GMPLS Signalling Extensions for G.709 Optical Transport Networks

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Abstract

Along with the current development of packet over lambda switching, there is considerable development in transport systems based on the ITU-T G.709 specification. For that purpose, the inter-working of G.709 capable devices on top lambda switched networks is relevant to new optical developments at the OIF and IETF.

We propose to introduce the G.709 Optical Transport Hierarchy (OTH) defined at the ITU-T [ITU-T-G709] into the label space of GMPLS. [GMPLS-ARCH] introduced the digital wrapper as an LSP encoding type for GMPLS. The objective of this draft is to specify additional extensions needed to support GMPLS [GMPLS-SIG] signalling for
Optical Transport Networks (OTN) currently under definition at the ITU-T. These extensions indicate the bit rate and hierarchical layer relationships needed for transport over a G.709 OTN.

1. Introduction

Recently, the ITU-T finalized the first version of the Optical Transport Networks (OTN) standardization [ITUT-G709] at the Network-to-Network Interface (NNI) to provide the transparent digital pipe (digital wrapper) to be associated with the optical channels.

Soon, the multiplexing of lower bit-rate wavelength with ODU structure will come to provide granularity transmission (where needed) in the backbone network. Where low cost is the first goal, OTN provides a further degree of flexibility allowing the management of a relatively small all-optical sub-network (even if today with some limitations).

At that point the OTN will have the two fundamental degrees of flexibility: in terms of wavelength and in terms of bandwidth transmission optimization without losing the integrity of the lower bit rates pipes filled by the access network.

Unfortunately the expected flexible OTN architecture has today no explicit association with a control layer, without which the future deployment of OTN equipment is really questionable. In any case, [ITUT-G709] foresees some margins for future evolutions that could be taken into consideration for future explicit support of the control layer. The forthcoming Automated Switched Transport Network [ITUT-GASTN] should overcome the deployment at the boundary layer.

GMPLS (as specified in [GMPLS-SIG], is today certainly the best candidate to provide the guidelines for the "control service" needed by the OTN. Moreover GMPLS may give today fundamental indications in terms of how OTN can be controlled and where something else (if needed) is to be added to the physical transmission level, which is open enough to hit the goal for the future intelligent optical networks.

2. Current Solutions

In this section, we describe the G.709 specification foundations:

2.1 Pre-OTN DWDM Development

ITU-T G709 describes also pre-OTN WDM development for backward compatibility with the state of the art of the equipments. Pre-OTN development has generated the current OTN development at the ITU-T but also the current all-optical development at the OIF and the IETF.
top of a mesh optical topology including Optical Cross-Connects (OXC) or Photonic Cross-Connects (PXC). A PXC is defined as an all-optical device (i.e. no O/E) and an OXC as a bit-rate transparent device (i.e. providing O/E/O conversion at each interface).

The signalling paradigm developed for Lambda-switched LSP-capable networks has been included of the MPLS signalling paradigm. The MPLS generalization for fiber (space switching) lambda (wavelength switching), TDM (circuit switching) and packet LSPs (packet switching) is referred to as Generalized MPLS [GMPLS-SIG].

The current bandwidth bottleneck is overcome by the use of DWDM systems. DWDM systems allow the multiplexing of more than 160 wavelengths of 10 Gbps (1.6 Tbps per fiber with a 25 GHz spacing) by using the C-band and the L-band simultaneously. Some vendors are proposing a lambda spacing of only 12.5 GHz. Consequently, it will be possible to house 320 wavelengths of 10 Gbps in a single fiber (for a total throughput of 3.2 Terabits per fiber). Note that the ITU-T currently only specifies 50 GHz spacing in [ITU-T-G692] within the so-called ITU-T Grid, in order to guarantee interoperability.

In the pre-OTN application, client signals (STM-N, GbE, IP, etc.) are directly mapped on wavelength through the use of a mapping-framing variable-length layer. This means that this development does not include G.709 client-signal mapping definition through the definition of a dedicated framing protocol. OAM (Operation and Management) capabilities and signal quality monitoring are currently under definition in [IPO-LMP].

2.2 OTN Standard

Optical networks are comprised of functionality providing transport, multiplexing, routing, supervision and survivability of client signals that are processed predominantly in the photonic domain. Optical signals are characterized by wavelength and may be processed per wavelength or as a wavelength division multiplexed group of wavelengths.

The OTN model is decomposed into independent transport network layers where each network layer can be separately partitioned in a way that reflects the internal structure of that network layer. So that the Optical Transport Network (OTN) layered structure is defined as follows:
- Optical Transmission Section (OTS) layer: This network layer provides functionality for transmission of optical signals on optical media of various types. This layer ensures the integrity and maintenance of the optical transmitted signal by overhead processing.
- Optical Multiplex Section (OMS) layer: This network layer provides functionality for networking of a multi-wavelength optical signal.
- Optical Channel (OCh) Layer: this network layer provides end-to-end networking of optical channels for transparently conveying
client information of various formats (e.g. SDH STM-N, ATM, IP, etc.). The capabilities of this network layer concern with connection rearrangement for flexible routing, overhead processing, administration and maintenance functions.

For the three layers specified above, non-associated overhead is transported via the Optical Supervisory Channel (OSC) in order to manage the optical connectivity. It has to be noted that these three layers are common to both pre-OTN and OTN applications.

As far as the client handling is concerned, the OCH layer is further layered as follows:
- The Optical Transport Unit (OTUk) provides FEC capabilities and optical section protection and monitoring capabilities.
- The Optical Data Unit (ODUk) layer provides client independent connectivity, connection protection and monitoring (also without the need to terminate the overhead information).
- Clients signals i.e. STM-N signals, IP packets, ATM cells and Ethernet frames are mapped (meaning digitally wrapped) into a new structured frame defined as Optical Payload Unit (OPU).

For each of the three layers specified above, an associated (in band) overhead carrying the management information is added inside the framed structure itself.

The need for the development of a hierarchical transport (i.e. transport networking layer) is required for the following reasons:
- Next step (after TDM - SDH/SONET) to support ever growing data driven needs for bandwidth and emergence of new broadband services.
- Support next generation Terabit/second per fiber via DWDM lines at the transport level as well as optical channels at 2.5 Gb/s, 10 Gb/s and 40 Gb/s bit rates wire speed level.
- To provide network operational management, planning, administration, survivability, and finally cost of maintenance limited only to the OTUk/ODUk rates of transmission without caring about the granularity of the client signal.

3. Optical Transport Networks

The OTN specifies an Optical Transport Hierarchy (OTH) supporting the operation and management aspects of optical networks of various architectures such as point-to-point, ring and mesh architectures.

The G.709 specification defines the interfaces of the OTN to be used within and between sub-networks of the optical network, in terms of:
- Optical Transport Hierarchy (OTH)

- functionality of the overhead in support of multi-wavelength optical sub-networks
- frame structures
- bit rates
- formats for mapping client signals
The OTN interfaces specifications can be applied at User to Network Interfaces (UNI) and Network Node Interfaces (NNI) of the OTN. The overhead functionality necessary for operations and management of optical sub-networks is also defined. For interfaces used within optical sub-networks, the aspects related to the interface depend on the optical technology progress and so are not covered by G.709 recommendation. This is within the scope of other ITU-T recommendations [ITUT-G959.1].

3.1 Optical Transport Hierarchy (OTH)

The Optical Transport Hierarchy (OTH) structure is defined as specified in [ITUT-G.872] that defines the Optical Channel (OCh) layer. The OTH further sub-structured the OCh layer in sub-layer networks in order to support the network management and supervision functions such as:

- The Optical Channel with full (OCh) or reduced functionality (OChr), provides transparent network connections between 3R regeneration points in the OTN.

- The fully standardized Optical Channel Transport Unit-k (OTUk) which provides supervision and conditions the signal for transport between regeneration points in the OTN (1R, 2R and for pre-OTN only, 3R).

- The Optical Channel Data Unit (ODUk) which provides tandem connection monitoring (ODUk-TCM), end-to-end path monitoring (ODUk-PM)

- The Optical Channel Payload Unit (OPUk) which provides adaptation of client signals

The Optical Transport Module-n (OTM-n) is the information structure used to support OTN interfaces. Two OTM-n structures are defined:

- OTM interfaces with full functionality (OTM-n.m)
- OTM interfaces with reduced functionality (OTM-0.m, OTM-nr.m)

The reduced functionality OTM interfaces are defined with 3R processing at each end of the OTN.

3.1.1 Full Functional Stack

The full functional stack (OTM n.m) is defined as follows:

```
+---------------------------------------------------------------------+
| OCh Payload Unit OPUk                                              |
+---------------------------------------------------------------------+
| OCh Data Unit ODUk                                                  |
+---------------------------------------------------------------------+
| OCh Transport Unit OTUk                                             |
+---------------------------------------------------------------------+
| Optical Channel Layer OCh                                           |
+---------------------------------------------------------------------+
| Optical Channel Carrier (OCC)                                      |
+---------------------------------------------------------------------+
| Lambda Multiplexing                                                |
```

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Up to n OCCr are multiplexed into an OCG-nrm using wavelength division multiplexing. The OCCr tributary slots of the OCG-nrm can be of different size. The OCG-nrm is transported via the OTM-nrm.

For the case of the full functionality OTM-n.m interfaces, the OSC is multiplexed into the OTM-n.m using wavelength division multiplexing.

### 3.1.2 Reduced Functionality Stack: OTM-0.r and OTM-nr.m

The OTM with reduced functionality could be either
- OTM-0: consists of a single optical channel without a specific wavelength assigned (see Figure)
- OTM-nr.m: consists of up to n multiplexed optical channels. Non associated overhead is not supported (see Figure)

The OTM-nr.m/OTM-0 is the information structure used to support Optical Physical Section (OPS) layer connections in the OTN.

The order of an OTM-nr is defined by the order of the OCG-nr that it supports. Note that the first version of G.709, only includes reduced functionality for standardized inter-domain interfaces (IrDI).

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3.2 Signal Types

Signal types defined by the [ITUT-G709] specification can be divided in Optical Channel Unit layer and Optical Transport Module (OTM). The Payload Unit layer can itself be sub-divided in OCh Payload Unit, OCh Data Unit and OCh Transport Unit. The Appendix 1 describes the indexes used within the [ITUT-G709] terminology.

3.2.1 OPUk Signal

Optical channel Payload Unit (OPU) is defined as a structured signal of order k (k = 1, 2, 3) and referred to as OPUk signal. The OPUk frame structure is organized in an octet based block frame structure with 4 rows and 3810 columns. The two main areas of the OPUk frame (4 x 3810 Bytes) are the OPUk Overhead area (column 15 and 16) and OPUk Payload area (columns 17 to 3824).

3.2.2 ODUk Signal

Optical channel Data Unit (ODU) is defined as a structured signal of order k (k = 1, 2, 3) and referred to as ODUk signal. The ODUk frame structure is organized in an octet based block frame structure with 4 rows and 3824 columns. The two main areas of the ODUk frame are ODUk Overhead area (columns 1 to 14 with column 1 dedicated to FA and OTUk specific alignment) and OPUk area (Columns 15 to 3824 which are dedicated to the OPUk area).

3.2.3 OTUk Signal

Optical channel Transport Unit (OTU) of order k (k = 1, 2, 3) defines the conditioning for transport over an Optical Channel network connection. This signal is referred to as OTUk signal. The OTUk (k=1,2,3) frame structure is based on the ODUk frame structure and extends it with a forward error correction (FEC). Scrambling is performed after FEC computation and insertion into the OTUk signal.

In the OTUk signal, 256 columns are added to the ODUk frame for the FEC and the reserved overhead bytes in row 1, columns 9 to 14 of the ODUk overhead are used for OTUk specific overhead, resulting in an octet based block frame structure with 4 rows and 4080 columns (4 x 4080 bytes).
3.2.4 OTM Module

The OTM-n supports n optical channels on a single fiber with 3R regeneration and termination of the OTUk signal on each end. As 3R regeneration is performed on both sides of the OTM-0.m and OTM-nr.m interfaces access to OTUk overhead is available and maintenance as well as supervision of the interface is provided via this overhead. Therefore non-associated OTN overhead is not required across the OTM-0.m and OTM-nr.m interfaces. Consequently, Optical Supervisory Channel (OSC) and OTM Overhead Signal (OOS) are not supported.

In the first G.709 version, only two OTM interfaces classes with reduced functionality are defined, OTM-0.m and OTM-16r.m.

1. OTM-16r.m Interface

The OTM-16r.m interface supports 16 optical channels \((n = 16)\) on a single optical span with 3R regeneration at each end. Six OTM-16r interface signals are currently defined.

The OTM-16r.m signal is an OTM-nr.m signal with 16 Optical Channel Carriers (OCCr) numbered OCCr #0 to OCCr #15. An Optical OSC is not present and there is no OOS either.

At least one of the OCCrs is in service during normal operation and transporting an OTUk. However, there is no predefined order in which the OCCrs are taken into service.

There are six defined OTM-16r.m interface signals and the OTM-16r.m multiplexing structure.

Note: OTM-16r.m OPS overhead is not defined. The interface will use the OTUk SMOH in this multi-wavelength interface for supervision and management. OTM-16r.m connectivity failure (TIM) reports will be computed from the individual OTUk reports by means of failure correlation in fault management.

2. OTM-0.m Interface

The OTM-0.m supports a single wavelength optical channel on a single optical fiber with 3R regeneration at each end. Three OTM-0.m interface signals are defined \((m = 1, 2, 3)\), each carrying a single channel optical signal containing one OTUk \((k = 1, 2, 3)\) signal. There is neither OSC defined nor OOS for OTM-0.m.

For instance, the OTM16 can be separated in several cases:
- the OTM16.0 (with up to 16 wavelengths mixing possibly bit-rates)
- the OTM16.1 (with up to 16 wavelengths only at 2.5Gbits/s)
- the OTM16.2 (with up to 16 wavelengths only at 10Gbits/s)
- the OTM16.3 (with up to 16 wavelengths only at 40Gbits/s)
ODUk TDM Multiplexing will be included in the future release of G.709. Note that ODUk and OTUk still remain in the electrical domain but referred to as Optical Channel layer within [ITU-T-G709].

Two levels of multiplexing could be defined: four ODU1 can be multiplexed in one ODU2, and four ODU2 can be multiplexed in one ODU3.

4. Client Signal Mapping

The specification of the Client-layer signal encapsulation in the OPU layer has been provided through the definition of different solutions depending upon the type of Client-layer signal.

4.1 Packet Mapping

IP and Ethernet packet mapping is defined by the G.709 specification through the use of the Generic Framing Procedure (GFP). This (new) framing has been specified in order to avoid the use of Ethernet framing or SDH/Sonet in order to encapsulate IP packets and other types of packet (such as ESCON, Fiber Channel, etc.).

GFP is defined as a generic mechanism to transport any client layer over a fixed data-rate optical channels (specifically, the so-called OTN ODU of unit-k). This means that GFP idle frames must be generated when the client layer does not send data packet. Consequently the service offered to the client packet layer is strictly equivalent to the one offered in SDH.

The Generic Framing Procedure (GFP) frame format is defined as:

```
+----------+--------------------------------------------+----------+
|  Header  |             Payload                        |   FCS    |
| 4 bytes  |         4 ã 65535 bytes                    | Optional |
+----------+--------------------------------------------+----------+
```

The header (4-bytes) is composed by a PDU Length Indicator (PLI) of 2 bytes and a HEC (Header Error Control) of 2 bytes.

A idle GFP frame includes a NULL PLI and a HEC of 2 bytes

GFP defines also two basic frame-oriented mechanisms:

1. GFP Frame Multiplexing: the GFP frame multiplexing is performed on a frame-by-frame basis. When no frames are waiting, idle frames are inserted.

2. GFP Frame Delineation Algorithm: as defined for cell delineation,
GFP frame delineation is based on the detection of correct HEC. PLI is used to find the start of the next frame.

The GFP frames constitute the OPUk payload. The corresponding OPUk overhead is defined as follows by the Payload Structure Identifier (PSI) which includes the following fields:
- PT: Payload Type (1-byte)
- RES: Reserved (254-bytes)

The GFP OPUk (k = 1, 2, 3) capacity are defined such that they can include the following client bit rates:
- GFP (OPU1): 2 488 320 kbit/s
- GFP (OPU2): 9 995 276 kbit/s
- GFP (OPU3): 40 150 519 kbit/s

Aligning the byte structure of every GFP frame with the byte structure of the OPUk Payload performs the mapping of GFP frames. Since the GFP frames are of variable length (the mapping does not impose any restrictions on the maximum frame length), a frame may cross the OPUk frame boundary.

GFP frames arrive as a continuous bit stream (Idle frames when no client packets) with a capacity that is identical to the OPUk payload area, due to the insertion of Idle frames at the GFP encapsulation stage. Note that here, the GFP frame stream is scrambled during encapsulation.

As currently defined in [ITUT-G709], GFP provides also ATM Constant Bit Rate (CBR) by using ATM cell multiplexing - and TDM Circuits Encapsulation and mapping into the OPUk payload area.

4.4 OCh Encapsulation

An overhead is associated to the OPUk, the ODUk and the OTUk signals. Moreover, the OTUk signal can include a tailer FEC.

The control non-associated overhead at the lower OCh level is multiplexed within the OOS and then inserted to the Optical Supervisory Channel.
The optical channel network-layer overhead bytes defined in [ITUT-G.709] support the following capabilities:
- Forward Error Correction (FEC)
- Performance Monitoring (PM)
- Network Fault localization
- Network Restoration Signaling
- Network General Communications Channels (GCC)
- Manufacturer-Specific Communications Channel

5. GMPLS Extensions for G.709

Adapting GMPLS to control G.709 (also previously known as the "Digital Wrapper") seems straightforward. Note that G.709 defines indeed two layers. First, an electrical layer (the old "Digital Wrapper"), aka the Optical Channel Network Layer, indeed a new TDM technology. Second, a photonic layer (with a digital OTN Overhead Signal: OOS), i.e. a non-associated overhead.

GMPLS extensions for G.709 need to cover the Generalized Label Request, the Generalized Label as well as specific fields currently assigned to the SDH/Sonet labels. Since the electrical multiplexing will be added soon, in the next version, we could already have a label for that purpose, so that GMPLS could already consider the requirements for G.709.

As specified already mentioned for GMPLS-over-SDH/Sonet [GMPLS-SDH], since GFP is only used as a framing protocol we don’t consider the transport of MPLS label within this layer. Rather as defined for Packet-over-SDH/Sonet, we directly use the G.709 OTH in order to define the label space.

5.1 Generalized Label Request

The Generalized Label Request [GMPLS-SIG] currently includes the LSP Encoding Type (i.e. Digital Wrapper) needed in order to enable the deployment of GMPLS signalling on top of G.709 networks.

For that purpose, a new G.709 specific Generalized Label Request
needs to be defined. The information carried in a Generalized Label Request for G.709 is:

```
+-----------------------------------+-----------------------------------+-----------------------------------+-----------------------------------+
| LSP Enc. Type | Transparency | G-PID | Transparency | Transparency | G-PID | Transparency | Transparency | G-PID |
+-----------------------------------+-----------------------------------+-----------------------------------+-----------------------------------+
| Reserved | Signal Type | OOS | Resv | Reserved | Signal Type | OOS | Resv | Reserved | Signal Type | OOS | Resv |
+-----------------------------------+-----------------------------------+-----------------------------------+-----------------------------------+
```

As mentioned here above, we suggest here to adapt the LSP Encoding Type (section 3.1.1) and the GPID to G.709:

- **LSP Encoding Type** (see section 3.1.1 [GMPLS-SIG])

  The current "Digital Wrapper" (DW) code could be replaced by two separate codes:
  - code for the G.709 Optical Channel Network Layer.
  - code for a generic DW (for proprietary implementations).

  In the same way, the "Lambda" code could be replaced by two separate codes:
  - code for the G.709 optical layer.
  - code for a generic lambda layer (transparent).

  The code for the G.709 optical layer will indicate the capability of an end-system to use the G.709 non-associated overhead (i.e. the OOS).

- **Transparency Type**: (See Section 3.1.1 [GMPLS-SIG])

  This vector of flags (8 bits) indicates the type of transparency being requested. It is only applicable to the G.709 Optical Channel Network Layer. Note that the transparency does not change the bit rate. This field is zeroed if only the G.709 optical layer is used.

  Bit 1: indicates ODU transparency. This means that the ODU overhead cannot be modified.

  Bit 2: indicates OTU transparency. This means that the OTU overhead and the ODU overhead cannot be modified.

- **Signal Type**: (See Section 3.1.1 [GMPLS-SIG])

  This field (8 bits) indicates the requested G.709 signal type. The possible values are:

<table>
<thead>
<tr>
<th>Value</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>irrelevant</td>
</tr>
<tr>
<td>1</td>
<td>2.5 Gbps</td>
</tr>
<tr>
<td>2</td>
<td>10 Gbps</td>
</tr>
<tr>
<td>3</td>
<td>40 Gbps</td>
</tr>
</tbody>
</table>
This field may equal to zero if only the G.709 optical layer is used.

- OOS (OTN Overhead Signal) Type:

This field (4 bits) indicates the type of OOS for the G.709 optical layer. Possible values are:

<table>
<thead>
<tr>
<th>Value</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>irrelevant</td>
</tr>
<tr>
<td>1</td>
<td>OOS reduced functionality (limited overhead)</td>
</tr>
<tr>
<td>2</td>
<td>OOS full overhead</td>
</tr>
</tbody>
</table>

5.2 Generalized Label

G.709 at the Optical Channel Network layer defines three different client payload bit rates. An Optical Data Unit (ODU) frame has been defined for each of these bit rates. ODUk refers to the frame at bit rate k, where k = 1 (for 2.5 Gbps), 2 (for 10 Gbps) or 3 (for 40 Gbps). Two levels of multiplexing could be defined: four ODU1 can be multiplexed in one ODU2, and four ODU2 can be multiplexed in one ODU3.

The G.709 Optical Channel Network Layer label has the following format:

```
+-------------------++-------------------++-------------------++-------------------+
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
```

k1: 0 -> 4: indicates a particular ODU1 in one ODU2.

k2: 0 -> 4: indicates a particular ODU2 in one ODU3.

If k1 and k2 are equal to zero means non-significant: a particular ODUk is not structured, i.e. ki=0 indicates that the ODUi+1 in not structured.

Examples:

- k2=0, k1=0 indicates a full ODU3 (full 40 Gbps).
- k2=2, k1=0 indicates the second unstructured ODU2 in the ODU3.
- k2=4, k1=2 indicates the second ODU1 of the fourth ODU2 in the ODU3.

5.3 In-band/In-fiber GMPLS Signalling Transport

Furthermore, standardization is required within ITU-T to define an in-fiber/in-band signaling transport mechanism through an OTN. We propose the allocation of a General Communication Channel (GCC), particularly GCC1, within the optical layer overhead, to transport the GMPLS signalling.
6. Security Considerations

Security considerations are left for further study.

7. Reference


8. Acknowledgments

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12. Appendix 1 — Abbreviations

1R            Re-amplification
2R            Re-amplification and Re-shaping
3R            Re-amplification, Re-shaping and Re-timing
AI            Adapted information
AIS           Alarm Indication Signal
APS           Automatic Protection Switching
BDI           Backward Defect Indication
BEI           Backward Error Indication
BI            Backward Indication
BIP           Bit Interleaved Parity
CBR           Constant Bit Rate
CI            Characteristic information
CM            Connection Monitoring
EDC           Error Detection Code
EXP           Experimental
ExTI          Expected Trace Identifier
FAS           Frame Alignment Signal
FDI          Forward Defect Indication
FEC          Forward Error Correction
GCC          General Communication Channel
IaDI         Intra-Domain Interface
IAE          Incoming Alignment Error
IrDI         Inter-Domain Interface
MFAS         MultiFrame Alignment Signal
MS           Maintenance Signal
naOH         non-associated overhead
NNI          Network-to-Network interface
OCC          Optical Channel Carrier
OCG          Optical Carrier Group
OCI          Open Connection Indication
OCh          Optical Channel (with full functionality)
Ochr         Optical Channel (with reduced functionality)
ODU          Optical Channel Data Unit
OH           Overhead
OMS          Optical Multiplex Section
OMU          Optical Multiplex Unit
OOS          OTM Overhead Signal
OPS          Optical Physical Section
OPU          Optical Channel Payload Unit
OSC          Optical Supervisory Channel
OTH          Optical transport hierarchy
OTM          Optical transport module

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OTN          Optical transport network
OTS          Optical transmission section
OTU          Optical Channel Transport Unit
PCC          Protection Communication Channel
PLD          Payload
PM           Path Monitoring
PMI          Payload Missing Indication
PRBS         Pseudo Random Binary Sequence
PSI          Payload Structure Identifier
PT           Payload Type
RES          Reserved
RS           Reed-Solomon
SM           Section Monitoring
TC           Tandem Connection
TCM          Tandem Connection Monitoring
UNI          User-to-Network Interface

13. Appendix 2 Å» G.709 Indexes

- Index k: The index "k" is used to represent a supported bit rate and the different versions of OPUk, ODUk and OTUk. k=1 represents an approximate bit rate of 2.5 Gbit/s, k=2 represents an approximate bit rate of 10 Gbit/s and k = 3 an approximate bit rate of 40 Gbit/s. The exact bit-rate values are in kbits/s:
  - OPU: 2 488 320.000, 9 995 276.962, 40 150 519.322
  - ODU: 2 498 775.126, 10 037 273.924, 40 319 218.983
  - OTU: 2 666 057.143, 10 709 225.316, 43 018 413.559

- Index m: The index "m" is used to represent the bit rate or set of
bit rates supported on the interface. This is a one or more digit \(k\), where each \(k\) represents a particular bit rate. The valid values for \(m\) are \(1, 2, 3, 12, 123, 23\).

- Index \(n\): The index "\(n\)" is used to represent the order of the OTM, OTS, OMS, OPS, OCG and OMU. This index represents the maximum number of wavelengths that can be supported at the lowest bit rate supported on the wavelength. It is possible that a reduced number of higher bit rate wavelengths are supported. The case \(n=0\) represents a single channel without a specific wavelength assigned to the channel.

- Index \(r\): The index "\(r\)" , if present, is used to indicate a reduced functionality OTM, OCG, OCC and OCh (non-associated overhead is not supported). Note that for \(n=0\) the index \(r\) is not required as it implies always reduced functionality.