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Recommendation ITU-T G.872

Architecture of optical transport networks

Summary
Recommendation ITU-T G.872 describes the functional architecture of optical transport networks (OTNs) using the modelling methodology described in Recommendations ITU-T G.800 and ITU-T G.805. The OTN functionality is described from a network level viewpoint, taking into account an optical network layered structure, client characteristic information, client/server layer associations, networking topology, and layer network functionality providing optical signal transmission, multiplexing, routing and supervision. The optical portion of the network is described in terms of media constructs, media elements and optical signal maintenance entities. The use of the black link approach defined in Recommendations ITU-T G.698.1 and ITU-T G.698.2 within the context of an OTN network is also described.

History

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Keywords
Media architecture, network media channel, optical transport networks (OTN), OTN functional architecture.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation’s unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.
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As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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Recommendation ITU-T G.872

Architecture of optical transport networks

1 Scope

This Recommendation describes the functional architecture of optical transport networks (OTNs) using the modelling methodology described in [ITU-T G.800] and [ITU-T G.805]. The OTN functionality is described from a network-level viewpoint. This takes into account an optical network layered structure, client characteristic information (CI), client/server layer associations, networking topology, and layer network functionality providing optical signal transmission, multiplexing, routing, supervision, performance assessment and network survivability. The optical portion of the network is described in terms of media constructs, media elements and optical signal maintenance entities. This Recommendation provides the functional description of OTN that support digital clients. The support of analogue signals as clients is outside the scope of this Recommendation.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.


3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 frequency slot: See [ITU-T G.694.1]
3.1.2 slot width: See [ITU-T G.694.1]
3.1.3 optical tributary signal (OTSi): See [ITU-T G.959.1]
3.1.4 optical data unit (ODU): See [ITU-T G.709]
3.1.5 optical payload unit (OPU): See [ITU-T G.709]
3.1.6 optical transport network (OTN): See [ITU-T G.709]
3.1.7 optical tributary signal assembly (OTSiA): See [ITU-T G.709]
3.1.8 optical tributary signal group (OTSiG): See [ITU-T G.709]
3.1.9 optical tributary signal overhead (OTSiG-O): See [ITU-T G.709]
3.1.10 optical transport unit (OTU): See [ITU-T G.709]
3.1.11 forwarding point: See [ITU-T G.800]
3.1.12 transitional link: See [ITU-T G.800]
3.1.13 transport entity: See [ITU-T G.800]
3.1.14 access point: See [ITU-T G.805]
3.1.15 adaptation: See [ITU-T G.805]
3.1.16 adapted information (AI): See [ITU-T G.805]
3.1.17 administrative domain: See [ITU-T G.805]
3.1.18 characteristic information (CI): See [ITU-T G.805]
3.1.19 **connection**: See [ITU-T G.805]

3.1.20 **connection supervision**: See [ITU-T G.805]

3.1.21 **layer network**: See [ITU-T G.805]

3.1.22 **link**: See [ITU-T G.805]

3.1.23 **network connection**: See [ITU-T G.805]

3.1.24 **subnetwork**: See [ITU-T G.805]

3.1.25 **topological component**: See [ITU-T G.805]

3.1.26 **trail**: See [ITU-T G.805]

3.1.27 **transport processing function**: See [ITU-T G.805]

### 3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 **effective frequency slot**: The effective frequency slot of a media channel is that part of the frequency slots of the filters along the media channel that is common to all of the filters’ frequency slots. It is described by its nominal central frequency and its slot width.

3.2.2 **media channel**: A media association that represents both the topology (i.e., the path through the media) and the resource (frequency slot) that it occupies.

3.2.3 **media subnetwork**: A media subnetwork is a topological construct that allows the associations (media channels) between its ports to be created or deleted.

3.2.4 **network media channel**: A network media channel is the serial concatenation of all media channels between an OTSi modulator and an OTSi demodulator. The network media channel may exist without an active OTSi.

**NOTE** – A network media channel supports a single unidirectional OTSi.

3.2.5 **optical power monitor (OPM)**: A function that monitors the optical power in one or more media channels.

3.2.6 **OSC**: The OSC supports the transfer of the non-associated overhead information for the OTSiA, OMS OSME and the OTS OSME.

### 4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

- **AI**: Adapted Information
- **AIS**: Alarm Indication Signal
- **AP**: Access Point
- **BDI**: Backward Defect Indication
- **BEI**: Backward Error Indication
- **CI**: Characteristic Information
- **FDI**: Forward Defect Indication
- **FlexE**: FlexEthernet; Flexible Ethernet
- **FP**: Forwarding Point
- **LOS**: Loss of signal
5 Conventions

This Recommendation uses the diagrammatic conventions defined in [ITU-T G.800] and [ITU-T G.805], supplemented by the additional conventions described in this clause, to encompass optical signal and media-related aspects.

5.1 Notational

To distinguish between the optical signals and the corresponding non-associated overhead, the –O suffix is used to identify the non-associated overhead for example OTSiG-O.

The following conventions are used for ODU:
- ODUk is used to indicate an ODU1, ODU2, ODU2e, ODU3, ODU4 or ODUflex
  - ODUj is used to indicate an ODUk where k>j (e.g., for ODUk multiplexing)
- ODUCn is used to indicate an ODUCn
  - n is an integer
- ODU is used to indicate either an ODUk or ODUCn

The following conventions are used for OTU:
- OTUk is used to indicate an OTU1, OTU2, OTU3 or OTU4
– OTUCn is used to indicate an OTUCn
  • n is an integer
– OTU is used to indicate either an OTUk or OTUCn

5.2 Diagrammatic
Media elements operate on the signal envelope (e.g., to amplify the signal, constrain or direct the media channel, etc.) and thus do not process the digital information carried therein. However, since some media constructs have some similarity to the functions performed by the topological components and transport processing functions used to describe the digital layers, it is convenient to reuse some of the [ITU-T G.800] and [ITU-T G.805] diagrammatic conventions. Where so used, shading is added to distinguish media constructs from topological components and transport processing functions for digital layers.

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Figure 5-1 – Diagrammatic shading convention

5.3 Terminological
The following terminological conventions are used to distinguish between connections in the digital layers and media associations.

The term Connection is used in the context of a transport entity, as defined in [ITU-T G.800] and [ITU-T G.805].

The term Association is used to describe the following relationships:
– between the ports on a media element;
– between the ports on a media construct;
– between a port on a network media channel and an optical tributary signal (OTSi) modulator; or
– between a port on a network media channel and an OTSi demodulator.

5.4 Representational
Within this Recommendation the media construct that represents a fixed grid filter is described in terms of the frequency slots it would have associated with it, if it were a flexible grid filter.
6 Functional architecture of OTN

The functionality of the OTN comprises providing transport, aggregation, routing, supervision and survivability of client signals that are processed in the digital domain and carried across the optical domain. This functionality for OTN is described from a network level viewpoint using the generic principles defined in [ITU-T G.800] and [ITU-T G.805]. The specific aspects concerning the OTN layered structure, characteristic information (CI), client/server layer associations, network topology, layer network functionality and media are provided in this Recommendation. A number of other ITU-T Recommendations provided detailed information on the implementation of the OTN. For example:

- [ITU-T G.709] provides the rates and formats used in the OTN;
- [ITU-T G.798] defines the equipment functional blocks;
- [ITU-T G.873.1] and [ITU-T G.873.2] describes linear and ring protection;
- [ITU-T G.874] and [ITU-T G.874.1] define the management interface;
- [ITU-T G.698.1], [ITU-T G.698.2] and [ITU-T G.959.1] define the physical interfaces.

In accordance with [ITU-T G.805] and [ITU-T G.800], the OTN is decomposed into independent transport layer networks, where each layer network can be separately partitioned in a way that reflects the internal structure of that layer network. The layer structure of the OTN is provided in Figure 6-1 below.

![Figure 6-1 – Overview of the OTN](image)

The digital layers of the OTN (optical data unit (ODU), optical transport unit (OTU) provide for the multiplexing of digital clients and for their maintenance. An OTU is supported by one optical tributary signal assembly (OTSiA) and the OTSiA supports one OTU. The OTSiA is a management/control abstraction that represents the optical tributary signal group (OTSiG) management/control abstraction and the non-associated overhead (OTSiG-O). The OTSiG represents

\[1\] The mapping between the OCh terminology and the OTSi terminology is provided in Appendix I.
one or more optical tributary signals (OTSi) that are each characterized by their central frequency and an application identifier\(^2\) (see [ITU-T G.698.2]). The OTSi is depicted by the optical signal modulator/demodulator, as shown in Figure 5-1.

Below the OTSi are the media constructs that provide the ability to configure the media channels (see clause 8.1.2) that are described separately from the entities that provide monitoring of the collections of the OTSi that traverse the media\(^3\). The nominal central frequency and width of a media channel is defined by its frequency slot (as defined in [ITU-T G.694.1]). Each OTSi is guided to its destination by an independent network media channel.

The OTSiA, together with the associated media channels, supports the OTU and may be managed as a part of an OTN network. While the OTSiA and media may support other clients, such clients are not considered to be a part of the OTN network since OTU monitoring capabilities are not necessarily supported by such clients. In some cases the OTSiA relies on the OTU for certain monitoring functions (e.g., path trace) in order to support the full operation, administration, maintenance (OAM) and fault management capabilities of the OTN.

Media channels must be configured before any OTSi can be carried. The effective frequency slot of a media channel is defined by the filters that are in the path of the media channel. The effective frequency slot may be sufficient to support more than one OTSi\(^4\).

The optical signal maintenance entities (OSME) (described in clause 8.4.3) provide for monitoring of the sets of the OTSi that traverse the media links (described in clause 8.1.3). Specifically, the set of OTSi carried by the optical multiplex section (OMS) media link or the optical transmission section (OTS) media link are monitored by the OMS OSME and OTS OSME respectively. This monitoring results in management information (MI) that is passed to a management system, as well as to the far end of the maintenance entity.

The digital layers are described in clause 7 and the OTSiA and media are described in clause 8.

7 OTN digital layers

The digital layers of the OTN are divided into the OTU layer and a hierarchy of one or more ODU layers. An OTU layer supports one ODU layer network as the client, and provides monitoring capability for the OTSiG\(^5\). The relationship between the ODUk and OTUk is shown in Figure 7-1.

---

\(^2\) An application identifier includes the application codes defined in the appropriate optical system Recommendations, as well as the possibility of proprietary identifiers. The identifier covers all aspects of the signal, including forward error correction, baud rate and modulation type.

\(^3\) This separation is necessary to allow the description of media constructs that may act on more than a single OTSi.

\(^4\) A media channel that may carry multiple OTSi may be used to provide what is commonly called an "express" channel.

\(^5\) The OTSiG is described in clause 8.2, the mapping between the OTSi terminology and the OCh terminology is provided in Appendix I.
Figure 7-1 – Client/server association of the digital OTN layers without ODU multiplexing

An ODU\(_k\) may support a single (non-OTN) client as shown in Figure 7-1. An ODU may support a heterogeneous assembly of ODU\(_k\) clients using ODU\(_k\) multiplexing as shown in Figure 7-2. ODU\(_k\) multiplexing is described in clause 7.1.1.
7.1 Optical data unit (ODU) layer network

The ODU layer network provides end-to-end transport of digital client information across the OTN. The description of the supported client layer networks is outside the scope of this Recommendation. A description of the use of the OTN to carry Flexible Ethernet (FlexE) is provided in Appendix II.

The CI of an ODU layer network is composed of:

– the ODU payload area for the transport of the digital client signals (the OPU); and
– the ODU overhead area for the transport of the associated overhead.

NOTE – An ODUCn carries n instances of the ODUC overhead, OPUC overhead and OPUC payload.

Details of the format are provided in [ITU-T G.709].

Figure 7-2 – Client/server association of the digital OTN layers with ODU multiplexing
The topological components of the ODU layer network are ODUk subnetworks and ODU links. The links are supported by either an OTU trail or a server ODU trail. As described in clause 7.1.1 an ODU server supports a heterogeneous assembly of ODUs. The ODUk subnetwork may provide connections for any ODUk. The tributary slot (TS) size supported by a server ODU and the bitrate of the client ODUk are modelled as parameters. This allows the ODU layer network to be viewed as a single layer network. When attempting to find a route for a particular ODUk, these parameters are used to identify the subset of the topological components in the ODU layer network that may be used\(^6\) to support that ODUk\(^7\), this is illustrated in Appendix III. These parameters also allow the number of TS that an ODU will occupy on an ODU link connection to be determined. Each client ODU is mapped into an integer number of server ODU TS\(^8\).

To provide end-to-end networking, the following capabilities are included in the ODU layer network:

– ODUk connection rearrangement for flexible network routing;
– ODU overhead processes to verify the integrity of the client adapted information (AI);
– ODU operations, administration and maintenance functions, including network survivability.

The ODU layer network contains the following topological components, transport processing functions and transport entities (see Figure 7-3 for the ODUk and Figure 7-4 for the ODUCn). The interlayer adaptation functions are described in clause 7.3.

Topological components:

– ODUk subnetwork
– ODU link.

Transport processing functions:

– ODU trail termination source
– ODU trail termination sink.

Transport entities:

– ODU trail
– ODU network connection
– ODU link connection
– ODUk subnetwork connection.

\(^6\) The restriction may be based on the capability of the resource (e.g., a link with 2.5 Gbit/s TS cannot support an ODU0 connection) or the restriction may be based on management policy (e.g., only ODU4 connections are allowed to use an ODUCn link).

\(^7\) This approach allows the topology of an ODUk specific layer network to be generated from the topology of the ODU layer network.

\(^8\) This may lead to inefficient use of bandwidth when the bit rate of the client ODU is less than the bit rate of a TS in the server ODU. (See Tables 7-2 and 7-4.)
The ODUCn forwarding point (FP) represent the location of OTUCn regeneration and allows ODUCn tandem connection monitoring (TCM).

### 7.1.1 ODUk multiplexing

In order to allow the transport of several lower bit rate ODUk clients over a higher bit rate ODU server, time division multiplexing of ODUks is defined. The ODU clients and servers are described in Table 7-2.

The TS of the ODU server may be allocated to any combination of ODUk clients up to the capacity of the server ODU.

The heterogeneous multiplexing of ODUks supports various network architectures, including those that are optimized to minimize stranded capacity, and/or to minimize the number of managed entities, and/or support carrier’s carrier scenarios, and/or enable ODU0/ODUFlex traffic to transit a region of the network that do not support these capabilities. Some examples of carrier’s carrier (multi-domain) applications are given in Appendix IV.
7.1.2 ODU clients and servers

The information in this sub clause was correct at the time of publication of this Recommendation, the current set of ODU and OTU and TS is provided in [ITU-T G.709].

The set of ODU servers and their non-OTN clients is provided in Table 7-1.

Table 7-1 – ODU servers and their non-OTN clients

<table>
<thead>
<tr>
<th>ODU Server</th>
<th>non-OTN Clients</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODU0</td>
<td>1.25 Gbit/s bit rate area</td>
</tr>
<tr>
<td>ODU1</td>
<td>2.5 Gbit/s bit rate area</td>
</tr>
<tr>
<td>ODU2</td>
<td>10 Gbit/s bit rate area</td>
</tr>
<tr>
<td>ODU2e</td>
<td>10.3125 Gbit/s bit rate area</td>
</tr>
<tr>
<td>ODU3</td>
<td>40 Gbit/s bit rate area</td>
</tr>
<tr>
<td>ODU4</td>
<td>100 Gbit/s bit rate area</td>
</tr>
<tr>
<td>ODUflex</td>
<td>CBR clients greater than 2.5 Gbit/s, or GFP-F mapped packet clients greater than 1.25 Gbit/s</td>
</tr>
<tr>
<td>ODUcn</td>
<td>None</td>
</tr>
</tbody>
</table>

The set of ODU servers and their ODU clients is provided in Table 7-2.

Table 7-2 – ODU servers and their ODU clients

<table>
<thead>
<tr>
<th>ODU Server</th>
<th>ODU Clients</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODU1</td>
<td>ODU0</td>
</tr>
<tr>
<td>ODU2</td>
<td>ODU0, ODU1, ODUflex</td>
</tr>
<tr>
<td>ODU3</td>
<td>ODU0, ODU1, ODU2, ODU2e, ODUflex</td>
</tr>
<tr>
<td>ODU4</td>
<td>ODU0, ODU1, ODU2, ODU2e, ODU3, ODUflex</td>
</tr>
<tr>
<td>ODUcn</td>
<td>ODU0, ODU1, ODU2, ODU2e, ODU3, ODU4, ODUflex</td>
</tr>
</tbody>
</table>

NOTE 1 – The ODU2 and ODU3 servers only support ODU0 and ODUflex clients if the ODU2 or ODU3 server has 1.25Gbit/s TS (see Table 7-4).

NOTE 2 – ODU0, ODU2e and ODUflex cannot be used as a server.

The set of OTU servers and their ODU clients is provided in Table 7-3.

Table 7-3 – OTU servers and their ODU clients

<table>
<thead>
<tr>
<th>OTU server</th>
<th>ODU client</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTU1</td>
<td>ODU1</td>
</tr>
<tr>
<td>OTU2</td>
<td>ODU2</td>
</tr>
<tr>
<td>OTU3</td>
<td>ODU3</td>
</tr>
<tr>
<td>OTU4</td>
<td>ODU4</td>
</tr>
<tr>
<td>OTUCn</td>
<td>ODUcn</td>
</tr>
<tr>
<td>OTUCn-M</td>
<td>ODUcn</td>
</tr>
</tbody>
</table>

NOTE 1 – The OTUCn-M is described in clause 7.2.

NOTE 2 – OTU servers have not been defined for ODU0, ODU2e or ODUflex.
The number of TS in a server ODU (when carrying an ODU client) is provided in Table 7-4.

**Table 7-4 – Number of tributary slots (TS) for each ODU**

<table>
<thead>
<tr>
<th>ODU server</th>
<th>Nominal TS capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.25 Gbit/s</td>
</tr>
<tr>
<td>ODU1</td>
<td>2</td>
</tr>
<tr>
<td>ODU2</td>
<td>8</td>
</tr>
<tr>
<td>ODU3</td>
<td>32</td>
</tr>
<tr>
<td>ODU4</td>
<td>80</td>
</tr>
<tr>
<td>ODU(Cn)</td>
<td>not applicable</td>
</tr>
</tbody>
</table>

**NOTE 1** – An ODU\(Cn\) supports a maximum of 10\(\times n\) ODU\(k\) clients.

**NOTE 2** – ODU0, ODU2e or ODUflex do not support ODU clients and therefore do not support tributary slots.

7.1.3 **ODU trail termination**

The following generic processes may be assigned to the ODU trail termination:

- validation of connectivity integrity
- assessment of transmission quality
- transmission defect detection and indication.

The requirements for these processes are outlined in clause 10.

There are three types of ODU trail termination:

- **ODU bidirectional trail termination**: consists of a pair of collocated ODU trail termination source and sink functions;
- **ODU trail termination source**: accepts AI from a client layer network at its input, inserts the ODU trail termination overhead as a separate and distinct logical data stream and presents the CI of the ODU layer network at its output;
- **ODU trail termination sink**: accepts the CI of the ODU layer network at its input, extracts the separate and distinct logical data stream containing the ODU trail termination overhead and presents the AI at its output.

7.1.4 **ODU transport entities**

Network connections, subnetwork connections, link connections, tandem connections and trails are as described in [ITU-T G.800].

7.1.4.1 **ODU tandem connections**

The ODU overhead includes information to support monitoring the end-to-end ODU trail and up to six levels of tandem connections. The ODU path OH is terminated where the ODU is assembled and disassembled. The tandem connection overhead is added and terminated at the end of each tandem connection.

**NOTE** – In normal operation, the monitored tandem connections may be nested, cascaded or both. For test purposes the monitored tandem connections may overlap. Overlapped monitored connections must be operated in a non-intrusive mode.
7.1.5 **ODU topological components**

Layer network, subnetworks, links (including transitional links) and access groups are as described in [ITU-T G.800].

The ODUk subnetwork provides flexibility within the ODUk layer network. ODUk CI is routed between input forwarding points [FPs] and output FPs.

The ODUk subnetwork does not support an ODUCn.

**NOTE** – Flexible connectivity of an ODUCn and its server OTUCn may be provided by the media layer described in clause 8.

7.2 **Optical transport unit (OTU) layer network**

The OTU layer network provides for the transport of ODU client signals through an OTU trail.

The CI of an OTU layer network is composed of:

– the OTU payload area that carries a single ODU as a client;
– the OTU overhead area.

**NOTE 1** – An OTUCn carries n instances of the OTUC overhead.

An OTUCn with a bit rate that is not an integer multiple of 100 Gbit/s is described as an OTUCn-M carries n instances of OTUC overhead, ODUC overhead and OPUC overhead, together with M 5Gbit/s OPUCn TS. An ODUCn-M and OPUCn-M are not defined. When an OTUCn-M is used to carry an ODUCn (20n–M), TS are marked as unavailable in the OPUCn multiplex structure identifier (MSI), since they cannot be used to carry a client.

Details of the format are provided in [ITU-T G.709].

The capabilities of this layer network include:

– OTU overhead processes to confirm the integrity of the client AI and conditioning for its transport over an OTSiG;
– OTU operations, administration and maintenance functions.

**NOTE 2** – Flexible connectivity of an OTU may be provided by the media layer described in clause 8.

The OTU layer network contains the following transport processing functions and transport entities (see Figure 7-5 for the OTU and Figure 7-6 for the OTUCn). The interlayer adaptation functions are described in clause 7.3.

Transport processing functions:

– OTU trail termination source
– OTU trail termination sink.

Transport entities:

– OTU trail
– OTU network connection
– OTUCn link connection.
7.2.1 OTU trail termination

The following generic processes are be assigned to the OTU trail termination:

- validation of connectivity integrity
- assessment of transmission quality
- transmission defect detection and indication.

The requirement for these processes are outlined in clause 10.

There are three types of OTU trail termination:

- OTU bidirectional trail termination: consists of a pair of collocated OTU trail termination source and sink functions;
- OTU trail termination source: accepts AI from an ODU network at its input, inserts the OTU trail termination overhead as a separate and distinct logical data stream and presents the CI of the OTU layer network at its output;
- OTU trail termination sink: accepts the CI of the OTU layer network at its input, extracts the separate and distinct logical data stream containing the OTU trail termination overhead and presents the AI at its output.
7.2.2  OTU transport entities

Network connections, link connections and trails are as described in [ITU-T G.800].

7.2.3  OTU topological components

Layer networks, links and access groups are as described in [ITU-T G.800].

7.3  Client/server associations

A principal feature of the OTN is the possibility of supporting a wide variety of circuit and packet client layer networks. The current set of supported clients is provided in [ITU-T G.709]. The structure of the OTN digital layer networks and the adaptation functions are shown in Figures 7-1 and 7-2. For the purposes of description, the interlayer adaptation is named using the server/client relationship. A full description of the adaptation functions is provided in [ITU-T G.798].

7.3.1  ODU/client adaptation

The ODU/client adaptation is considered to consist of two types of processes: client-specific processes and server-specific processes. The description of the client-specific processes is outside the scope of this Recommendation. The ODU servers are defined in Table 7-1.

The bidirectional ODU/client adaptation function is performed by a collocated pair of source and sink ODU/client adaptation functions. The ODU/client adaptation source performs the following processes between its input and its output:

– all the processing required to adapt the client signal to the ODU payload area. The processes are dependent upon the particular client signal;
– generation and termination of management/maintenance signals as described in clause 10.

The ODU/client adaptation sink performs the following processes between its input and its output:

– recovery of the client signal from the ODU payload area. The processes are dependent upon the particular client/server relationship;
– generation and termination of management/maintenance signals as described in clause 10.

A detailed description is provided in [ITU-T G.798].

7.3.2  ODU/ODU adaptation

The bidirectional ODU/ODU adaptation function is performed by a collocated pair of source and sink ODU/ODU adaptation functions. The ODU/ODU adaptations are defined in Table 7-2.

The ODU/ODU adaptation source performs the following processes between its input and its output:

– multiplexing lower rate ODUk to form a higher bit rate ODU;
– generation and termination of management/maintenance signals as described in clause 10.

The ODU/ODU adaptation sink performs the following processes between its input and its output:

– demultiplexing the lower rate ODUs from the higher rate ODU;
– generation and termination of management/maintenance signals as described in clause 10.

A detailed description is provided in [ITU-T G.798].

7.3.3  OTU/ODU adaptation

The bidirectional OTU/ODU adaptation function is performed by a collocated pair of source and sink OTU/ODU adaptation functions. The OTU servers are defined in Table 7-3.
The OTU/ODU adaptation source performs the following processes between its input and its output:
– mapping the ODU into the OTU payload area. The processes are dependent upon the particular implementation of the client/server relationship.

The OTU/ODU adaptation sink performs the following processes between its input and its output:
– recovery of the ODU signal from the OTU payload area. The processes are dependent upon the particular implementation of the client/server relationship.

A detailed description is provided in [ITU-T G.798].

8 Architecture of the media layer

This clause provides the description of the architecture of the media layer and the OTSi.

The architecture of the media layer is described using media constructs (see clause 8.1) to represent the different functions that are present in the media layer. Media constructs operate on the signal envelope (e.g., amplify or attenuate the signal, constrain or direct the media channel, etc.) and are not aware of the information being carried. Media constructs do not demodulate the signal and therefore do not process the digital information that is carried by the signal. This architectural description is not intended to imply any particular implementation.

For the purposes of management and control the media layer is represented by a set of media elements (see clause 8.2). A media element encompasses the functionality of one or more of the media constructs, it may also encompass the OTS OSME or OMS OSME reference point (see clause 8.4.3) and may provide a management/control interface.

8.1 Media constructs

The following architectural media constructs are used to describe the architecture of the media layer:
– media port
– media channel
– media link
– media subnetwork
– filter
– coupler
– optical amplifier.

The following architectural construct is also used:
– optical power monitor.

These architectural media constructs have been selected since they allow the reference points for the OTS OSME (see clause 8.4.3) and OMS OSME to be defined in this Recommendation.

8.1.1 Media port

A media port is a logical abstraction that represents the ends of a media channel, the boundary of a media construct or the boundary of a media element. A media port that is on the boundary of a media element may also represent the location of a signal reference point as defined in other Recommendations, for example [ITU-T G.680] or [ITU-T G.698.1]. A media port on the boundary of a media construct or a media element may encompass one end of zero or more media channels.

8.1.2 Media channel

The media channel is a topological construct that represents both the path through the media and the resource (frequency slot) that it occupies. A media channel is bounded by its ports. A media channel can span any combination of media constructs including fibres. A media channel may be a serial
concatenation of multiple media channels, each with its own frequency slot. A media channel that cannot be decomposed into a concatenation of other media channels is known as an atomic media channel. Figure 8-1 below provides some examples of the serial concatenation of media channels to form a longer media channels.

For example in Figure 8-1 a media channel is formed by the concatenation of media channels C+E+F+G+J. A media channel has no internal structure, i.e., the examples of "narrower" and "wider" media channels illustrated in Figure 8-1 simply reflect their respective "narrower" and "wider" effective frequency slots, and should not be interpreted as illustrating a containment relationship of the media channels. No hierarchy is created in either the media channels or the signals carried.

The size of a media channel is specified by its effective frequency slot, which is described by its nominal central frequency and its slot width [ITU-T G.694.1]. The effective frequency slot of a media channel is that part of the frequency slots of the filters along the media channel that is common to all of the filters' frequency slots. The parameters "n" and "m" as defined in [ITU-T G.694.1], are used to describe the effective frequency slot with the exception that n and m (for cases where the n value of the constituent filters' frequency slots are not all the same) may have a granularity of 0.5 rather than being integers. The only media construct that enforces the frequency slot is the filter (clause 8.1.5). Filtering may be implemented as a part of a coherent receiver (clause 8.1.5).

The signal between an OTSi modulator and an OTSi demodulator is carried by a network media channel. A network media channel is a type of media channel that is the serial concatenation of all media channels between an OTSi modulator and an OTSi demodulator, it supports a single OTSi. For example in Figure 8-1 the network media channel for OTSi #2 is formed by the concatenation of media channels A+E+F+G+H. A network media channel cannot be concatenated with another media channel. The effective frequency slot of the network media channel must be sufficient to accommodate the characteristics of the OTSi that it is intended to support. If the OTSi demodulator includes a coherent receiver which implements an optical filter, this filter must be taken into account when the effective frequency slot of the network media channel is computed. The network media

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9 For the purposes of management or control when a "wider" media channel is a part of the concatenation that is used to form longer media channels, it may be necessary to record the frequency slots of the longer media channels that are attached at each end. For example in Figure 8-1 for media channel E the frequency slots of media channels A, B, C, D, F and K should be marked as "occupied".

10 The relationship between the effective frequency slot, the passband of the filters concatenated to form a network media channel and the characteristics of the OTSi that transits the network media channel are outside the scope of this Recommendation.
channel also has an application identifier\(^\text{11}\) that is defined by considering the combined effect of the effective slot width and the transfer parameters of each of the media channels. This application identifier is used to confirm the compatibility between the network media channel and the OTSi that it is intended to carry. The mapping from the effective slot width and transfer parameters to the application code is, in general, a complex process and is not within the scope of this Recommendation.

The relationship between signals, media channels and the ports on other media constructs is shown in Figure 8-2.

\[\text{Figure 8-2 – Relationship between signals and media channels}\]

A media channel may be dimensioned to carry more than one OTSi. A media channel may be configured before it has been decided which OTSi will be allocated to it. A media channel may not be capable of supporting a particular OTSi.

Transition between different types of media is described in Annex A.

### 8.1.3 Media link

A media link is a unidirectional point-to-point topological construct that represents a set of one or more media channels, it is bounded by a pair of media ports. The constituent media channels may be atomic media channels or the serial concatenation of multiple media channels. For example a media link may be used to represent a line system with optical amplifiers. The constituent media channels are not necessarily in a single contiguous block of the optical spectrum. A bidirectional media link is formed by a pair of (contra directional) media links.

### 8.1.4 Media subnetwork

The media subnetwork is a topological construct that represents a point of flexibility where the associations (represented by media channels) between the media ports of the media subnetwork may be created or deleted. The association between a pair of media ports is provided by a "wide" media channel.

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\(^{11}\) An application identifier includes the application codes defined in the appropriate optical system Recommendations, as well as the possibility of proprietary identifiers. The identifier covers all aspects of the media channel.
A media subnetwork may be decomposed into smaller media subnetworks interconnected by media links. This decomposition may also expose filters (see clause 8.1.5) or amplifiers (see clause 8.1.7) that are also interconnected by media links. In addition, media subnetworks, filters, amplifiers, and the media links that interconnect them can be aggregated into a larger (containing) media subnetwork. In this case, the details of the contained media subnetworks, filters, amplifiers, and media links are not visible. This is illustrated in Figure 8-3. For the purposes of management and control a media subnetwork is encompassed by a media element (together with other media constructs see clause 8.2). This represents the limit of decomposition of a media subnetwork.

8.1.5 Filter

The filter models the ability to allow only those signals that are within a defined portion of spectrum to be passed from one media port to another media port\(^\text{12}\). The association between the media ports on a filter is described by a media channel. The media channel is specified by the media ports that bound it and its frequency slot. The frequency slot is described by its nominal central frequency and its slot width [ITU-T G.694.1]. A media port on a filter may be associated with zero or more media channels (with non-overlapping frequency slots). Within this Recommendation a fixed grid filter is described in terms of the frequency slot(s) it would have associated with it if it were a flexible grid filter. The frequency slot(s) of some filters (e.g., devices that support the flexible dense wavelength division multiplexing grid defined in [ITU-T G.694.1]) can be configured (via the management plane).

A filter may be implemented as a part of a coherent receiver (OTSi demodulator) and the characteristics of this filter must be included when determining the effective frequency slot and transfer characteristics of the network media channel. In this case the reference point at the OTSi demodulator is implemented inside the optical receiver module (media element) and is not located on an external port.

\(^{12}\) This is often referred to as the pass band of the filter.
The frequency slot is the frequency range allocated to a slot and unavailable to other slots and the passband of a filter will be narrower than its frequency slot. The following are outside the scope of this Recommendation:

– the relationship between the frequency slot and the passband of the filter;
– the passband of the concatenation of the filters that form a network media channel.

8.1.6 Coupler

The coupler provides a set of atomic media channels between one (common) port and two or more other (branch) ports. All of these atomic media channels have the same frequency slot. Any signals present at the common media port are transferred to all of the branch media ports. Signals present at any of the branch media ports are aggregated and appear at the common media port. The term coupler (splitter-combiner) is a synonym for an optical branching component (wavelength non-selective) as defined in [ITU-T G.671].

8.1.7 Optical amplifier

The optical amplifier models the ability to act on the envelope of the OTSi to increase the optical power level. It is unidirectional and has two media ports with a media channel between the ports. The power level of any OTSi present at the input port is increased and it is transferred to the output port. In a discrete optical amplifier, the amplification effect is contained inside the media construct. In a distributed amplifier, the amplification effect is achieved via a portion of the optical fibre used for transmission. Therefore one of the media ports of the amplifier will be at some (unspecified) location in the transmission fibre. For the purposes of the architecture the location of a distributed optical amplifier is considered to be the location where the pump wavelength is inserted. Optical amplifiers are described in terms of optical components, devices and subsystems in [ITU-T G.663] and [ITU-T G.665].

8.1.8 Optical power monitor (OPM)

The OPM measures the power of any optical signals that are present in a media channel. The optical spectrum over which the measurement is made is determined by the frequency slot of the media channel. For example, the frequency slot of the OPM may encompass the frequency slots of an OMS link or OTS link and therefore will measure the total power of the OTSi present on the OMS link or OTS link. If the frequency slot is set to that of a network media channel, then the OPM will measure the power of the OTSi that has been assigned to that network media channel.

NOTE – Based on the knowledge of the OTSi that are expected to be present, a threshold may be set, which would allow loss of signal (LOS) to be declared.

8.2 Media element

For the purposes of management and control, the media layer is represented by a set of media elements. An instance of a media element encompasses the functionality represented by one or more of the media constructs described above, and it may also encompass the OTS OSME or OMS OSME reference points (see clause 8.4.3). A media element cannot encompass another media element. One or more media ports exist at the boundary of a media element. The media element also provides zero or more interfaces that are used to manage the media element.

The internal structure of a media element is not visible, only the atomic media channels between the ports are defined. All media elements are described in the same way. The capabilities of the media element (and the media constructs that it encompasses) are described by the atomic media channels that provide the associations between its media ports.

When a signal is transferred from the common port to the branch port the signal power is divided across the branches.
An OTSi that is present at a media port may be transferred to zero or more other media ports on that media element. The ability to transfer an OTSi between ports is modelled by an atomic media channels:

- Each pair of media ports that allow signal transfer has one or more atomic media channels with a frequency slot (defined by m and n) for each atomic media channel.
- Each atomic media channel has zero or more transfer parameters. The transfer parameters may include the latency and the optical characteristics of the atomic media channel that are defined in other Recommendations, including for example [ITU-T G.663] and [ITU-T G.680].

The atomic media channel and signal transfer are modelled independently for each direction of signal propagation.

An example of a media element is a reconfigurable optical add/drop multiplexer (ROADM), as described in [ITU-T G.680], that may be composed of a set of interconnected filters and a media subnetwork, without defining the internal structure or exposing any internal interconnection of the media constructs.

8.3 Optical tributary signals and interfaces

The media layer described in clause 8.1 is used to carry the OTSi that convey the digital information of the OTN.

An OTU is supported by a set of one or more OTSi that are represented by the OTSiG management/control abstraction – an OTSiG carries one OTU. The OTSi is characterized by the central frequency and an application identifier. Each OTSi is carried in an independent network media channel. The differential delay between members of the OTSiG must be controlled. If the OTSiG-O is used, then all members of the OTSiG and the OSC that carries the OTSiG-O are carried over the same fibre.

NOTE – The OTSi supports the transfer of OTU information. In some cases it may also support the transfer of additional information to manage the OTSi. In this case these two information streams may be independently modulated onto the same OTSi in a way that allows the OTU information and OTSi management information to be demodulated and extracted independently.

\[\text{\textsuperscript{14}}\] An application identifier includes the application codes defined in the appropriate optical system Recommendations, as well as the possibility of proprietary identifiers. The identifier covers all aspects of the signal, including forward error correction, baud rate and modulation type. The characteristics of the OTSi are outside the scope of this Recommendation.
The case where the OTU is carried by a single OTSi is shown in Figure 8-4.

![Diagram of OTU mapping to OTSi and OTSiG](image)

**Figure 8-4 – Mapping an OTU to an OTSiG that contains one OTSi**

The case where the OTU is carried by more than one OTSi is illustrated in Figure 8-5.

![Diagram of OTU mapping to OTSiG with multiple OTSIs](image)

**Figure 8-5 – Mapping an OTU to an OTSiG**

The OTSiG may have non-associated overhead (OTSiG-O). The combination of the OTSiG and OTSiG-O is represented by the OTSiA management/control abstraction (which is not present in the media layer). This is illustrated in Figure 8-6.
The digital payload processing functions related to the OTU termination, OTSiA/OTU adaptation and OTSiG-O termination use the processes defined in [ITU-T G.798] and the frame formats defined in [ITU-T G.709].

Figures 8-4, 8-5 and 8-6 above give an overview of the payload processing functions that provide the interface to the media. The client of the OTSi (the OTU) is presented to the OTSiG/OTU adaptation function. The OTSi is generated from a digital stream by a modulator and converted back to a digital stream by a demodulator. The OTSi is carried in a network media channel.

8.3.1 Types of interfaces

The OTN provides four different types of interface as described in Table 8-1.

<table>
<thead>
<tr>
<th>Interface type</th>
<th>Number of OTU clients</th>
<th>Non-associated overhead carried by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single OTU interface (SOTU)</td>
<td>One</td>
<td>Not supported</td>
</tr>
<tr>
<td>Multiple OTU interface (MOTU)</td>
<td>Multiple</td>
<td>Not supported</td>
</tr>
<tr>
<td>Single OTU interface with management (SOTUm)</td>
<td>One</td>
<td>OCC†</td>
</tr>
<tr>
<td>Multiple OTU interface with management (MOTUm)</td>
<td>Multiple</td>
<td>OSC</td>
</tr>
</tbody>
</table>

Table 8-1 – Types of OTN interfaces

A media layer interface between a network provider and an end user, or between two network providers, is normally implemented using a short reach interface as defined in [ITU-T G.695] or [ITU-T G.959.1]. 3R regeneration is used on both sides of these interfaces. Other types of interfaces may be used by mutual agreement.

NOTE – A short reach SOTU interface may be implemented using Flexible OTN (FlexO), as defined in [ITU-T G.709.1]. The FlexO interface implements the functionality of the OTSiG/OTU adaptation and the OTSi modulator/demodulator. The FlexO interface bonds (i.e., combines) n standard-rate, for example, 100G interfaces to provide a contiguous capacity of n×100G, over which the OTUCn is carried. Each of the 100G interfaces is carried over a separate fibre.
8.4 Management of optical signals

8.4.1 OMS and OTS media links

The OMS media link and OTS media link are topological constructs that are used for management control.

The OMS media link represents:
- The topological relationship between the media port on a filter or coupler where a set of OTSi are aggregated and the media port on a filter or coupler where one or more OTSi is added to or removed from that aggregate. All of the media channels that are represented by the OMS media link must be carried over the same serial concatenation of fibres.

The OTS media link represents the topological relationship between:
- The output media port of one amplifier and the input media port of the next amplifier. For distributed optical amplifiers, (described in [ITU T G.665]) the input media port or output media port of the amplifier may not be accessible. In this case the OTS media link is considered to start or terminate at the location where the pump wavelength is inserted.

The composition of the OTS and OMS media links when optical amplifiers are deployed is shown in Figure 8-7 below.

![Figure 8-7 – OTS and OMS media links with optical amplifiers](image)

The case where remote amplifiers are not deployed is shown in Figure 8-8 with both discrete and distributed amplifiers deployed at the sites where the OMS media link terminates.
In the case that an amplifier is not deployed at one end of the OMS media link, the OTS media link represents the topological relationship between:

- the media port at the start of an OMS media link and the input media port of the first amplifier in the OMS media link;

or:

- the output media port of the last amplifier in the OMS media link and the media port at the end of that OMS media link.

In the case where no optical amplifiers are deployed, the OTS media link is not present.

### 8.4.2 OSC

The OSC is an OTSi that may be used to carry the OTSiG-O and a Data Communications Channel (DCC) described in [ITU-T G.7712], between amplifier sites, between a terminal site and an amplifier site or, in the case where remote amplifiers are not deployed, between terminal sites. It is labelled as OSC (instead of OTSi) within this Recommendation to distinguish it from an OTSi that is used to carry other clients. It is carried in a media channel (labelled as an OSC media channel). The OSC media channel is aggregated with the OTS media link by the OSC filter. This is illustrated in Figure 8-9 below.
The case of a distributed amplifier is illustrated in Figure 8-10 below.

The media element injects the pump wavelength into the transmission fibre. The pump may be injected in the same direction as the signal or in the opposite direction to the signal or both. The operation of distributed amplifiers is described in [ITU-T G.665].

In the case where no amplifiers are deployed, the OSC media channel is aggregated with the OMS media link by the OSC filter.

The OTS media link, OMS media link and the OSC media channel must be carried by the same fibre to provide the OAM functions described clause 10.

8.4.3 Optical signal maintenance entities (OSME)

Optical power monitors (OPM) may be attached to the OMS media link or OTS media link, the attachment of the OPM creates the OMS OSME and OTS OSME reference points. The same set of signals is carried by both the OMS media link and the OTS media link. The attachment of a pair of OPMs results in the creation of the OSME. This is illustrated below in Figure 8-11 for discrete amplifiers.
Figure 8-11 – Optical signal maintenance entities with discrete amplifiers

Figure 8-12 illustrates the OSME for distributed amplifiers.

Figure 8-12 – Optical signal maintenance entities with distributed amplifiers
The OMS OSME monitors the optical power of the OTSi carried by the OMS media link. The reference points at the end of the OMS OSME are defined by the location of the OMS OPMs. The OMS OPM are not required to be in the same location as the OMS media link aggregation/disaggregation.

The OTS OSME provides bulk monitoring of the OTSi carried by the OTS media link. The end points of the OTS OSME are defined by the location of the OTS OPMs. The set of OTSi in the OMS media link and OTS media link are identical.

When the OTS OSME and OMS OSME start or end at the same location a single (common) OPM may be used. This occurs, for example, when a discrete amplifier is not deployed in a terminal site.

A network media channel (see clause 8.1.2) can exist in the absence of the OMS OSME and OTS OSME, however, some of the alarm management, fault detection and fault isolation capabilities described in clause 10 will not be supported.

NOTE – The implementation of the OTS OPM or OMS OPM may include the ability to detect which frequency slots have an active OTSi. This capability is particularly useful when the frequency slot of the OPM matches the effective frequency slot of a network media channel. The information from this capability may be used for fault isolation in the case where a fault occurs in a frequency selective component and therefore not all of the OTSi being carried by the OTS or OMS media link are impacted. Further details of other optical monitoring capabilities are provided in [ITU-T G.697].

8.4.4 Media channels and OSMEs

The relationship between the media, OTSi and the OSME for a terminal or add/drop site that supports the MOTUm interface is illustrated in Figure 8-13 below (for clarity this figure shows the case of a single OTU; other OTSiA at the same interface would share the media subnetwork and OTSiG-O subnetwork).
Figure 8-13 – Example of a terminal implementation for the MOTUm interface

The media subnetwork, aggregation, optical amplifier OSC filter and OPMs are shown as discrete (independent) media constructs to allow the reference points associated with the OMS OSME and OTS OSME to be exposed. The OMS OPM and OTS OPM observe the bulk aggregate power level of the signals transiting the media. Frequently these OPM functions are integrated into the optical amplifier. The output of the OSC modulator is an OTSi, it is labelled as OSC (instead of OTSi) to improve the clarity of the description. In the case where the OMS media link and OTS media link are coincident (see Figure 8-8) or the OTS media link is not present the OTS-O/OMS-O adaptation, OTS-O termination and OSC/OTS-O adaptation are replaced by an OSC/OMS-O adaptation.
As described in clause 8.2, for management/control purposes the media layer is represented by media elements (that encapsulate media constructs). An example of a media element that encompasses all of the media constructs OTS OMSE reference point and OMS OMSE reference point shown in Figure 8-13 is shown in Figure 8-14, other encapsulations that use more than one media element are possible\(^{15}\).

Figure 8-14 – Example of a terminal implementation using a single media element

In this case the media element provides media channels between the MOTU\(m\) interface and each of the OTSi and OSC termination functions. It may also provide the OMS LOS and OTS LOS indications.

\(^{15}\) Placing the media constructs in different media elements provides management/control with more visibility of the implementation.
8.5 Management of media and signals

8.5.1 Management of media channels
As described in clause 8.1.2, a media channel may be a serial concatenation of multiple media channels, each with its own effective frequency slot. Media subnetworks provide a point of flexibility where the route of a media channel across the media layer may be created or modified.

The frequency slot of a media channel is defined by a filter and, for a flexible grid capable filter, the frequency slot can be configured. The configuration of a frequency slot in a flexible grid capable filter may create or modify the media channel between the ports of the filter. This configuration can modify the route of a media channel across the network (see Appendix V).

A media channel that has a "wide" frequency slot may be concatenated with multiple media channels each with its own "narrower" frequency slot. The effective frequency slot of a media channel is defined by the concatenation of the filters that are included in that media channel. Some examples of the construction of media channels are provided in Appendix V.

8.5.2 Assignment of signals to media channels
A media channel may be configured before it has been decided which OTSi will be allocated to it. As described in clause 8.1.2, the OTSi must be compatible with the network media channel that has been assigned.

A network media channel with an effective frequency slot that supports a single OTSi may be constructed, as described in clause 8.5.1, between the OTSi modulator and the OTSi demodulator. Alternatively, the media layer may be constructed using only couplers, without any discrete filters. This creates a set of point-to-multipoint media channels between all OTSi modulators and all OTSi demodulators. Point-to-point communications between a specific pair of OTSi modulators and demodulators can be achieved by configuring the same frequency slot at the OTSi modulator and OTSi demodulator. This creates a point-to-point network media channel. An example of this type of network is provided in Appendix VI.

8.5.3 Management of OTSiA connections
From a management control perspective, a request to carry an OTSiA should be considered as a single action. This action involves the configuration of the OTSi modulator and demodulator, the network media channels and the OTSiG-O. Configuration of the network media channels includes the configuration of the media elements that encompass the media constructs (e.g., media subnetworks, flexible grid capable filters and possibly amplifiers) that are part of the serial concatenation of media channels that forms the network media channel.

Two simple cases for the configuration of a network element that includes a media subnetwork when an OTSiA connection request is received are described below:

1) Pre-configured media elements: In this case the media channels in the media subnetwork and the associated filters are configured before the OTSiA connection request is received:
   • The OTSiG-O connection function and the OMS-O MSI are configured.

---

16 A "wide" media channel may be used to provide what is commonly called an "express" channel in a ROADM.

17 This may be achieved by using a tunable transmitter with a confined output spectrum.

18 This may be achieved by use of a coherent receiver or a flexible grid capable filter at the OTSi demodulator.

19 As described above, the network media channel may be fully or partially configured before the OTSiA connection request is received.
• The media channel(s) in media subnetwork must be checked to verify that the correct ports are connected so that all members of the OTSiG are directed to and or from the same OMS media port. The associated filters are checked to ensure that frequency slot of each filter is compatible with the frequency slot requested for each OTSi.

• In general when the OTSiA is deleted, only the OTSiG-O connection and OMS-O MSI (for that OTSiG) should be removed, the configuration of the media elements should not be changed.

or:

2) The media elements are not configured:

• In this case, the media channels in the media subnetworks and filters are configured as a result of the OTSiA connection request. The media channels in the media subnetwork and the associated filters, the OTSiG-O connection and the OMS-O MSI are configured. The consistency checks described above should be performed.

• In general, deletion of the OTSiA should also result in the deletion of the OTSiG-O connection the OMS-O MSI. The media subnetwork and filter media channels should also be deleted, except in the case where a media channel is being used to support another network media channel.

8.5.3.1 OTSiA subnetwork

The OTSiA subnetwork is a management abstraction that represents the flexible media associations and the corresponding OTSiG-O subnetwork. As described in clause 8.5.3, a request for an OTSiA subnetwork connection is mapped into the appropriate configuration commands for media channels in the media subnetwork and flexible grid filters and the corresponding connection in the OTSiG-O subnetwork and configuration of the OMS-O MSI.

A simple example of an OTSiA subnetwork in the context of an add/drop site is provided in Figure 8-15. The filters, optical amplifiers and media subnetwork are shown as independent media constructs, the OTS OPM and OMS OPM are not shown and the OTSiA only has one OTSi. The forwarding of the OTSiG-O OAM information carried by the non-associated overhead is modelled by the OTSiG-O subnetwork. Connection points on the OTSiG-O subnetwork must correspond to those of the media channels in the filters and media subnetwork that carry the corresponding set of OTSi in the OTSiG, and the OAM information flow must follow that of the media channel configured in the media subnetwork.

20 This flexibility may be implemented by a media subnetwork, a set of interconnected flexible grid filters or some combination of flexible grid filters and media subnetworks.
The granularity of the OTSiG-O sub-network connection is always that of a single OTSiG-O. The granularity of the media channel associations in the media subnetwork is determined by the effective slot width of the filters that are attached to the ports of the media subnetwork. The slot width may be the same as a network media channel (and hence support a single OTSi) or it may be larger so that the media channel may be a part of multiple network media channels (and hence support multiple OTSi). In this case the request to configure an OTSiA connection is mapped into requests to configure the OTSiG-O subnetwork, the OMS MSI, the media subnetwork and the filters if they are flexible grid capable.

An example of a media element that encompasses all of the media constructs shown in Figure 8-15 is shown in Figure 8-16. Other encapsulations that use more than one media element are possible. The encapsulation shown in Figure 8-16 represents a ROADM as described in [ITU-T G.680].
In this case the request to configure an OTSiA connection is mapped into a request to configure the OTSiG-O subnetwork, the OMS MSI and the corresponding media channels between ports L1 and L2 or between ports L1 and D1 or between ports L2 and D1 of the media element. In this case the media element translates the request for an atomic media channel between its ports into the required configuration of the internal media constructs (such as flexible grid filters and media subnetworks).

### 8.6 Modulator and termination functions

#### 8.6.1 OTSi bidirectional modulator

The following generic processes take place at the OTSi bidirectional modulator:
- transmission defect detection and indication.

The requirement for these processes are outlined in clause 10.2.
There are three types of OTSi modulator:
- OTSi bidirectional modulator: consists of a pair of collocated OTSi modulators and OTSi demodulators.
- OTSi modulator: accepts digital information at its input, modulates the digital information onto an optical signal with a particular central frequency.
- OTSi demodulator: accepts an optical signal at its input checks that an optical signal with the appropriate power level is present. Demodulates the optical signal and presents the digital information at its output.

8.6.2 OTSiG-O trail termination function
The following generic processes are assigned to the OTSiG-O trail termination function:
- assessment of transmission quality
- transmission defect detection and indication.

The requirement for these processes are outlined in clause 10.221.

There are three types of OTSiG-O trail termination function:
- OTSiG-O bidirectional termination: consists of a pair of collocated OTSiG-O termination source and sink functions;
- OTSiG-O source: accepts the input from the OPM associated with the OTSi modulator (if present) and generates the OTSiG-O;
- OTSiG-O sink: processes the OTSiG-G overhead and the input from the OPM associated with the OTSi demodulator (if present) and generates any OTSiA management information.

8.6.3 OMS-O trail termination function
The following generic processes are assigned to the OMS-O trail termination function:
- assessment of transmission quality;
- transmission defect detection and indication.

The requirement for these processes are outlined in clause 10.222.

There are three types of OMS-O trail termination function:
- OMS-O bidirectional termination: consists of a pair of collocated optical multiplex section termination source and sink functions;
- OMS-O source: accepts the input from the OPM located at the start of the OMS media link and generates the OMS overhead;
- OMS-O sink: processes the OMS overhead and the input from the OPM located at the end of the OMS media link and generates any OMS management information.

The bulk property monitoring of the OMS OSME takes place in the co-collocated OPM.

Note that these functions are absent if the OAM functions described in clause 10 are not supported.
8.6.4 OTS-O trail termination function

The following generic processes may be assigned to the OTS-O trail termination function:

- validation of connectivity; note that the OTS-O must arrange for squelching\textsuperscript{23} all components of the OTS in the event of a validation mismatch;
- assessment of transmission quality;
- transmission defect detection and indication.

The means of providing these processes are described in clause 10.2\textsuperscript{24}.

There are three types of OTS-O trail termination function:

- OTS-O bidirectional trail termination: consists of a pair of collocated OTS-O trail termination source and sink functions;
- OTS-O source: accept input from the OPM located at the start of the OTS media link and generates the OTS trail overhead;
- OTS-O sink: accepts input from the OPM located at the end of the OTS media link, processes the OTS overhead contained within the OSC and generates any OTS management information.

The bulk property monitoring of the OTS OSME takes place in the co-collocated OPM.

8.6.5 OSC bidirectional modulator

The following generic processes take place at the OSC bidirectional modulator:

- transmission defect detection and indication.

The requirement for these processes are outlined in clause 10.2.

There are three types of OSC modulator:

- OSC bidirectional modulator: consists of a pair of collocated OSC modulators and OSC demodulators.
- OSC modulator: accepts non-associated overhead digital information at its input, modulates the digital information onto an optical signal with a particular central frequency.
- OSC demodulator: accepts an optical signal at its input and checks that an optical signal with the appropriate power level is present. Demodulates the optical signal and presents the non-associated overhead digital information at its output.

8.7 Client/server associations

8.7.1 OTSiA/OTU adaptation function

The bidirectional OTSiA/OTU adaptation function is performed by a collocated pair of source and sink OTSi/OTU adaptation functions.

The OTSiA/OTU adaptation source performs the following processes between its input and its output:

- accepts the output of the OTU trail termination and performs the processing required to generate a continuous data stream that can be modulated onto an OTSi or multiple OTSi. The actual processes required are dependent upon the particular implementation of the client/server. Forward error correction is an optional feature.
- generate any OTSiG-O.

\textsuperscript{23} Note that this requirement can be met by a blocking switch at different locations. It is an equipment design matter to place the switch.

\textsuperscript{24} Note that these functions are absent if the OAM functions described in clause 10 are not supported.
The OTSiA/OTU adaptation sink performs the following processes between its input and its output:
– recovery of the OTU data stream. The actual processes are dependent upon the particular implementation of the client/server relationship. Forward error correction is an optional feature.
– accept and process any OTSi overhead from the OTSiG-O trail termination function.

8.7.2 OMS-O/OTSiG-O adaptation function
The bidirectional OMS-O/OTSiG-O adaptation function is performed by a collocated pair of source and sink OMS-O/OTSiG-O adaptation functions.

The OMS-O/OTSiG-O adaptation source performs the following processes between its input and its output:
– generation of management/maintenance signals, as described in clause 10.2.

The OMS-O/OTSiG-O adaptation sink performs the following processes between its input and its output:
– termination of management/maintenance signals, as described in clause 10.2.

8.7.3 OTS-O/OMS-O adaptation function
The bidirectional OTS-O/OMS-O adaptation function is performed by a collocated pair of source and sink OTS-O/OMS-O adaptation functions.

The OTS-O/OMS-O adaptation source performs the following process between its input and its output:
– generation of management/maintenance signals as described in clause 10.2.

The OTS-O/OMS-O adaptation sink performs the following process between its input and its output:
– termination of management/maintenance signals as described in clause 10.2.

8.7.4 OSC/OTS-O adaptation
The bidirectional OSC/OTS-O adaptation function is performed by a collocated pair of source and sink OSC/OTS-O adaptation functions.

The OSC/OTS-O adaptation source performs the following processes between its input and its output:
– all the processing required to generate a continuous data stream that can be modulated onto an OTSi. The actual processes required are dependent upon the particular implementation of the client/server.

The OSC/OTS-O adaptation sink performs the following processes between its input and its output:
– recovery of the digital stream from OSC. The actual processes are dependent upon the particular implementation of the client/server relationship.

8.7.5 OSC/OMS-O adaptation
The bidirectional OSC/OMS-O adaptation function is performed by a collocated pair of source and sink OSC/OMS-O adaptation functions.

NOTE – This function is used when the OTS-O is not present (clause 8.4.1).

The OSC/OMS-O adaptation source performs the following processes between its input and its output:
– all the processing required to generate a continuous data stream that can be modulated onto an OTSi. The actual processes required are dependent upon the particular implementation of the client/server.

The OSC/OMS-O adaptation sink performs the following processes between its input and its output:
– recovery of the digital stream from OSC. The actual processes are dependent upon the particular implementation of the client/server relationship.

25 Some of these processes may rely on information extracted from the modulated optical signal by the OTSi demodulator.
9 Media topology

The OTN digital layers can support unidirectional and bidirectional point-to-point connections, and unidirectional point-to-multipoint connections as described in [ITU-T G.805]. This clause describes the topology of the media layer. The media can be configured to provide point-to-point and point-to-multipoint media channels. Note that a media channel may support the propagation of a signal in one direction or both directions. A bi-directional OTSi is supported by two network media channels (one for each direction of propagation).

As described in clause 8.2 a media element contains one or more media constructs and has n ports. Each pair of ports that allows signal transfer has one or more atomic media channels, with a frequency slot. Each media channel has zero or more transfer parameters.

As described in clause 6, the OTSi is characterized by its central frequency and an application identifier. The OTSi is guided to its destination by a network media channel.

The topology of the media is first expressed in a simple graph, where media subnetworks are represented by vertices and the media links (e.g., fibres) that interconnect them by edges. The parameters of the media channels (frequency slot and any relevant transfer parameters) are attached to the graph as edge semantics and regions of the graph having identical edge semantics are formed.

The initial network topology of the media layer comprises all available resources (e.g., all frequency slots). A topology instance is derived from the initial network topology by selecting those topological components that support a specific set of parameters (e.g., a frequency slot). Any components that do not support the selected parameter values are removed from the initial topology graph. Similarly any unreachable media subnetworks are removed. The resulting topology now shows available connectable resources.

For example, selecting a particular frequency slot for an OTSi removes all resources operating at different frequencies from the initial topology graph. The resulting topology instance now shows available connectable media channels that support the selected frequency slot. Determining whether the network media channel provided by this topology instance will actually support communication between an OTSi modulator and an OTSi demodulator is outside the scope of this Recommendation.

The process of removing resources operating at different frequencies or that result in paths that are not viable (i.e., cannot support the intended OTSi) may result in a topology graph that has isolated regions. Electrical regeneration can be used to provide connectivity for the client of the OTSi (e.g., OTU) between isolated instances of the media topology. Since the regenerator terminates the OTSi and generates a new OTSi it can provide functions such as, frequency slot translation, changes in the modulation and/or forward error correction. In the topology regeneration can be represented as a transitional link and represent the means of transforming between disjoint regions.

9.1 Unidirectional and bidirectional connections

A bidirectional OTSi may be supported by one optical fibre for both directions (single fibre working), or each direction may be supported by different fibres (two fibre working). For single fibre working, the bidirectional OTSi is realised by a pair of unidirectional media channels, using normally different frequency slots on the same fibre. For two fibre working, the bidirectional OTSi is supported by two media channels, one on each fibre that may use the same frequency slots.

The use of the OSC in single fibre working is currently not considered in this Recommendation.

9.2 Point-to-multipoint media channels

A point-to-multipoint media channel is used to broadcast the OTSi from one OTSi modulator to a number of OTSi demodulators. This is illustrated in Figure 9-1 where a point-to-multipoint association is provided in the media by means of a coupler. This represents the root of a multipoint
media channel. The point-to-multipoint media channel should only be used to support a point-to-multipoint OTSi.

Figure 9-1 – Point-to-multipoint OTSi

10 Management

This clause outlines the requirements for fault, performance and configuration management for the OTN.

The OTN digital layers (ODU, OTU) use digital overhead to provide OAM, which can report on the status of the layer and may be used to infer the status of the server layer.

A media channel has no inherent monitoring capability. The continuity of a media channel can be inferred by examining the signals present in that media channel. The OMS OSME and OTS OSME provide information about the continuity of the OMS media link and OTS media link respectively. The status of a network media channel may be inferred directly from the OTSi digital overhead (if present) or from the OTU overhead in the case where the OTSi digital overhead is not present.

NOTE – The OTU is 1:1 with the OTSiG, hence the OTU digital overhead may be used to infer the status of the OTSiG and from that, the status of the network media channels that support the OTSiG can be inferred.

10.1 Requirements

10.1.1 Fault, configuration and performance management

The OTN shall provide support for fault, configuration and performance management end to end, within an administrative domain and between the boundaries of administrative domains.

The OTN shall provide the capability to:

– interconnect reference points e.g., FP (with compatible AI) and media ports that will support compatible OTSi;
– detect and isolate faults and initiate recovery actions where applicable;
– support single-ended maintenance;
– detect and report misconnections;
– report any interruptions within a layer to the upstream and downstream entities in that layer;
– detect performance degradation and verify quality of service.

10.1.2 Client/server interaction

The server shall detect and indicate to the client layer when a digital stream or optical signal is not present.
To avoid unnecessary, inefficient or conflicting survivability actions, escalation strategies (e.g., introduction of hold-off times and alarm suppression methods) may be required:

– within a layer
– between a server and client layer.

10.1.3 Adaptation management

Adaptation management refers to the set of processes for managing the adaptation of a client layer network to/from the server layer network. A payload type identification (PTI) is used for adaptation management in the ODU layer network.

A PTI mismatch detected at an ODU/client adaptation source or sink indicates that the adaptation function has not been configured correctly. The ODU/client adaptation may also provide client-specific supervision processes. Definition of these processes is outside the scope of this Recommendation.

10.1.4 Connection and media channel supervision

10.1.4.1 Continuity supervision

Continuity supervision refers to the set of processes for monitoring the continuity of an entity (e.g., connection, trail, media channel).

The following process is identified for continuity supervision:

– detection of loss of continuity.

In general, a continuity failure in a server is indicated to a client through server signal fail (SSF) indication.

Continuity supervision of media

Media channels have no monitoring capabilities, the continuity of a media channel may be inferred from presence of the OTSi that are intended to be supported by that media channel. An OMS media link is supported by zero or more OTS media links (see clause 8.4.1). A loss of continuity of an OTS media link will result in a loss of continuity for the OMS media link. Similarly the loss of continuity of an OMS media link will result in the loss of continuity for any network media channels which include that OMS media link. The OMS media link is monitored by an OMS OSME, the OTS media link is monitored by an OTS OSME (see clause 8.4.3).

A media channel failure may be caused by fibre disruptions, equipment failures or both. Equipment failures may be detected and reported by the equipment monitoring capabilities.

A disruption to a fibre will interrupt an OTS media link. In this case the OPM at the end of that OTS OSME will observe a reduction in optical power, indicating that the OTSi that were being carried by that OTS media link have suffered a disruption. The associated OSC demodulator will also observe a loss of signal. This combination of failures will be reported to the associated OTS-O trail termination sink as a loss of OTS media link continuity. This will cause the insertion of an OTS FDI in the downstream OTS-O and OTS BDI in the upstream OTS-O. A loss of continuity of the OSC by itself shall not initiate these consequent actions (i.e., OTS FDI and BDI should not be generated). A failure in media element may cause a loss of OTS media link continuity (detected by the OTS OSME). However, this may not cause a failure of the OSC. The consequent actions for this case are as described above.

The loss of continuity of an OMS media link may be detected by the OPM at the end of the OMS OSME, or it may be inferred from the SSF indication provided by the OTS-O.

NOTE – Depending on the network configuration and the location of the fault, amplified optical noise may prevent the OMS OSME from detecting a reduction in optical power.
When a loss of OMS media link continuity is reported to an OMS-O trail termination sink, an SSF will be passed to the OTSiG-O sink. For any OTSi that are not terminated, the SSF will be passed to the downstream OMS-O adaptation source and will cause the insertion of FDI for the affected OTSi.

A SSF reported to the OTSiG-O trail termination sink will cause the generation of SSF towards the client layer (OTU). It is possible that the OMS OSME will detect a loss of continuity without SSF being reported by the OTS-O trail termination function. Consequent actions are the same as described above. It is possible that the OTSi demodulator or OTSiA/OTU adaptation will detect a loss of continuity of the network media channel without a loss of continuity being reported by the OTS-O or OMS-O. Consequent actions are the same as for the OMS SSF case.

A loss of continuity of the OSC by itself shall not initiate these consequent actions (i.e., OMS SSF should not be generated). A failure in media element may cause a loss of OMS media link continuity (detected by the OMS OSME). However this may not cause a failure of the OSC, and consequent actions for this case are as described above.

Since no replacement OTSi are provided, failure conditions within the media can result in the expected OTSi being absent in the downstream OTS OSME and OMS OSME. This may cause the optical power level to be lower than normal at any downstream OPMs. Appropriate maintenance signalling via the non-associated overhead (e.g., FDI) shall be used to prevent this from being reported as a loss of continuity.

10.1.4.2 Connectivity supervision

Connectivity supervision refers to the set of processes for monitoring the integrity of the routing of a media link or a connection between source and sink trail terminations.

Connectivity supervision is necessary to confirm proper routing of a connection between trail termination source and sink during the connection set-up process. Furthermore, connectivity supervision is needed to ensure that connectivity is maintained while the connection is active.

Media channels have no monitoring capabilities, the connectivity of a media channel may be inferred from the connectivity of the OTSi supported by that media channel. An OMS media link is supported by zero or more OTS media links (see clause 8.4.1). Consequently a connectivity error in an OTS media link will result in a connectivity error in the OMS media link. The following process is identified for connectivity supervision:

– trail trace identification (TTI).

TTI is necessary to ensure that the signal received by a trail termination sink originates from the intended trail termination source. The following requirements are identified:

– TTI is required in the OTS-O: this confirms that the fibres are connected correctly. This connectivity check is only valid if the OTS media link and the OSC are carried on the same fibre.

– TTI is not required in the OMS-O when the OMS media link is carried by one or more serially-concatenated OTS media links: the connectivity of the OMS media link may be inferred from the connectivity of the OTS media links. There is a fixed one-to-one relationship between the OTS media link and the OMS media link. The connectivity of the OMS media link within an amplifier site should be verified by the equipment. Further, flexible connectivity of the OMS media link is not envisaged.

– TTI is required in the OMS-O when an OTS media link is not present: this confirms that the fibres are connected correctly. This connectivity check is only valid if the OMS media link and the OSC are carried on the same fibre.

– TTI is not required for the OTSi because there is a fixed one-to-one relationship between the OTSiG and the OTU trail that it is supporting.

NOTE – An OTSi TTI may be useful for the purposes of reassembling the OTSiG and for fault isolation.
– TTI is required at the OTU layer to ensure proper OTU layer connections.
– TTI is required at the ODU layer to ensure proper ODU layer connections.

When the OTSiG-O is carried by an overhead communications channel (OCC) in an overhead communications network (OCN) (see clause 12) it is necessary to carry a TTI and the frequency slot(s) of the associated OTSi with the OTSiG-O in the OCC to ensure there are no misconnections across the OCN.

Detection of connectivity defects will lead to the same consequent actions as those described above for the detection of loss of continuity. Except that detection of OTS-O or OMS-O loss of connectivity will result in the generation of OTS SSF or OMS SSF as described above.

10.1.4.3 Maintenance information

Maintenance information refers to the set of processes for indicating defects in a connection, which is part of a trail. The defect indications are given in the downstream and upstream directions of a bidirectional trail.

Four maintenance information processes are identified:
– forward defect indication (FDI) and alarm indication signal (AIS)
– backward defect indication (BDI)
– backward error indication (BEI)
– open connection indication.

These processes enable defect localization and single-ended maintenance.

FDI/AIS are used to indicate downstream that a defect condition has been detected upstream. This allows the suppression of superfluous failure reports due to this defect.

BDI and BEI signal the state of the trail at the local trail termination sink back to the remote trail termination. BDI and BEI support the real-time requirements of bidirectional performance monitoring.

FDI is applicable for the ODU, OTU and OTS-O.
AIS is for the ODU and OTU.
BDI is applicable for the ODU, OTU, OMS-O and OTS-O.
BEI is applicable for the ODU and OTU.
Open connection indication is applicable for the ODU.

10.1.4.4 Subnetwork/tandem/unused connection supervision

Supervision for subnetwork connections, tandem connections and unused connections is required for the ODU layer. Connection supervision techniques and applications are listed in clauses 10.2 and 10.3.

10.1.5 Connection quality supervision

Connection quality supervision refers to the set of processes for monitoring the performance of a connection. Generic processes include parameter measurement, collection, filtering and processing.

Connection quality supervision, by means of BIP-8, is only supported for the ODU and OTU layer networks.

10.1.6 Management communications

Management communications that are not associated to a particular OTN layer are transported via a data communications network (DCN) as specified in [ITU-T G.7712]. The DCN may be supported by one of the ODU overhead communications channels (OCC) or by the OSC.
10.2 Connection supervision techniques

Connection supervision is the process of monitoring the integrity of a given connection in the digital layers of the OTN. The integrity may be verified by means of detecting and reporting connectivity and transmission performance defects for a given connection. [ITU-T G.805] defines four types of monitoring techniques for connections:

– inherent monitoring
– non-intrusive monitoring
– intrusive monitoring
– sublayer monitoring.

10.3 Connection or media channel supervision applications

10.3.1 Unused connections or media channels

No mechanisms exist for monitoring an unused media channel, so any such information must come from administrative processes.

In order to detect the inadvertent opening of a media channel in a media subnetwork, the OMS-O should include an indication of whether a frequency slot is occupied or not (OMS MSI). This allows a downstream network element to raise an alarm should a persistent unexpected change in frequency slot allocation occur.

In order to detect the inadvertent opening of a subnetwork connection in a subnetwork, ODU overhead includes an indication of whether an ODU TS is occupied or not (OPU MSI). See [ITU-T G.798] for further details.

10.3.2 Connection monitoring

ODU connection monitoring may be applied to:

– a network connection;
– a subnetwork connection, establishing a serving operator administrative domain tandem connection;
– a link connection, establishing a service requesting administrative domain tandem connection or a protected domain tandem connection;
– a link connection (by means of the OTU), for fault and performance degradation detection for network maintenance purposes.

ODU connection monitoring can be established for a number of nested connections, up to the maximum level defined by [ITU-T G.709]. The number of connection monitoring levels that can be used by each operator/user involved in an ODU connection must be mutually agreed between these operators and users.

11 OTN survivability techniques

It is expected that survivability techniques will only be used in the OTN for the ODUk layer network and the media.

For ODU transport entities digital overhead is used to detect faults or performance degradations (see clause 10) these events may be used to trigger the replacement of the failed transport entity.

For a media channel, a loss of continuity is detected by an OPM as the optical power level being lower than expected (see clause 10). This may be used to trigger the replacement of the affected media channel and any digital transport entities that convey the non-associated overhead.
For example, loss of continuity detected by the OPM at the end of an OMS OSME (see clause 8.4.3) may be used to trigger the replacement of both the OMS media link and the digital transport entities that convey the OTSiG-O and OMS-O. Note that to maintain the connection supervision, fault detection and localization capabilities (see clause 10) the OMS media link and the non-associated overhead must be carried by the same fibre.

Specific survivability techniques include protection (defined in the G.873.x series) and restoration (e.g., controlled by ASON or SDN) are out of the scope of this Recommendation.

12 The black link approach

The black link approach is described in [ITU-T G.698.1] and [ITU-T G.698.2]. The specification method used in these Recommendations uses a "black link" approach, which means that optical interface parameters for only (single-channel) optical tributary signals and the transfer function of the media path are specified by a set of application codes. Use of a common application code ensures the compatibility of the media path, transmitter and receiver. This approach enables transverse compatibility at the single-channel point using a direct wavelength-multiplexing configuration. However, it does not enable transverse compatibility at the multichannel points. Only the SOTU\textsubscript{m} interfaces are supported and the OTU must be supported by a single OTSi. The non-associated overhead for the SOTU\textsubscript{m} interface must be provided by an OCC as defined in [ITU-T G.7712].

The black link approach may be used to provide a network media channel between an OTSi modulator/demodulator pair as shown in Figure 12-1. The network media channel, OTSi modulator and OTSi demodulator may be provided by different vendors but must all be within the domain of a single network operator.

The black link approach provides a media channel, which is pre-certified for a particular intra-domain OTSi, the characteristics of this signal at the S\textsubscript{s} and R\textsubscript{s} reference points are defined in [ITU-T G.698.1] and [ITU-T G.698.2]. The media channel has no internal structure visible from either the OTSi modulator or demodulator.

The OTSiG-O must also be supported; however, in this application it cannot be carried across the complete network by the OSC as described in clause 8.3. To complete the OTSiG-O connection, it is carried across the interface between the OTSiA subnetwork and the OTSi modulator/demodulator by an OCC within the OCN as shown in Figure 12-1. Within the OTSiA subnetwork the connection of the OTSiG-O and the media channel associations must be coordinated as described in clause 8.5.3.

NOTE – S\textsubscript{s} and R\textsubscript{s} in Figure 12-1 identify the reference points defined in [ITU-T G.698.1] and [ITU-T G.698.2].
Figure 12-1 – Example OTSi subnetwork using the black link approach
Annex A

Media change and physical domain change

(This annex forms an integral part of this Recommendation.)

Signals can be classified into different physical domains which have different wave properties. For example, acoustical and electromagnetic physical domains. A signal propagating in one physical domain may continue into another physical domain when there is a function capable of performing the change. A signal may also change the media it is being propagated on. Both types of changes are independent of any information that may be present on the signal. Depicting these changes separately from information transfer is important as the information (if present) is not altered.

An example of media and physical domain change is the electro/optical (E/O) change. In this case, an EM wave carried on, for example, copper wire is changed into an optical wave that is carried on an optical fibre. The information (if present) is modulated onto the wave in each physical domain and those modulations are independent of each other. This is illustrated in Figure A.1 below:

![Figure A.1 – Media and physical domain change – E/O conversion example](image1)

In Figure A.1, the thin lines represent ITU-T G.800 information transfer. Media is represented by a thick line. The signal, carried by the media, is not represented. Between physical domains, a digital information stream is shown between the top of the adaptations. The electrical signal and OTSi are carried within the media channels of their respective media.

A change of media may occur in a media element, for example in a photonic cross connect. This is shown in Figure A.2, where an OTSi is carried, first in an optical fibre, then enters free space, then continues in a second optical fibre. There is no change to the physical domain. The OTSi traverses a concatenation of three media channels, the middle of which is in a different media.

![Figure A.2 – Media change – OTSi example](image2)
Appendix I

Relationship between OCh and OTSi terminology

(This appendix does not form an integral part of this Recommendation.)

The mapping from the previous OCh terminology to the current OTSi terminology is provided in Table I.1 and Figure I.1 below.

Table I.1 – Mapping between OCh and OTSi terminology

<table>
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<th>OCh Term</th>
<th>OTSi Term</th>
<th>Number of OTSi in the OTSiG</th>
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<td>OCh-P</td>
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</tr>
<tr>
<td>none</td>
<td>OTSi</td>
<td>&gt;1</td>
</tr>
<tr>
<td>OCh-P</td>
<td>OTSiG</td>
<td>1</td>
</tr>
<tr>
<td>none</td>
<td>OTSiG</td>
<td>&gt;1</td>
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<tr>
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<td>OTSiG-O</td>
<td>*</td>
</tr>
<tr>
<td>OCh</td>
<td>OTSiA</td>
<td>1</td>
</tr>
<tr>
<td>none</td>
<td>OTSiA</td>
<td>&gt;1</td>
</tr>
<tr>
<td>OCh-P connection function</td>
<td>Media subnetwork</td>
<td>not applicable</td>
</tr>
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</table>

NOTE – The OCh-O and OTSiG-O support the same function but the OTSiG-O carries additional information related to the structure of the OTSiG.
Figure I.1 – Relationship between OCh and OTSi terminology

* NOTE – This figure only applies for the case where the OTSiG has a single member
Appendix II

Use of the OTN to carry Flex Ethernet

(This appendix does not form an integral part of this Recommendation.)

II.1 Overview of Flex Ethernet

Flex Ethernet (FlexE) provides two, essentially independent, capabilities:

– Bonding:

The ability to bond existing Ethernet physical interfaces (PHYs) allows, for example a 400G MAC to be supported over four bonded 100GBASE-R PHYs. The set of PHYs that are bonded are referred to as a FlexE group.

– Support of sub-rate clients:

FlexE allows a PHY to support MAC clients at rates of 10, 40 or m×25Gbit/s, the bitrate of these MAC clients is not constrained to correspond to an existing Ethernet PHY rate. The allocation of the capacity of the PHY is managed by a calendar. The calendar can allocate the PHY capacity to a combination of MAC clients, up to the capacity of the PHY, for example:

• A 100GBASE-R PHY could support two 25Gbit/s and five 10Gbit/s MAC clients; or

• Two bonded 100GBASE-R PHYs could be used to support one 150Gbit/s MAC client (with the remainder of the PHY calendar slots marked as unused).

The capabilities of FlexE are defined in [b-OIF FlexE IA], the mapping of FlexE into an ODUk is defined in [ITU-T G.709].

Ethernet PHY interfaces to the OTN, which are being used for FlexE, may operate in one of the three modes described below.

II.2 FlexE unaware

In this case the OTN is unaware of FlexE. This case allows, for example, an OTN network that only supports OTU4s to be used to carry FlexE clients with a bitrate in excess of 100 Gbit/s.

The payload from each Ethernet PHY is independently mapped (using a PCS codeword transparent mapping) into the appropriate ODUk, which is carried by an OTU (see clause 7).

If the FlexE group is carried over more than one OTU then, to control the differential delay between the members of the FlexE group, all of the OTUs must be carried over the same OMS link.

II.3 FlexE aware

In this case the OTN is aware of FlexE but the FlexE group is not terminated. This case supports, for example, applications where the bitrate carried by an OTU does not match the bitrate of the Ethernet PHY or is not an exact multiple of the Ethernet PHY rate.

The FlexE clients from one or more of the Ethernet PHYs, in the same FlexE group, are mapped into an ODUflex which is carried by an OTU (see clause 7).

If the FlexE group is carried over more than one OTU then, to control the differential delay between the members of the FlexE group, all of the OTUs must be carried over the same OMS link.

In cases where the bitrate of the Ethernet PHY is greater than the OTU bitrate or is not an integral multiple of the OTU bitrate, the transport network may discard bits or bytes from the unavailable calendar slots at the ingress to the OTN network ingress. These bits or bytes are re-inserted with fixed values at the egress of the OTN network (to restore the original Ethernet PHY bitrate).
II.4 FlexE terminating

In this case the FlexE is fully terminated, the members of the FlexE group are aligned (i.e., the differential delay is compensated) and the FlexE clients are extracted. Each FlexE client is then mapped into an ODUflex. Each of the FlexE clients (carried in an ODUflex) may be routed to a different destination.
Appendix III

Examples of views of an ODU layer network

(This appendix does not form an integral part of this Recommendation.)

This appendix provides examples of how the topology of an ODU layer network may be viewed either independent of k or to provide a view for a specific value of k.

Figure III.1 shows the topology of a simple ODU network, this view is independent of the value of k.

**Figure III.1 – Example ODU network**

A link or subnetwork may not be able to support all values of k because of limitations in the resources that support it, or because of a decision by the network operator. Because of these limitations for a specific value of k, some links and subnetworks may be removed from the topology. Considering the example in Figure III.1, if links 1 and 5 cannot support an ODU4 but all other links and subnetworks can support an ODU4, then the topology for an ODU4 would be reduced as shown in Figure III.2 below.

**Figure III.2 – Example for ODU4 network**
In the case where some regions of a network cannot support particular ODUj connections, for example in Figure III.3 below, subnetwork B cannot support ODU0 connections. With this topology it is not possible to support an ODU0 connection between ODUk subnetworks A and C.

**Figure III.3 – Limited capability ODUk subnetwork**

To allow ODU0 to be carried between ODUk subnetwork A and C, an ODUk connection can be established, as shown in Figure III.4 below.

**Figure III.4 – ODUj link construction**

The ODUk trail supports an ODU0 link, which then appears in an ODUk topology, as shown in Figure III.5 below.

**Figure III.5 – Modified ODUk topology**

For the ODU0 topology, ODUk subnetwork B and ODUk links 3 and 5 are removed resulting in the ODU0 topology shown in Figure III.6 below.

**Figure III.6 – ODU0 topology**
The topology for other values of k would be as shown in Figure III.7. The capacity of ODUk links 3 and 5 are reduced by the capacity used by the ODU0 link.

Figure III.7 – ODUk topology
Appendix IV

Examples of multi-domain OTN applications

(This appendix does not form an integral part of this Recommendation.)

This appendix provides an example of the use of OTN in multi-domains where two disjoint domains in the network of carrier A (domain A1 and domain A2) are interconnected through the network of another carrier (domain B). The interconnection is supported by an ODUk. Carrier A multiplexes several (lower rate) ODUj services into this ODUk. This ODUk may be carried across domain B in several different ways, the following three scenarios illustrate these options.

In scenario 1 shown in Figure IV.1 the ODUk is carried directly by an OTUk in domain B.

![Figure IV.1 – Multi-domain OTN scenario 1](G.672(17)_IV.1)
In scenario 2 shown in Figure IV.2 ODUk is carried by a higher rate ODU in domain B.

![Figure IV.2 – Multi-domain OTN scenario 2](image)

Figure IV.3 illustrates the scenario 2 with the addition of TCM in domain B. This allows carrier B to directly monitor the service being provided to carrier A.

![Figure IV.3 – Multi-domain OTN scenario 3](image)
Appendix V

Examples of the configuration of media channels

(This appendix does not form an integral part of this Recommendation.)

V.1 Construction of network media channels

An example of construction of network media channels is provided in Figure V.1

The OMS media links shown in blue provides connectivity between the different sites. The filters F1-F6 aggregate and disaggregate the media channels.

- F1 aggregates the red, blue and green network media channels into OMS media link A
- F2 disaggregates the green network media channel and the yellow media channel (that aggregates the red and blue media channels) from OMS media link A
- F3 aggregates the orange and purple media channels into OMS media link B
- F4 disaggregates the red purple and blue network media channels from OMS media link B
- F5 aggregates the blue network media channel into OMS media link C
- F6 disaggregates the blue network media channel from OMS media link C

V.2 Use of flexible grid capable filter to route media channels

The ability to configure media channels within a flexible grid capable filter can be used to modify or create a route for a media channel across the network.

Consider for example a filter with the initial configuration of the media channels in as illustrated in Figure V.2.
The filter disaggregates the media channel at port 1 into:
- a red media channel that is delivered to port 2
- a purple media channel that is delivered to port 3
- a green media channel that is delivered to port 4.

The atomic media channels within the filter may be reconfigured as shown in Figure V.3:

- a blue media channel that is delivered to port 2
- a red media channel that is delivered to port 3
- a green media channel that is delivered to port 4.
Appendix VI

Example of media network using tuneable modulator/demodulator for routing

(This appendix does not form an integral part of this Recommendation.)

VI.1 Network using couplers

A media network may be constructed using tuneable sources (modulators), frequency selective receivers (demodulators) and couplers (with amplifiers to compensate for the loss of the couplers). This architecture has limitations, in that frequency slots cannot be reused across the network. However in the case of a simple linear add/drop chain where the traffic demands are predominantly from a hub site to downstream remote sites, this approach can simplify network operations.

A simple example of such a network is provided in Figure VI.1.

![Diagram of network example](G.872(17)_FA.1)

**Figure VI.1 – Simple network example**

In this simple example each OTSi modulator is able to provide an optical signal in any defined frequency slot and the OTSi demodulators are able to select a specific frequency slot. Couplers C1 and C4 aggregate media channels. Couplers C2, C3 and C5 duplicate the media channel to provide two or more copies.

The couplers provide a point-to-multipoint media channel between site 1 and all downstream sites. Coupler C4 in site 3 allows any attached source to use the point-to-multipoint media channel between sites 3 and 4 (or any other downstream sites). When the (restricted spectrum) of the source and the effect of the filter in the sink are considered, a point-to-point network media channel is established between a specific OTSi modulator and demodulator, which supports a point-to-point communication.

VI.2 Network using wide-band filters and couplers

Couplers provide complete flexibility, in that all frequency slots are delivered to all sites. They have the disadvantages of high loss and that frequency slots cannot be reused within the network. In the example of Figure VI.1, if C3 were replaced by a filter that that split the available spectrum between its output ports, then it would result in lower loss to both output ports and would allow the frequency slots that are dropped at site 3 to be reused downstream. However, some flexibility would be lost (i.e., some frequency slots from sites 1 and 2 are always delivered to site 3, while the remaining frequency slots are not delivered to site 3. The connectivity of the network is now constrained by the (wideband) filter.
and controlled by the selection of the frequency slot used by the OTSi modulator and OTSi demodulator.
Bibliography

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