the ODU label is the same as that of generalized label described in [RFC3473], i.e., Class-Num = 16, C-Type = 2.

- LSP_ATTIBUTES Object:

New TLV with Type = 2 (TBA). This TLV is carried in the LSP_ATTIBUTES Object (Class-Num = 197, C-Type = 1). See Section 7 for the detail definition.

- Error Code = 38 (LSP Hierarchy Issue, referring to [RFC6107]):

  A new Error Value is added to the Error Code "LSP Hierarchy Issue":

Error Value	Error case
y1	Last hop of an ODU FA-LSP doesn't support specified adaptation capabilities (Section 7.2).

- Error Code = x2:

  New Error Code, indicating errors occurring when controlling a resizable ODUflex connection.

Error Value	Error case
y1	Do not support hitless assignment of ODUflex (GFP) (Section 8).

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