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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, which is to be specified in ITU-T G.hao.

- 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 (TS) granularity (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-frwk].

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].

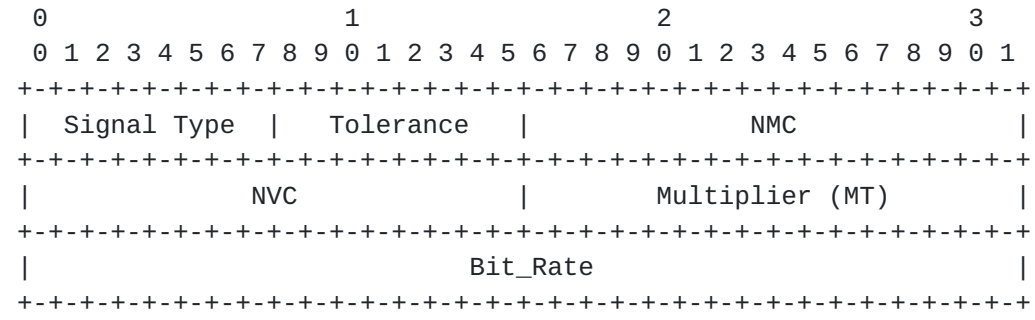
[RFC4328] describes GMPLS signaling extensions to support the control for G.709 Optical Transport Networks (OTN) [G709-V1]. However, [RFC4328] needs to be updated because it does not provide the means to signal all the new signal types and related mapping and multiplexing functionalities. Moreover, it 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. 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)

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

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

4.1. Usage of ODUflex(CBR) Traffic Parameter

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

N = Ceiling of

$$\frac{\text{ODUflex(CBR) nominal bit rate} * (1 + \text{ODUflex(CBR) bit rate tolerance})}{\text{ODTUk.ts nominal bit rate} * (1 - \text{HO OPUk bit rate tolerance})}$$

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

Table 1 below shows the actual bandwidth of the tributary slot of ODUk (in Gbps), referring to [G709-V3].

Table 1 - Actual TS bandwidth of ODUk

ODUk	Minimum	Nominal	Maximum
ODU2	1.249 384 632	1.249 409 620	1.249 434 608
ODU3	1.254 678 635	1.254 703 729	1.254 728 823
ODU4	1.301 683 217	1.301 709 251	1.301 735 285

Note that:

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

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

Where: HO OPUk bit rate tolerance = 20ppm

For different ODUk, the bandwidths of the tributary slot 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. This is why the traffic parameter should bring the actual bandwidth information other than the NMC field.

4.2. Example of ODUflex(CBR) Traffic Parameter

This section gives an example to illustrate the usage of ODUflex(CBR) traffic parameter.

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 parameter indicates that Signal Type is 33 (ODUflex(CBR)), Bit_Rate is 2.5Gbps and Tolerance is 100ppm.

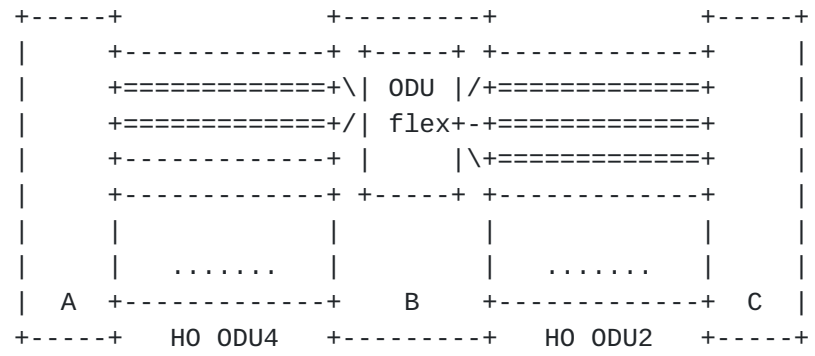


Figure 1 - Example of ODUflex(CBR) Traffic Parameter

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

  The maximum bandwidth of the ODUflex equals 2.5Gbps * (1 + 100ppm), and the minimum bandwidth 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) / 1.301 683 217) = 2

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

  The maximum bandwidth of the ODUflex equals 2.5Gbps * (1 + 100ppm), and the minimum bandwidth 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) / 1.249 384 632) = 3

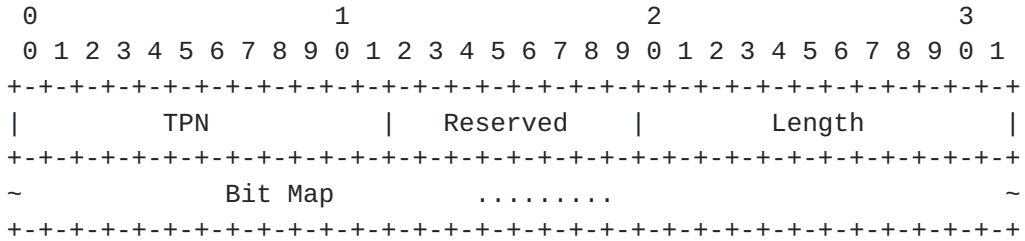
5. Generalized Label

[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.

5.1. 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 2 - TPN Assignment Rules (2.5Gbps TS granularity)

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

Table 3 - 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
	ODU1	1~16	Flexible, != other existing LO ODU1s' TPNs
ODU3	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 or routing to make the two

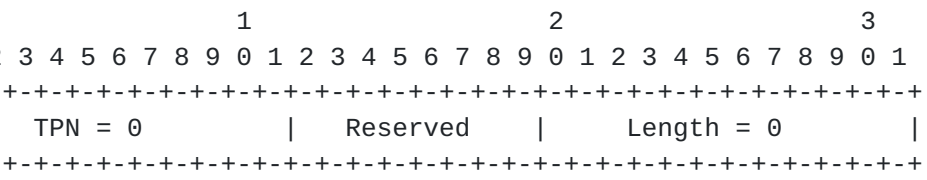
end points of the link to know the TSG, the TSG information used by another end can be deduced from the label format. For example, for HO ODU2 link, the value of the length filed will be 4 or 8, which indicates the TS granularity is 2.5Gbps or 1.25Gbps, respectively.

5.2. 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:

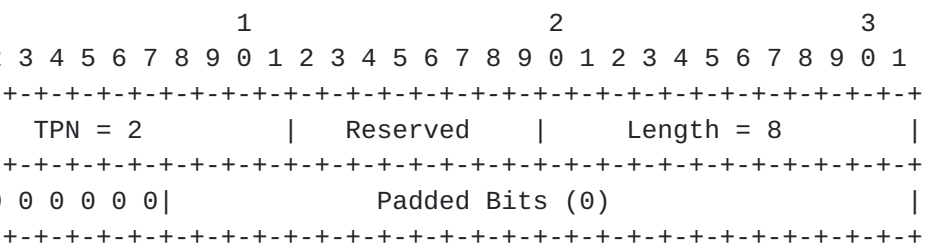
In such conditions, the downstream node along an LSP returns a label indicating that the ODUk (k=1, 2, 3, 4) is directly mapped into the corresponding OTUk. The following example label indicates an ODU1 mapped into OTU1.



(2) ODUj into ODUk multiplexing:

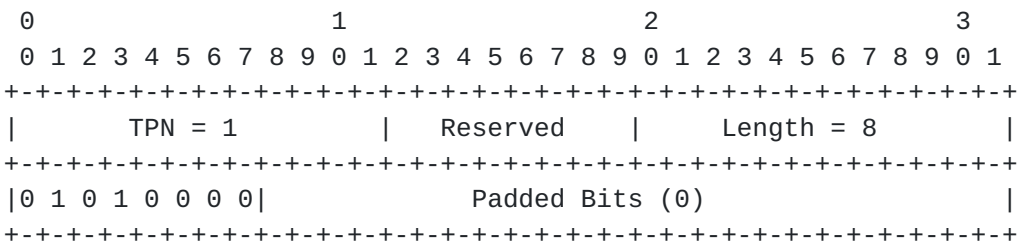
In such conditions, this label indicates that an ODUj is multiplexed into several tributary slots of OPUk and then mapped into OTUk. Some instances are shown as follow:

- ODU0 into ODU2 Multiplexing:



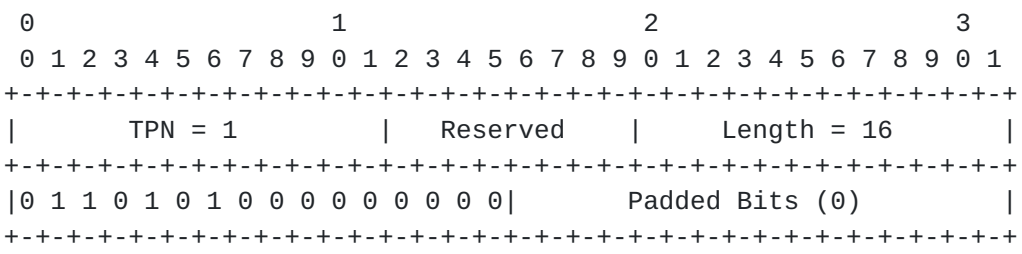
This above label indicates an ODU0 multiplexed into the second tributary slot of ODU2, wherein there are 8 TS in ODU2 (i.e., the type of the tributary slot is 1.25Gbps), and the TPN value is 2.

- 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.

5.3. 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.

5.3.1. 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.

5.4. Supporting Virtual Concatenation and Multiplication

As per [VCAT], 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 [VCAT].

5.5. Control Plane Backward Compatibility Considerations

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

For backward compatibility consideration, the new node SHOULD have the ability to generate and parse legacy labels.

- A legacy node always generates and sends legacy label to its upstream node, no matter the upstream node is new or legacy, as described in [RFC4328].

- A new node SHOULD generate and send legacy labels if its upstream node is a legacy one, and generate and send new label if its upstream node is a new one.

One backward compatibility example is shown in Figure 2:

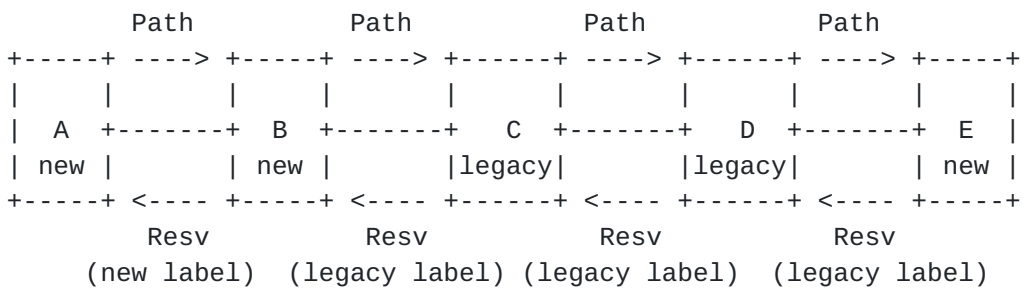


Figure 2 - Backwards compatibility example

As described above, for backward compatibility considerations, it is necessary for a new node to know whether the neighbor node is new or legacy.

One optional method is manual configuration, but it is recommended to use LMP to discover the capability of the neighbor node automatically, as described in [OTN-LMP].

When performing the HO ODU link capability negotiation:

- If the neighbor node only support the 2.5Gbps TS and only support ODU1/ODU2/ODU3, the neighbor node SHOULD be treated as a legacy node.

- If the neighbor node can support the 1.25Gbps TS, or can support other LO ODU types defined in [G709-V3]), the neighbor node SHOULD be treated as new node.

- If the neighbor node returns a LinkSummaryNack message including an ERROR_CODE indicating nonsupport of HO ODU link capability negotiation, the neighbor node SHOULD be treated as a legacy node.

6. Supporting Multiplexing Hierarchy

As described in [OTN-FRWK], 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 3, 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.

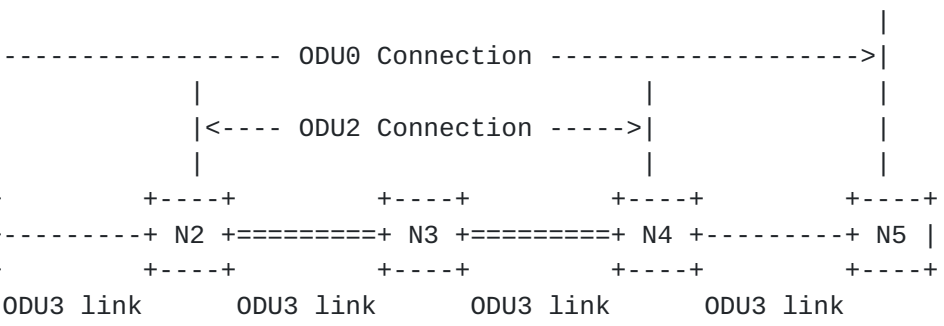


Figure 3 - Example of multiplexing hierarchy

The control plane signaling should support the provisioning of hierarchical multiplexing. Two methods are provided below (taking Figure 3 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.

6.1. ODU FA-LSP Creation

The required hierarchies and TS type for both ends of an FA-LSP is for further study.

7. 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.

8. 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 5) 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.

9. References

9.1. Normative References

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