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GMPLS Signaling Extensions for Control of Evolving G.709 Optical Transport Networks

Abstract

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

This document updates the ODU-related portions of RFC 4328 to provide extensions to GMPLS signaling to control the full set of OTN features, including ODU0, ODU4, ODU2e, and ODUflex.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 5741.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at http://www.rfc-editor.org/info/rfc7139.

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1. Introduction

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

[RFC7062] 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, [RFC7096] 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 the ODU-related portions of [RFC4328] to provide Resource Reservation Protocol - Traffic Engineering (RSVP-TE) extensions to support 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 (i.e., 1.25 Gbps) is also described in [G709-2012]. Thus, there are now two tributary slot (TS) granularities for the foundation OTN ODU1, ODU2, and ODU3 containers. The TS granularity at 2.5 Gbps is used on the 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), [G709-2012] 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 [RFC7062].

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, [RFC7096] 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 (Multiframe Structure Identifier) 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-TDM Generalized Label format. (Here, TDM refers to Time-Division Multiplexing.) Additionally, procedures about Tributary Port Number assignment through the control plane are also provided in this document.

4. Generalized Label Request

The GENERALIZED_LABEL_REQUEST object, 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 object, 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 introduces a new Switching Type to indicate the ODUk Switching Capability [G709-2012] in order to support backward compatibility with [RFC4328], as described in [RFC7062]. The new Switching Type (OTN-TDM Switching Type) is defined in [RFC7138].

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

Value	G-PID Type
47	Type field updated from "G.709 ODUj" to "ODU-2.5G" to indicate transport of Digital Paths (e.g., at 2.5, 10, and 40 Gbps) via 2.5 Gbps TS granularity.
56	Type field updated from "ESCON" to "SBCON/ESCON" to align with [G709-2012] payload type 0x1A.

Note: Value 47 includes 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 a Higher Order ODU (HO ODU) via 1.25G TS granularity, 2.5G TS granularity, or ODU-any. Since the G-PID type "ODUk" defined in [RFC4328] is only used for 2.5 Gbps TS granularity, 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 1.25 Gbps TS granularity.

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

The full list of payload types defined in [G709-2012] and their mapping to existing and new G-PID types are as follows:

G.709 Payload Type	G-PID	Type/Comment	LSP Encoding
0x01		No standard value	
0x02	49	CBRa	G.709 ODUk
0x03	50	CBRb	G.709 ODUk
0x04	32	ATM	G.709 ODUk
0x05	59	Framed GFP	G.709 ODUk
	54	Ethernet MAC (framed GFP)	G.709 ODUk
	70	64B/66B GFP-F Ethernet	G.709 ODUk (k=2)
0x06		Not signaled	
0x07	55	Ethernet PHY (transparent GFP)	G.709 ODUk (k=0,3,4)
0x08	58	Fiber Channel	G.709 ODUk (k=2e)

0x09	59	Framed GFP	G.709 ODUk (k=2)
	70	64B/66B GFP-F Ethernet	G.709 ODUk (k=2)
0x0A	60	STM-1	G.709 ODUk (k=0)
0x0B	61	STM-4	G.709 ODUk (k=0)
0x0C	58	Fiber Channel	G.709 ODUk (k=0)
0x0D	58	Fiber Channel	G.709 ODUk (k=1)
0x0E	58	Fiber Channel	G.709 ODUflex
0x0F	58	Fiber Channel	G.709 ODUflex
0x10	51	BSOT	G.709 ODUk
0x11	52	BSNT	G.709 ODUk
0x12	62	InfiniBand	G.709 ODUflex
0x13	62	InfiniBand	G.709 ODUflex
0x14	62	InfiniBand	G.709 ODUflex
0x15	63	Serial Digital Interface	G.709 ODUk (k=0)
0x16	64	SDI/1.001	G.709 ODUk (k=1)
0x17	63	Serial Digital Interface	G.709 ODUk (k=1)
0x18	64	SDI/1.001	G.709 ODUflex
0x19	63	Serial Digital Interface	G.709 ODUflex
0x1A	56	SBCON/ESCON	G.709 ODUk (k=0)
0x1B	65	DVB_ASI	G.709 ODUk (k=0)
0x1C	58	Fiber Channel	G.709 ODUk
0x20	47	G.709 ODU-2.5G	G.709 ODUk (k=2,3)
	66	G.709 ODU-1.25G	G.709 ODUk (k=1)
0x21	66	G.709 ODU-1.25G	G.709 ODUk (k=2,3,4)
	67	G.709 ODU-any	G.709 ODUk (k=2,3)
0x55		No standard value	
0x66		No standard value	
0x80-0x8F		No standard value	
0xFD	68	Null Test	G.709 ODUk
0xFE	69	Random Test	G.709 ODUk
0xFF		No standard value	

Note: Values 59 and 70 include mapping of SDH.

Note that the mapping types for ODUj into OPUk are unambiguously per Table 7-10 of [G709-2012], so there is no need to carry mapping type information in the signaling.

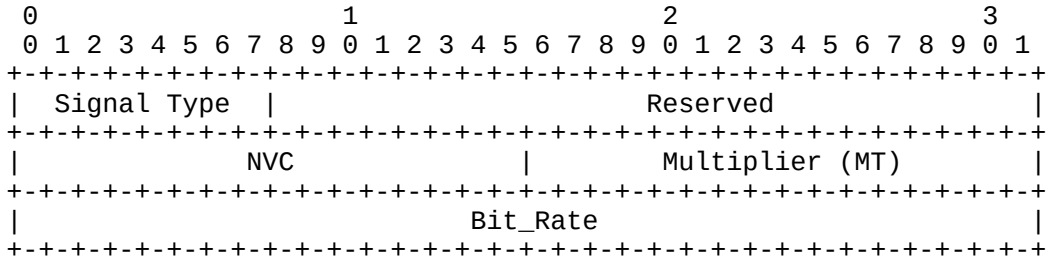
Note also that additional information on G.709 client mapping can be found in [G7041].

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

The Traffic Parameters for the OTN-TDM-capable Switching Type are carried in the OTN-TDM SENDER_TSPEC object in the Path message and the OTN-TDM FLOWSPEC object in the Resv message. The objects have the following class and type:

- OTN-TDM SENDER_TSPEC object: Class = 12, C-Type = 7
- OTN-TDM FLOWSPEC object: Class = 9, C-Type = 7

The format of Traffic Parameters in these two objects is defined as follows:



Signal Type: 8 bits

As defined in Section 3.2.1 of [RFC4328], with the following additional values:

Value	Type
4	ODU4 (i.e., 100 Gbps)
9	OCh at 100 Gbps
10	ODU0 (i.e., 1.25 Gbps)
11	ODU2e (i.e., 10 Gbps 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)

Note: Above, CBR stands for Constant Bit Rate, and GFP-F stands for Generic Framing Procedure - Framed.

NVC (Number of Virtual Components): 16 bits

As defined in Section 3.2.3 of [RFC4328]. This field MUST be set to 0 for ODUflex Signal Types.

Multiplier (MT): 16 bits

As defined in Section 3.2.4 of [RFC4328]. This field MUST be set to 1 for ODUflex Signal Types.

Bit_Rate: 32 bits

In the case of ODUflex, including ODUflex(CBR) and ODUflex(GFP) Signal Types, this field indicates the nominal bit rate of ODUflex expressed in bytes per second, encoded as a 32-bit IEEE single-precision floating-point number (referring to [RFC4506] and [IEEE]). For other Signal Types, this field MUST be set to zero on transmission, MUST be ignored on receipt, and SHOULD be passed unmodified by transit nodes.

5.1. Usage of ODUflex(CBR) Traffic Parameters

In the case of ODUflex(CBR), the Bit_Rate information carried in the ODUflex Traffic Parameters MUST be used to determine the actual bandwidth of ODUflex(CBR) (i.e., Bit_Rate * (1 +/- Tolerance)). Therefore, the total number of tributary slots N in the HO ODUk link can be reserved correctly. Where:

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

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]:

$$\text{ODUflex(CBR) nominal bit rate} = \text{CBR client bit rate} * (239/238) / T$$

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]).

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

Table 1: Actual TS Bit Rate of ODUk (in Kbps)

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)

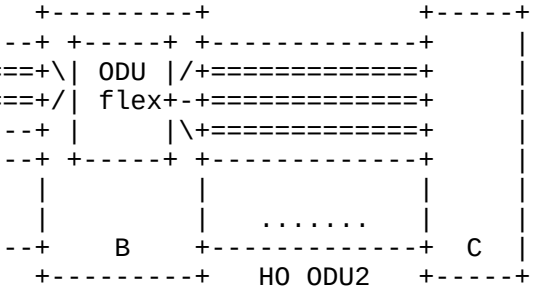
Where: HO OPUk bit rate tolerance = 20 ppm (parts per million)

Note that the bit rate tolerance is implicit in Signal Type and the ODUflex(CBR) bit rate tolerance is fixed and it is equal to 100 ppm as described in Table 7-2 of [G709-2012].

Therefore, a node receiving a Path message containing an ODUflex(CBR) nominal bit rate can allocate a 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, 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.



=========: TSs occupied by ODUflex
---------: available TSs

Figure 1: Example of ODUflex(CBR) Traffic Parameters

As shown in Figure 1, assume there is an ODUflex(CBR) service requesting a bandwidth of 2.5 Gbps from node A to node C.

In other words, the ODUflex Traffic Parameters indicate that Signal Type is 20 (ODUflex(CBR)) and Bit_Rate is 2.5 Gbps (note that the tolerance is not signaled as explained above).

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

  The maximum bit rate of the ODUflex(CBR) equals 2.5 Gbps * (1 + 100 ppm), 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 (2.5 Gbps * (1 + 100 ppm) / 1,301,683.217 Kbps) = 2

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

  The maximum bit rate of the ODUflex equals 2.5 Gbps * (1 + 100 ppm), 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 (2.5 Gbps * (1 + 100 ppm) / 1,249,384.632 Kbps) = 3

5.2. Usage of ODUflex(GFP) Traffic Parameters

[G709-2012] recommends that the ODUflex(GFP) 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.

ODU Type	Nominal Bit Rate	Tolerance
ODUflex(GFP) of n TSs, 1<=n<=8	n * ODU2.ts	+/-100 ppm
ODUflex(GFP) of n TSs, 9<=n<=32	n * ODU3.ts	+/-100 ppm
ODUflex(GFP) of n TSs, 33<=n<=80	n * ODU4.ts	+/-100 ppm

Table 2: Recommended ODUflex(GFP) Bit Rates and Tolerance

According to this table, the Bit_Rate field for ODUflex(GFP) MUST be 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.

5.3. Notification on Errors of OTN-TDM Traffic Parameters

There is no Adspec associated with the OTN-TDM SENDER_TSPEC object. Either the Adspec is omitted or an Int-serv Adspec with the Default General Characterization Parameters and Guaranteed Service fragment is used (see [RFC2210]).

For a particular sender in a session, the contents of the OTN-TDM FLOWSPEC object received in a Resv message SHOULD be identical to the contents of the OTN-TDM SENDER_TSPEC object received in the corresponding Path message. If the objects do not match, a ResvErr message with a "Traffic Control Error/Bad Flowspec value" error MUST be generated.

Intermediate and egress nodes MUST verify that the node itself, and the interfaces on which the LSP will be established, can support the requested Signal Type, NVC, and Bit_Rate values. If the requested value(s) cannot be supported, the receiver node MUST generate a PathErr message with a "Traffic Control Error/Service unsupported" indication (see [RFC2205]).

In addition, if the MT field is received with a zero value, the node MUST generate a PathErr message with a "Traffic Control Error/Bad Tspec value" indication (see [RFC2205]).

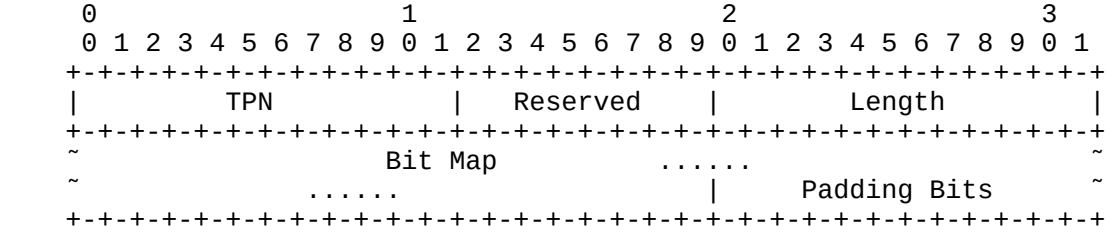
Further, if the Signal Type is not ODU1, ODU2, or ODU3, and the NVC field is not 0, the node MUST generate a PathErr message with a "Traffic Control Error/Bad Tspec value" indication (see [RFC2205]).

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 object format that MUST be used with the OTN-TDM Switching Type:



The OTN-TDM GENERALIZED_LABEL object 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 the case of an LO ODUj multiplexed into an HO ODU1/ODU2/ODU3, only the lower 6 bits of the TPN field are significant; the other bits of the TPN field MUST be set to 0.

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

- In the 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 an 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 according to the following tables:

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 (2.5 Gbps 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 ODU2s and ODUflexes' TPNs
ODU4	Any ODU	1-80	Flexible, != ANY other existing LO ODUs' TPNs

Table 4: TPN Assignment Rules (1.25 Gbps TS Granularity)

Note that in the case of "Flexible", the value of TPN MAY not correspond 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 TSs in the HO ODUk link. The TS granularity, 1.25 Gbps or 2.5 Gbps, may be derived by dividing the HO ODUk link's rate by

the value of the Length field. In the context of [G709-2012], the values of 4 and 16 indicate a TS granularity of 2.5 Gbps, and the values 2, 8, 32, and 80 indicate a TS granularity of 1.25 Gbps.

In the 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 the 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 the HO ODUk. Each bit in the bit map represents the corresponding tributary slot in the HO ODUk with a value of 1 or 0 indicating whether the tributary slot will be used by the 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 on receipt.

6.2. Procedures

The ingress node MUST generate a Path message and specify the OTN-TDM Switching Type and corresponding G-PID in the GENERALIZED_LABEL_REQUEST object, which MUST be processed as defined in [RFC3473].

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

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

The ingress node or upstream node MAY generate a LABEL_SET object 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 that is in the LABEL_SET object.

The ingress node or upstream node MAY also generate a SUGGESTED_LABEL object 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 labels; it may use another label based on local decision and send it to the upstream node, as described in [RFC3473].

When an upstream node receives a Resv message containing a GENERALIZED_LABEL object with an OTN-TDM label, it MUST first identify which ODU Signal Type is multiplexed or mapped into which ODU Signal Type according to the Traffic Parameters and the IF_ID RSVP_HOP object in the received message.

- In the 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 granularity (according to the total TS number of the ODUk or pre-configured TS granularity), so that the node can multiplex the ODUj into the ODUk based on the TS granularity. 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 Expected MSI (ExMSI) and determine whether there is any mismatch defect.

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

When a downstream node or egress node receives a Path message containing a GENERALIZED_LABEL_REQUEST object 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 available resources (i.e., available tributary slots of ODUk) that will be reserved for the LSP and send the label to its upstream neighbor node.

- In the case of ODUj-to-ODUk multiplexing, the node MUST first 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 values 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 the case of ODUk-to-OTUk mapping, the TPN field MUST be set to 0. Bit Map information is not required and MUST NOT be included, so the Length field MUST be set to 0 as well.

6.2.1. Notification on Label Error

When an upstream node receives a Resv message containing a GENERALIZED_LABEL object with an OTN-TDM label, the node MUST verify if the label is acceptable. If the label is not acceptable, the node MUST generate a ResvErr message with a "Routing problem/Unacceptable label value" indication. Per [RFC3473], the generated ResvErr message MAY include an ACCEPTABLE_LABEL_SET object. With the exception of label semantics, a downstream node processing a received ResvErr message and ACCEPTABLE_LABEL_SET object is not modified by this document.

Similarly, when a downstream node receives a Path message containing an UPSTREAM_LABEL object with an OTN-TDM label, the node MUST verify if the label is acceptable. If the label is not acceptable, the node MUST generate a PathErr message with a "Routing problem/Unacceptable label value" indication. Per [RFC3473], the generated PathErr message MAY include an ACCEPTABLE_LABEL_SET object. With the exception of label semantics, the upstream nodes processing a received PathErr message and ACCEPTABLE_LABEL_SET object are not modified by this document.

A received label SHALL be considered unacceptable when one of the following cases occurs:

- The received label doesn’t conform to local policy;

- An invalid value appears in the Length field;

- The selected link only supports 2.5 Gbps TS granularity while the Length field in the label along with ODUk Signal Type indicates the 1.25 Gbps TS granularity;

- The label includes an invalid TPN value that breaks the TPN assignment rules; and

- The indicated resources (i.e., the number of "1"s 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 the One LSP approach or the Multiple LSPs approach.

In the case of the One LSP approach, the explicit ordered list of all labels MUST reflect the order of VCG members, which is similar to [RFC4328]. In the 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 the 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.

Support for Virtual Concatenation of ODU1, ODU2, and ODU3 Signal Types, as defined by [RFC6344], is not modified by this document. Virtual Concatenation of other Signal Types is not supported by [G709-2012].

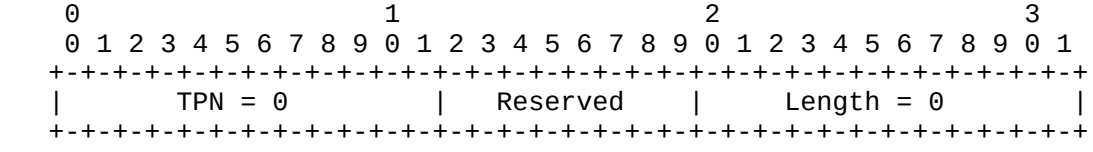
Multiplier (MT) usage is as defined in [RFC6344] and [RFC4328].

6.4. Examples

The following examples are given in order to illustrate the label format described in Section 6.1 of this document.

(1) ODUk-to-OTUk Mapping:

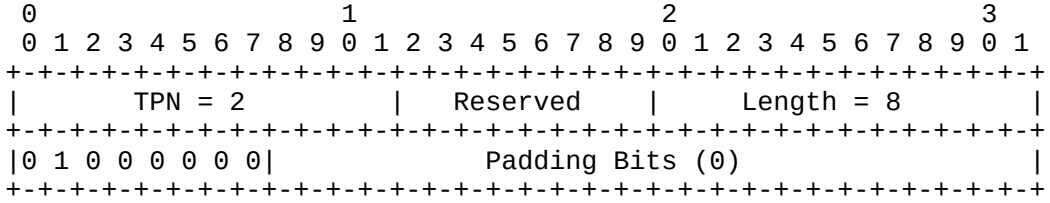
In this scenario, the downstream node along an LSP returns a label indicating that the ODUk (k=1, 2, 3, 4) is directly mapped into the corresponding OTUk. The following example label indicates an ODU1 mapped into OTU1.



(2) ODUj-to-ODUk Multiplexing:

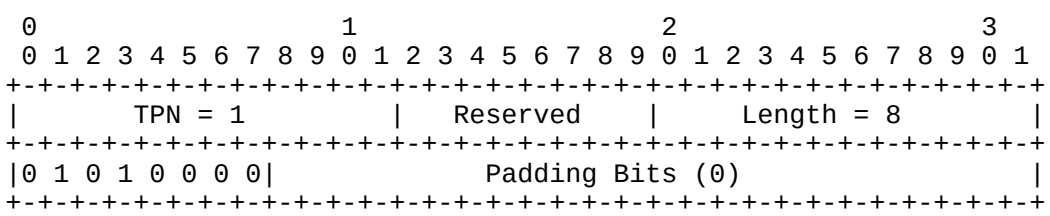
In this scenario, this label indicates that an ODUj is multiplexed into several tributary slots of OPUk and then mapped into OTUk. Some instances are shown as follows:

- ODU0-to-ODU2 Multiplexing:



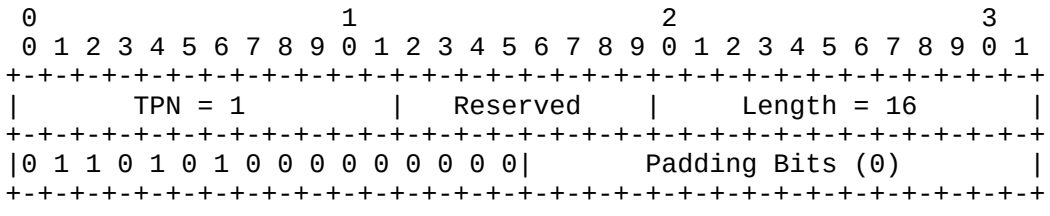
The label above indicates an ODU0 multiplexed into the second tributary slot of ODU2, wherein there are 8 TSs in ODU2 (i.e., the type of the tributary slot is 1.25 Gbps), and the TPN value is 2.

- ODU1-to-ODU2 Multiplexing with 1.25 Gbps TS Granularity:



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

- ODU2 into ODU3 Multiplexing with 2.5 Gbps TS Granularity:



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

7. Supporting Hitless Adjustment of ODUflex(GFP)

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

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

  For the ingress node, 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.

  The ingress node will trigger the BWR protocol when successful completion of LCR protocols on every hop after the Resv message is processed. On success of BWR, the ingress 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.

  A downstream node receiving a Path message with SE style compares the old Traffic Parameters (stored locally) with the new one carried in the Path message to determine the number of TSs to be added. After choosing and reserving new available TS(s), the downstream node MUST send back a Resv message carrying both the old and new GENERALIZED_LABEL objects in the SE flow descriptor.

  An upstream neighbor receiving a Resv message with an SE flow descriptor MUST determine which TS(s) is/are added and trigger the LCR protocol between itself and its downstream neighbor node.

- Bandwidth Decreasing

  For the ingress node, a Path message with SE style SHOULD also be sent for decreasing the ODUflex bandwidth.

The ingress node will trigger the BWR protocol when 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. After decreasing the bandwidth, the ingress node SHOULD send a ResvErr message to tear down the old control state.

A downstream node receiving a Path message with SE style compares the old Traffic Parameters with the new one carried in the Path message to determine the number of TSs to be decreased. After choosing TSs to be decreased, the downstream node MUST send back a Resv message carrying both the old and new GENERALIZED_LABEL objects in the SE flow descriptor.

An upstream neighbor receiving a Resv message with an SE flow descriptor MUST determine which TS(s) is/are decreased and trigger the first step of the LCR protocol (i.e., LCR handshake) between itself and its downstream neighbor node.

8. Operations, Administration, and Maintenance (OAM) Considerations

OTN OAM configuration could be done through either Network Management Systems (NMSs) or the GMPLS control plane as defined in [TDM-OAM]. [RFC4783] SHOULD be used for communication of alarm information in GMPLS-based OTN.

Management Information Bases (MIBs) may need be extended to read new information (e.g., OTN-TDM Generalized Label and OTN-TDM SENDER_TSPEC / FLOWSPEC) from the OTN devices. This is outside the scope of this document.

More information about the management aspects for GMPLS-based OTN, refer to Section 5.7 of [RFC7062].

9. Control-Plane Backward-Compatibility Considerations

As described in [RFC7062], since [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 [RFC7138].
- 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.

10. Security Considerations

This document is a modification to [RFC3473] and [RFC4328]; it only differs in specific information communicated. As such, this document introduces no new security considerations to the existing GMPLS signaling protocols. Refer to [RFC3473] and [RFC4328] for further details of the specific security measures. Additionally, [RFC5920] provides an overview of security vulnerabilities and protection mechanisms for the GMPLS control plane.

11. IANA Considerations

IANA has made the following assignments in the "Class Types or C-Types - 9 FLOWSPEC" and "Class Types or C-Types - 12 SENDER_TSPEC" section of the "Resource Reservation Protocol (RSVP) Parameters" registry located at <http://www.iana.org/assignments/rsvp-parameters>.

Value	Description	Reference
7	OTN-TDM	[RFC7139]

IANA maintains the "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Parameters" registry (see <http://www.iana.org/assignments/gmpls-sig-parameters>). The "Generalized PIDs (G-PID)" subregistry is included in this registry, which is extended and updated by this document as detailed below.

Value	Type	Technology	Reference
47	G.709 ODU-2.5G	G.709 ODUk	[RFC4328]
	(IANA updated the Type field)		[RFC7139]
56	SBCON/ESCON	G.709 ODUk,	[RFC4328]
	(IANA updated the Type field)	Lambda, Fiber	[RFC7139]
59	Framed GFP	G.709 ODUk	[RFC7139]
60	STM-1	G.709 ODUk	[RFC7139]
61	STM-4	G.709 ODUk	[RFC7139]
62	InfiniBand	G.709 ODUflex	[RFC7139]
63	SDI (Serial Digital Interface)	G.709 ODUk	[RFC7139]
64	SDI/1.001	G.709 ODUk	[RFC7139]
65	DVB_ASI	G.709 ODUk	[RFC7139]
66	G.709 ODU-1.25G	G.709 ODUk	[RFC7139]
67	G.709 ODU-any	G.709 ODUk	[RFC7139]
68	Null Test	G.709 ODUk	[RFC7139]
69	Random Test	G.709 ODUk	[RFC7139]
70	64B/66B GFP-F Ethernet	G.709 ODUk	[RFC7139]

The new G-PIDs are shown in the TC MIB managed by IANA at <https://www.iana.org/assignments/ianagmplstc-mib> as follows:

```
g709FramedGFP(59),
g709STM1(60),
g709STM4(61),
g709InfiniBand(62),
g709SDI(63),
g709SDI1point001(64),
g709DVBASI(65),
g709ODU1point25G(66),
g709ODUAny(67),
g709NullTest(68),
g709RandomTest(69),
g709GFPFEthernet(70)
```

Note that IANA has not changed the names of the objects in this MIB module with the values 47 and 56.

IANA has defined an "OTN Signal Type" subregistry to the "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Parameters" registry:

Value	Signal Type	Reference
0	Not significant	[RFC4328]
1	ODU1 (i.e., 2.5 Gbps)	[RFC4328]
2	ODU2 (i.e., 10 Gbps)	[RFC4328]
3	ODU3 (i.e., 40 Gbps)	[RFC4328]
4	ODU4 (i.e., 100 Gbps)	[RFC7139]
5	Unassigned	[RFC4328]
6	Och at 2.5 Gbps	[RFC4328]
7	OCh at 10 Gbps	[RFC4328]
8	OCh at 40 Gbps	[RFC4328]
9	OCh at 100 Gbps	[RFC7139]
10	ODU0 (i.e., 1.25 Gbps)	[RFC7139]
11	ODU2e (i.e., 10 Gbps for FC1200 and GE LAN)	[RFC7139]
12-19	Unassigned	[RFC7139]
20	ODUflex(CBR) (i.e., 1.25*N Gbps)	[RFC7139]
21	ODUflex(GFP-F), resizable (i.e., 1.25*N Gbps)	[RFC7139]
22	ODUflex(GFP-F), non-resizable (i.e., 1.25*N Gbps)	[RFC7139]
23-255	Unassigned	[RFC7139]

New values are to be assigned via Standards Action as defined in [RFC5226].

12. References

12.1. Normative References

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12.2. Informative References

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