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SERIES G: TRANSMISSION SYSTEMS AND MEDIA,
DIGITAL SYSTEMS AND NETWORKS

Access networks – Optical line systems for local and
access networks

Multiple-wavelength passive optical networks (MW-PONs)

Recommendation ITU-T G.9802

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TRANSMISSION MEDIA AND OPTICAL SYSTEMS CHARACTERISTICS	G.600–G.699
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
MULTIMEDIA QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
PACKET OVER TRANSPORT ASPECTS	G.8000–G.8999
ACCESS NETWORKS	G.9000–G.9999
Metallic access networks	G.9700–G.9799
Optical line systems for local and access networks	**G.9800–G.9899**
In premises networks	G.9900–G.9999

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T G.9802

Multiple-wavelength passive optical networks (MW-PONs)

Summary

Recommendation ITU-T G.9802 describes the general requirements and architecture of multiple-wavelength passive optical network (PON) systems. It specifies the mechanism of wavelength assignment, wavelength tuning and wavelength maintenance in multiple-wavelength PON systems. The functionalities of wavelength resource management and wavelength channel performance monitoring and supervision are also included within the scope of this Recommendation. The specifications in this Recommendation can be applied to various types of multiple-wavelength PON systems.

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FOREWORD

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Table of Contents

Recommendation ITU-T G.9802

Multiple-wavelength passive optical networks (MW-PONs)

1   Scope

This Recommendation describes the general requirements and architecture of multiple-wavelength passive optical network (PON) systems. It specifies the mechanism of wavelength assignment, wavelength tuning and wavelength maintenance in multiple-wavelength PON systems. The functionalities of wavelength resource management and wavelength channel performance monitoring and supervision are also included within the scope of this Recommendation.

The specifications in this Recommendation can be applied to various types of multiple-wavelength PON systems such as:

−   a stack of several TDM PON systems in a single ODN, realized by assigning different wavelengths to each TDM PON system, where wavelength tunable devices may be employed in the transceivers,

−   a TDM PON enhanced by dynamic or semi-dynamic wavelength tuning to allow traffic load balancing, selective OLT-port sleep, etc.,

−   a WDM PON in which ONUs do not share wavelengths for offering logical point to point connectivity,

−   a hybrid scheme that combines these or other options.

This Recommendation considers the following three classes as the tunability of ONU: fixed, electrically controlled and optically controlled.

This Recommendation considers the following three classes as the wavelength tuning speed:

−   slow (25 ms to 1 s),

−   middle (10 μs to 25 ms),

−   fast (< 10 μs).

This Recommendation includes specification of the functions necessary:

−   to initiate the ONU discovery process, and recognize new ONUs on the PON and their tunability in a way that does not disrupt existing traffic,

−   to assign a newly recognized ONU to an initial operating wavelength set, both upstream and downstream,

−   to reassign an ONU's operating wavelength set during operation.

Not every OLT, nor every ONU, need to implement all of these functions. The annex and appendix of this Recommendation provide specific implementations of MW-PON technologies in several systems.

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.

[ITU-T G.984.2]	Recommendation ITU-T G.984.2 (2003), *Gigabit-capable Passive Optical Networks (G-PON): Physical Media Dependent (PMD) layer specification*.
[ITU-T G.987]	Recommendation ITU-T G.987 (2010), *10-Gigabit-capable passive optical network (XG PON) systems: Definitions, abbreviations and acronyms*.
[ITU-T G.989.3]	Recommendation ITU-T G.989.3 (2015), *40-Gigabit-capable passive optical networks (NG-PON2): Transmission convergence layer specification*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined in [ITU-T G.987]:

3.1.1 optical distribution network (ODN): A point-to-multipoint optical fibre infrastructure. A *simple* ODN is entirely passive and is represented by a single-rooted point-to-multipoint tree of optical fibres with splitters, combiners, filters, and possibly other passive optical components. A *composite* ODN consists of two or more passive *segments* interconnected by active devices, each of the segments being either an optical trunk line segment or an optical distribution segment. A passive optical distribution segment is a simple ODN itself. Two ODNs with distinct roots can share a common subtree.

3.1.2 optical line termination (OLT): A network element in an ODN-based optical access network that terminates the root of at least one ODN and provides an OAN SNI.

3.1.3 optical network unit (ONU): A network element in an ODN-based optical access network that terminates a leaf of the ODN and provides an OAN UNI.

3.1.4 passive optical network (PON) system: A combination of network elements in an ODN-based optical access network that includes an OLT and multiple ONUs and implements a particular coordinated suite of physical medium dependent layer, transmission convergence layer, and management protocols.

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 OLT port: Each of the physical ports in the optical line terminal (OLT) that connects to/from a fibre of the optical distribution network (ODN).

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CT	Channel Termination
demux	demultiplexer
DWDM	Dense Wavelength Division Multiplexing
EPON	Ethernet Passive Optical Network
LLID	Logical Link IDentifier
MAC	Media Access Control
mux	multiplexer
MPCP	Multi-Point Control Protocol
MW	Multiple Wavelength

ODN   Optical Distribution Network

OLT   Optical Line Terminal

OMCC   ONU Management and Control Channel

ONU   Optical Network Unit

PLOAM   Physical Layer Operation, Administration and Maintenance

PON   Passive Optical Network

PS   Power Splitter

R/S   R/S Reference point

Rx   Receiver

SNI   Service Node Interface

S/R   S/R Reference point

TDM   Time Division Multiplexing

TWDM   Time and Wavelength Division Multiplexing

Tx   Transmitter

UNI   User-Network Interface

WC   WDM Coupler

WDM   Wavelength Division Multiplexing

WM   Wavelength Multiplexer

5   Conventions

This Recommendation uses conventions defined in [ITU-T G.987].

6   Multiple-wavelength PON architecture

6.1   Network architecture

Figures 6-1 and 6-2 show an MW-PON architecture with a single OLT and multiple OLTs, respectively. The architecture includes an OLT or OLTs, ONUs and an ODN between them.

In the downstream direction, the OLT or OLTs transmit multiple-wavelength signals to the ONUs. The ODN distributes signals via a point-to-multipoint optical fibre infrastructure. Depending on the deployment scenario, the ODN could be single or multiple stages.

In the upstream direction, an ONU transmits one of the upstream wavelength signals during its transmission time. The ODN combines multiple upstream wavelengths. The OLT or OLTs receive and process more than one upstream wavelength.
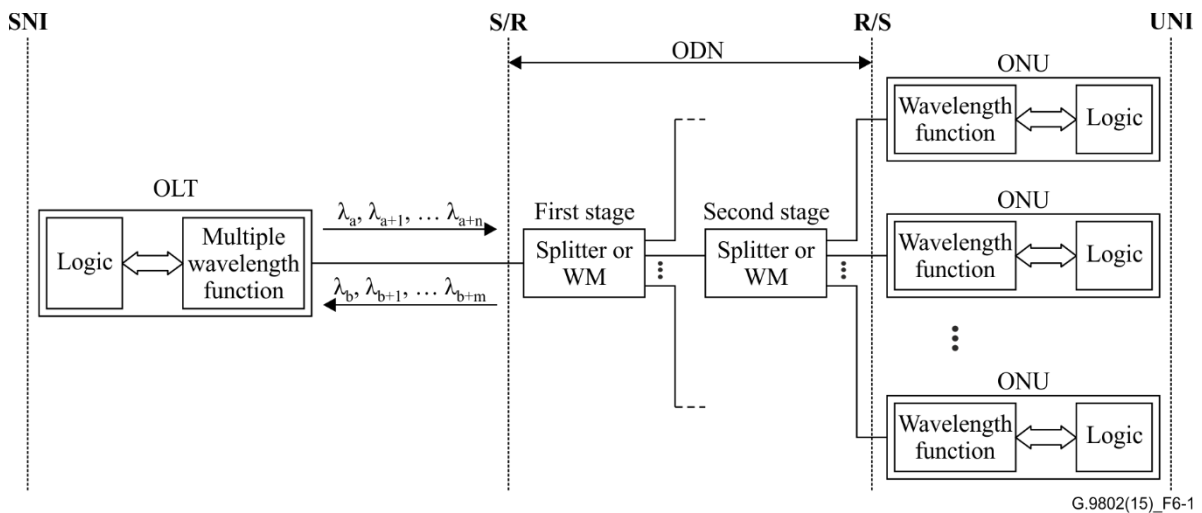
Figure 6-1 – MW-PON architecture with a single OLT
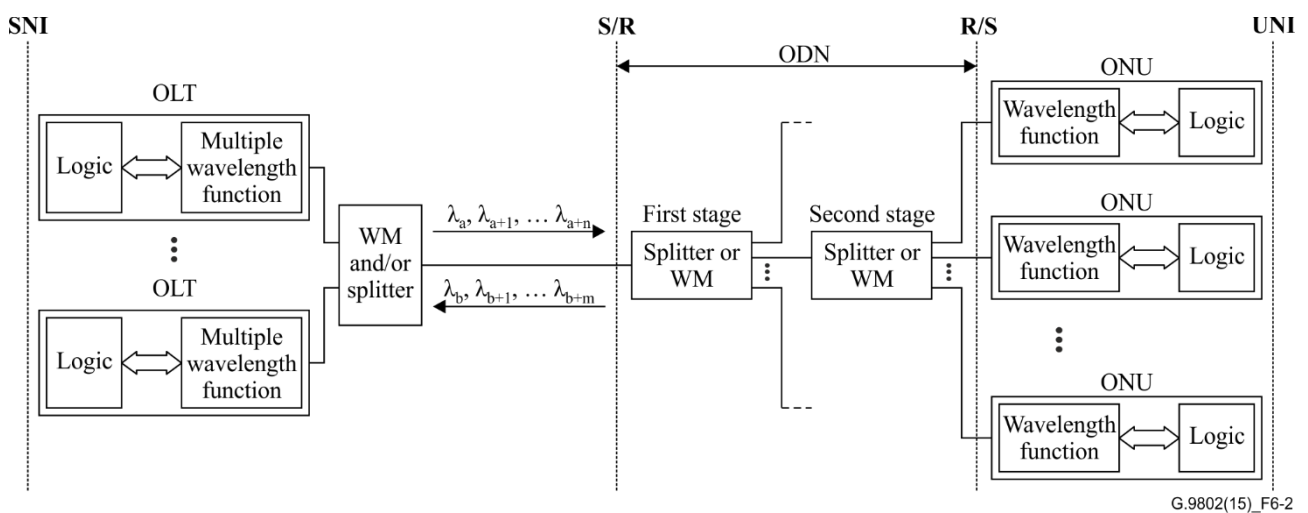
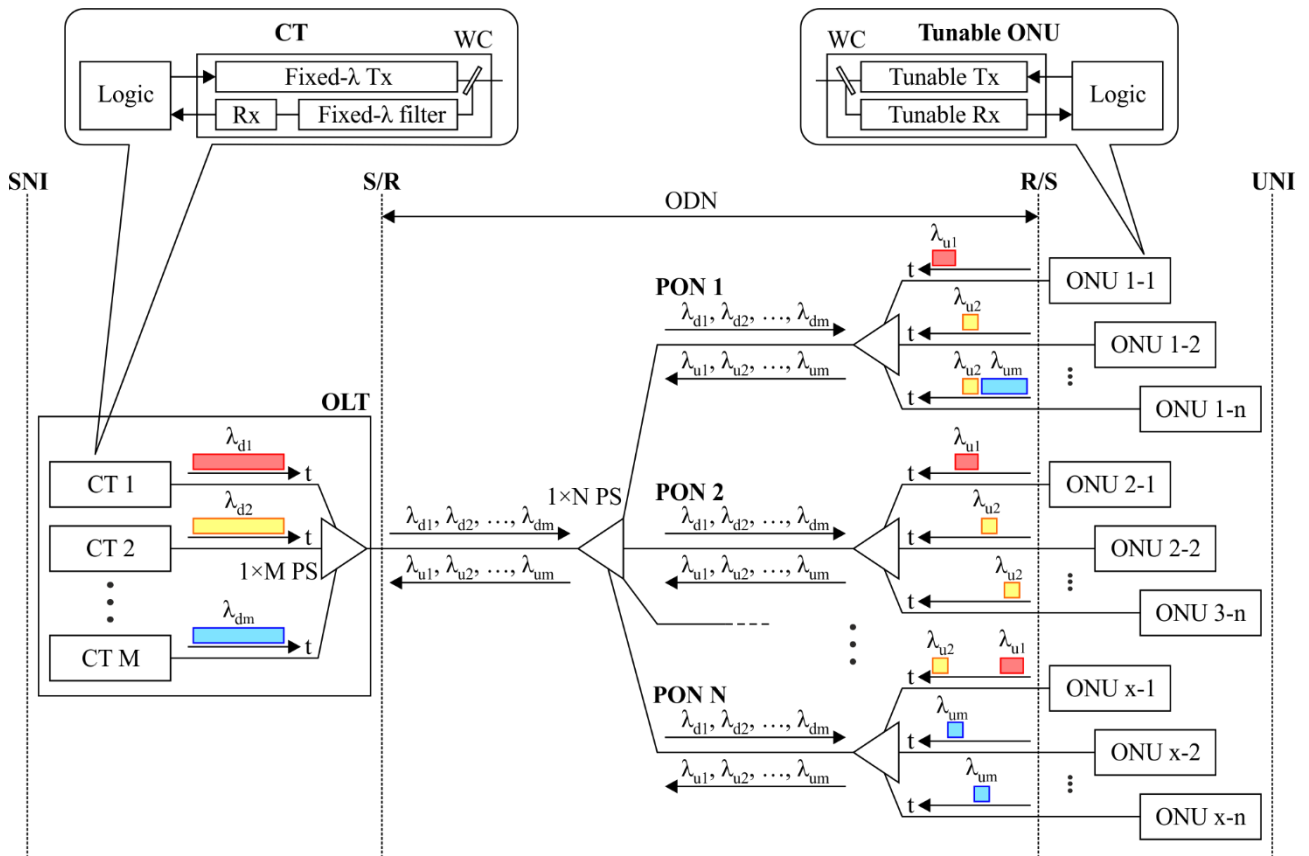**Figure 6-2 – MW-PON architecture with multiple OLTs**

6.2   Reference configuration

6.2.1   ODN

There can be several types of ODN architecture to achieve service distribution in MW-PONs. Figures 6-3 and 6-4 show examples of MW-PON with power-splitter-based ODN. Figures 6-5 and 6-6 are examples of MW-PON with wavelength-mux (demux)-based ODN, where "mux" denotes "multiplexer". Figure 6-7 is an example of an MW-PON with an ODN consisting of power splitters and multiple feeder fibres. Figure 6-8 is an example of MW-PON with an ODN consisting of an NxM wavelength mux (demux) and multiple power splitters. Figure 6-9 is a reference diagram of an MW-PON with Type C protection and an ODN of one-stage power or wavelength mux (demux). Figure 6-10 is a reference diagram of the MW-PON in Figure 6-9 with a two-stage splitter ODN. Figure 6-11 is an example of an MW-PON with wavelength muxs (demuxs) at the OLT and at the ODN.

Note that Figures 6-3 to 6-11 simply provide reference examples of the ODN architectures. They are not intended to limit designs and implementations of OLTs and ONUs. In addition, the designs and implementations of MW-PON OLT and ONU are outside the scope of this Recommendation.
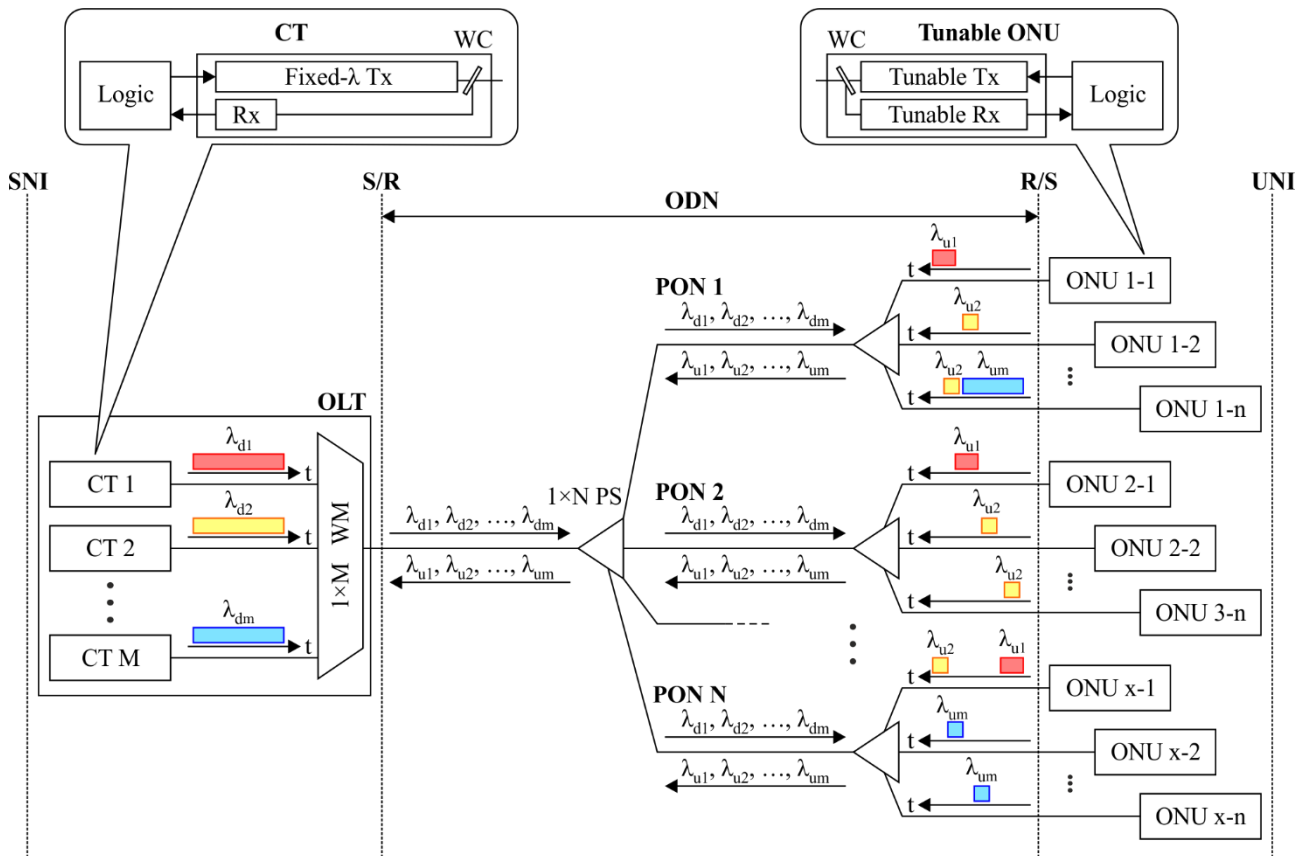
Also note that this Recommendation recognizes ODN architectures with multiple stages. Each stage can be a different type of ODN configuration depending on the chosen technology.

Figure 6-3 – Configuration example of MW-PON with a 1xM power splitter at the OLT and 1xN power splitters at the ODN
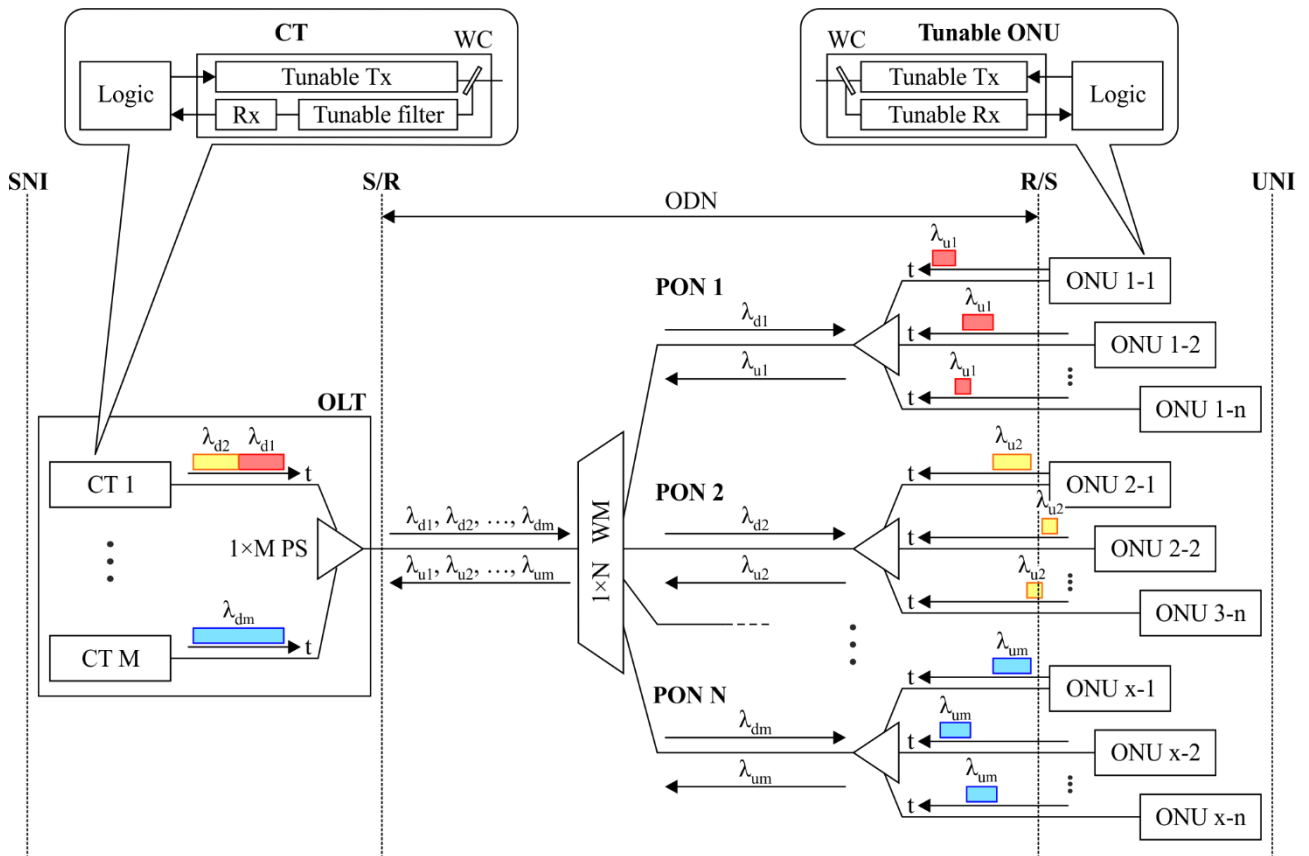
Figure 6-4 – Configuration example of MW-PON with an 1xM wavelength mux (demux) at the OLT and 1xN power splitters at the ODN

Figure 6-5 – Configuration example of MW-PON with an 1xN power splitter at the OLT and a 1xN wavelength mux (demux) at the ODN
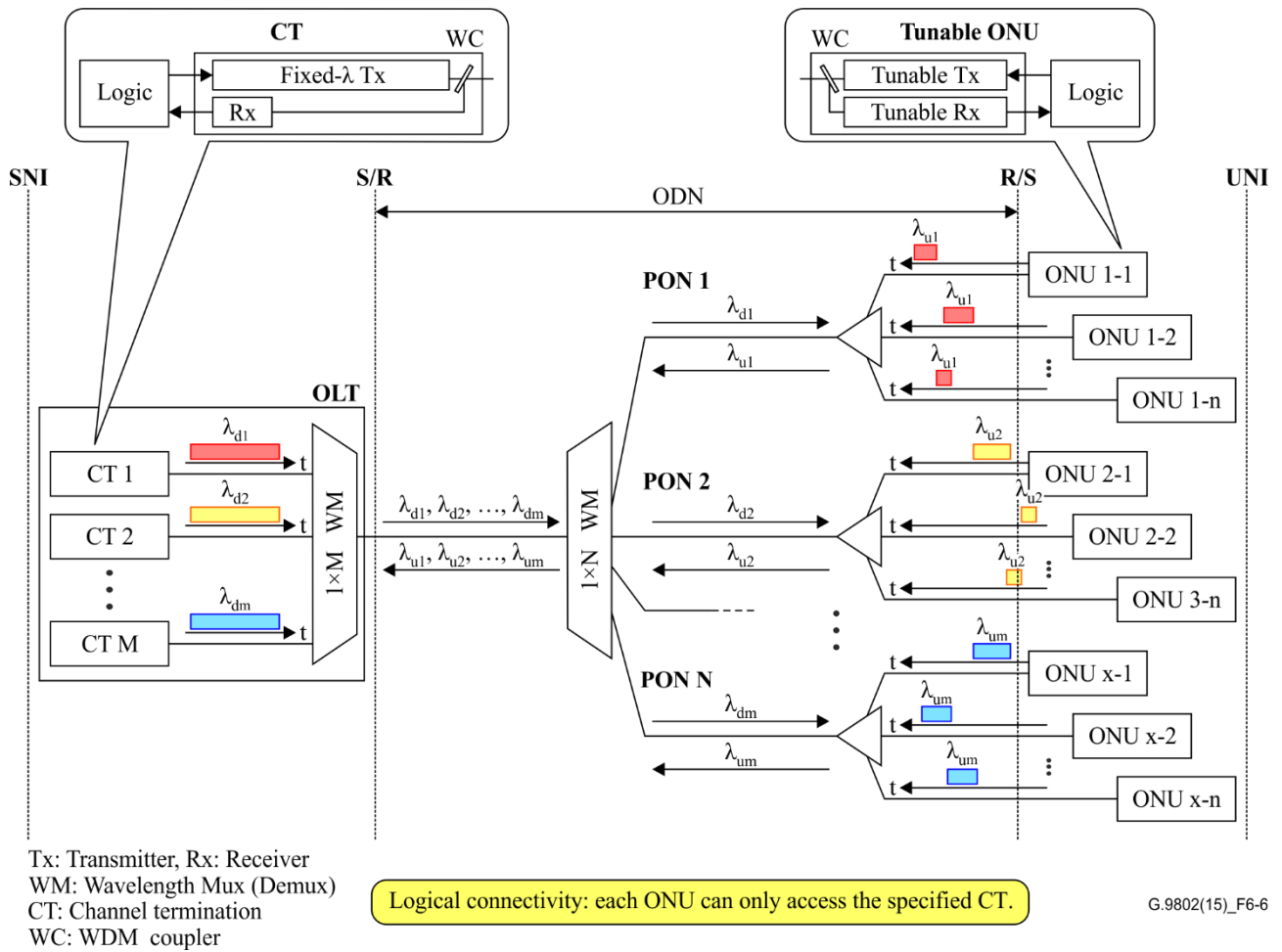
Figure 6-6 – Configuration example of MW-PON with an 1xM wavelength mux (demux) at the OLT and an 1xN wavelength mux (demux) at the ODN

Figure 6-7 – Configuration example of MW-PON with an NxM wavelength mux (demux) at the OLT and 1xN power splitters at the ODN

Tx: Transmitter, Rx: Receiver
WM: Wavelength Mux (Demux)
CT: Channel termination
WC: WDM coupler

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Figure 6-8 – Configuration example of MW-PON with an 1xM wavelength mux (demux) at the OLT and an NxM wavelength splitter at the ODN
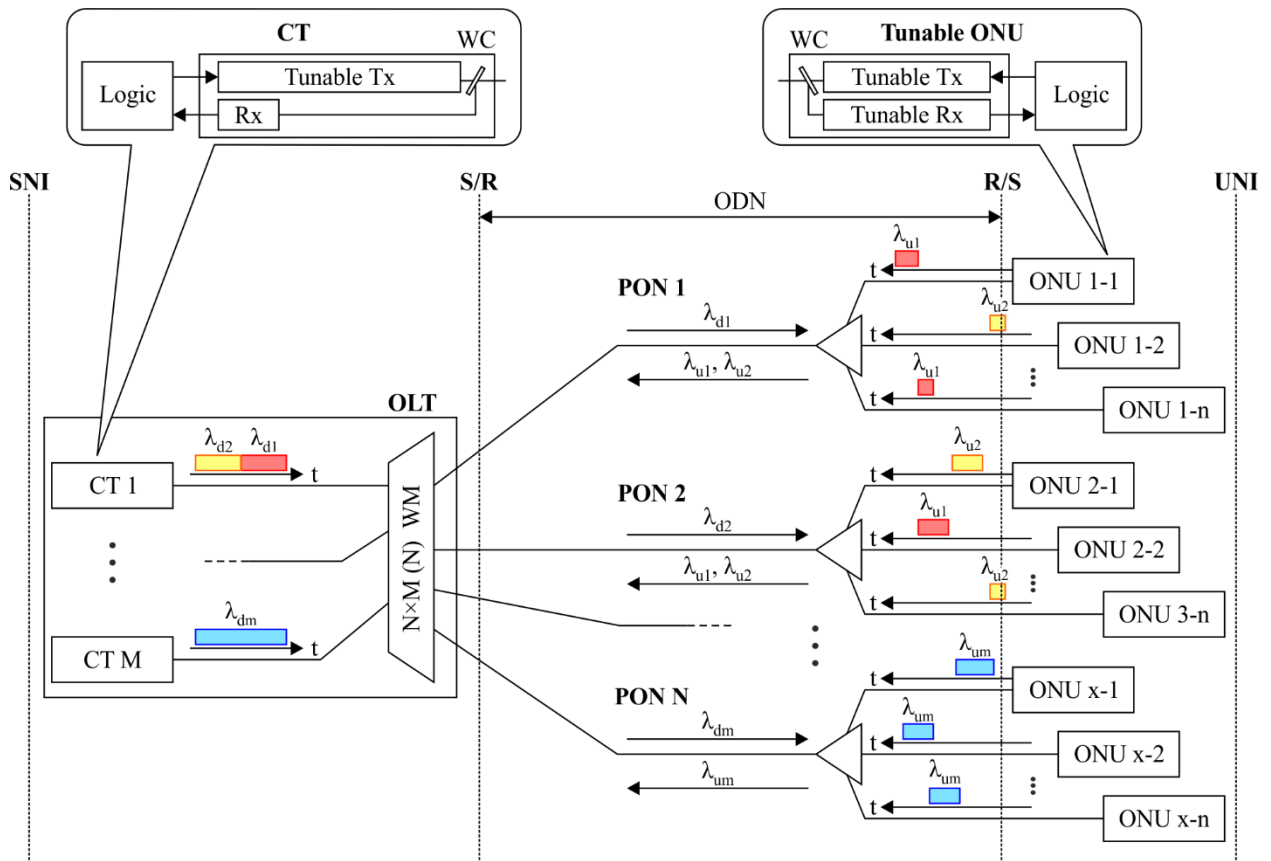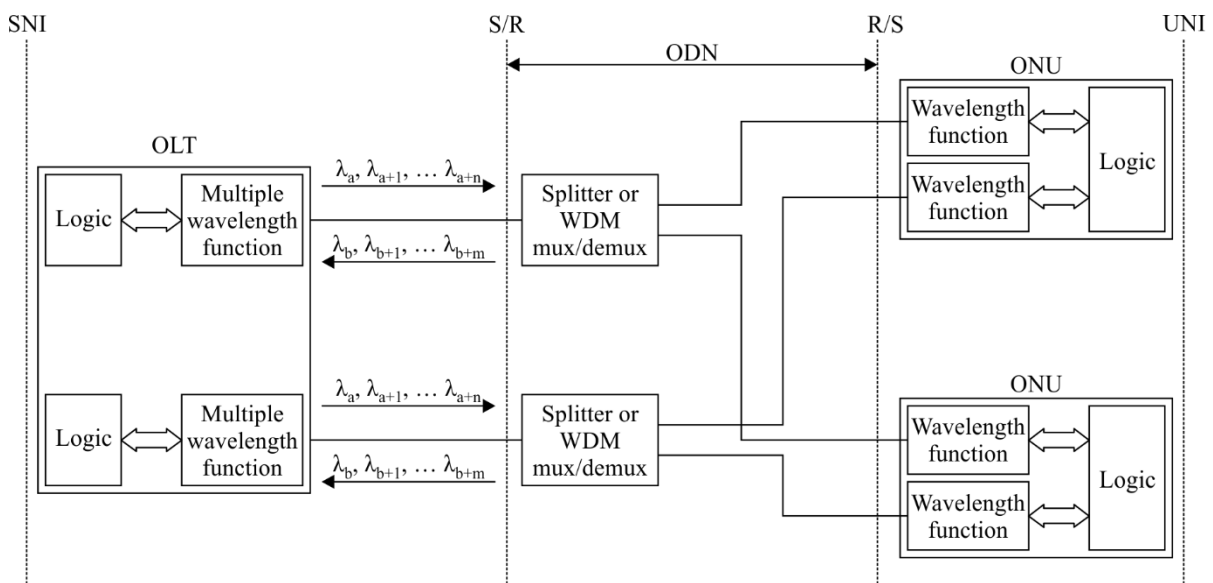

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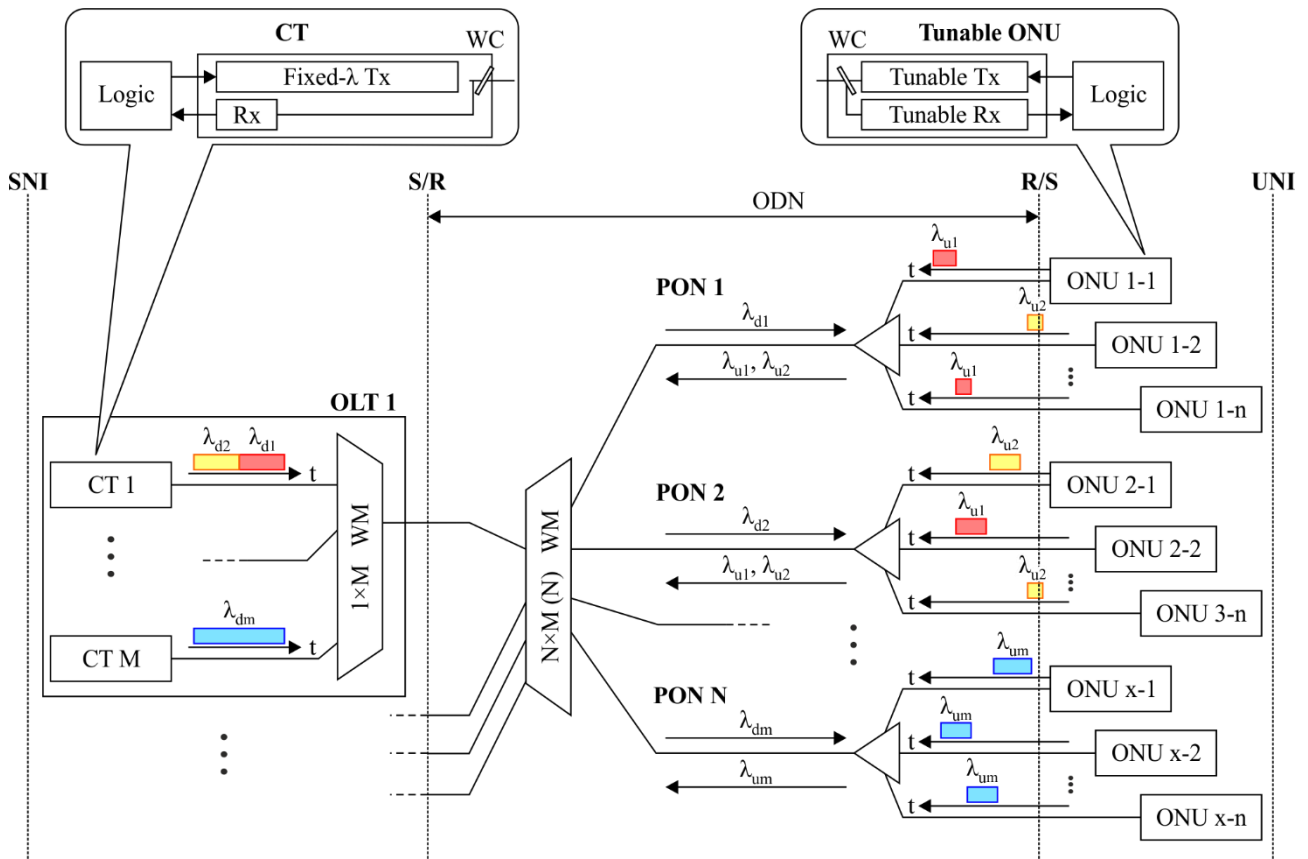
Figure 6-9 – Reference configuration of Type C protection with one stage splitter at the ODN
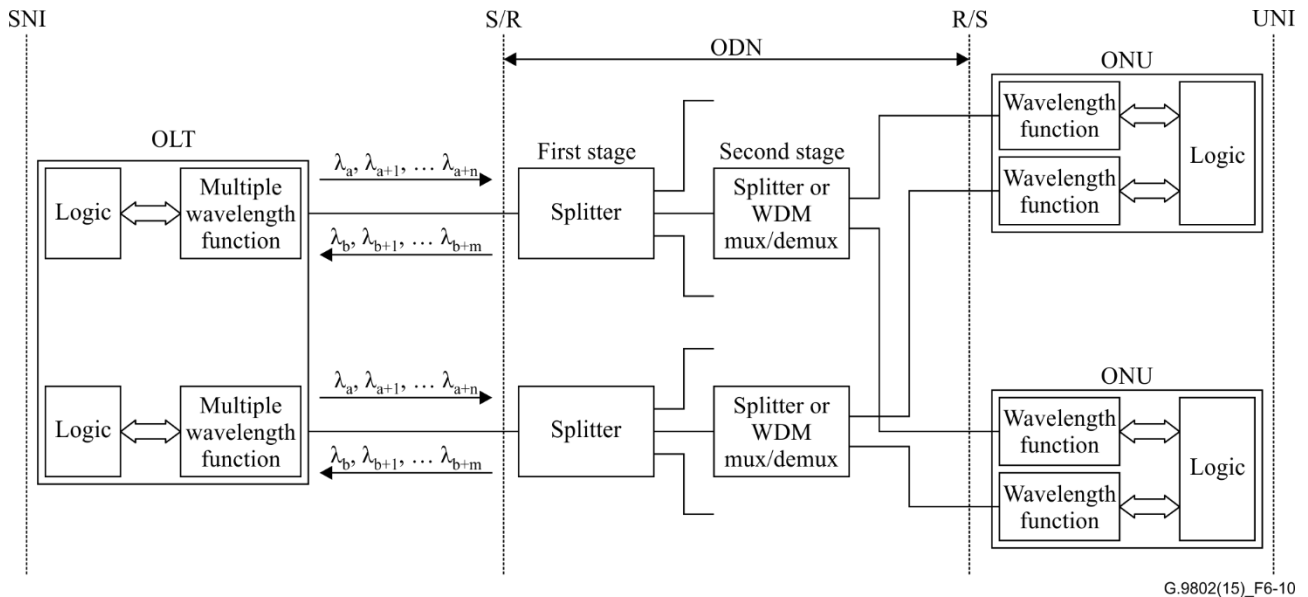
Figure 6-10 – Reference configuration of Type C protection with two stages of splitters at the ODN

Tx: Transmitter, Rx: Receiver
CT: Channel termination
WC: WDM coupler
WM: Wavelength mux (demux)

Logical connectivity: each ONU can access the specified CT
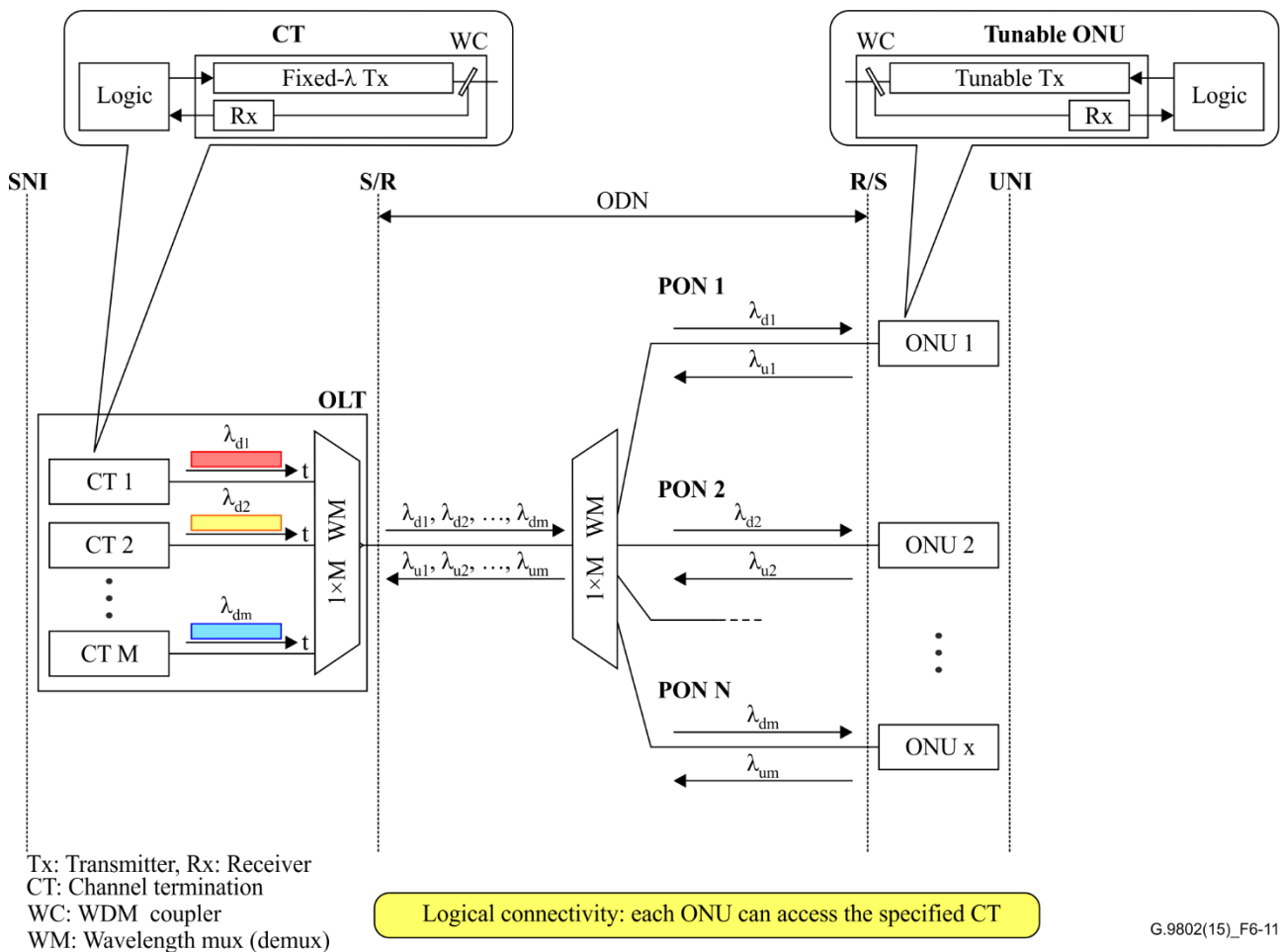
Figure 6-11 – Configuration example of MW-PON with wavelength mux (demux) at the OLT and at the ODN

6.2.2   ONU

This recommendation recognizes several types of ONUs with respect to the transmitter and receiver implementation. The first type of ONU is with fixed wavelength configuration. The ONU receiving

and transmitting wavelengths are not tunable. The second type of ONU is with a fixed receiver and a tunable transmitter. The third type of ONU is with a tunable receiver and a tunable transmitter.

Note that the ONU tunable receiver and/or transmitter can be electrically controlled or optically controlled depending on the chosen technology.

7   General requirements on multiple-wavelength PON systems

MW-PON general requirements are defined as four logical function requirements, including wavelength assignment, wavelength tuning, wavelength resource administration and wavelength channel performance supervision. They are elaborated in the following.

–   *Wavelength assignment*: In an MW-PON system with a splitter-based ODN, wavelength assignment is critical to bring an inactive ONU into operation. When a new ONU is installed on the ODN, the initial downstream and upstream wavelengths have to be automatically and remotely assigned between the OLT and the new ONU. This wavelength assignment process has to be carried out as a part of the ONU activation. To properly communicate with the OLT, the ONU downstream and upstream wavelengths should be designated as early as possible, and wavelength tuning may be needed during activation. In an MW-PON system with a wavelength mux-based ODN, only a single wavelength can pass in the ODN from the OLT to an ONU or from an ONU to the OLT. In this case, wavelength assignment is done during the physical installation process.

–   *Wavelength tuning*: If ONUs are capable of wavelength tuning, during the process of ONU activation, a newly activated ONU may need to tune its wavelengths by following an OLT command. During the operation of an MW-PON system with wavelength tunability, the assigned wavelengths may need further change. For example, in an MW-PON system, ONUs could be equipped with tunable transceivers; if some wavelengths are heavily loaded while there are idle wavelengths, a good practice might be tuning some ONUs from the heavily loaded wavelengths into the idle ones. This would balance traffic among the available wavelengths, maintaining the stable status of the PON. Alternatively, OLT power savings could be realized by turning off certain OLT ports under light load conditions (e.g., midnight to 6 AM), while tuning the ONUs to a subset of the available wavelengths. In addition, dynamic wavelength changes with fast wavelength tuning may be necessary for some MW-PON systems for the purpose of efficient wavelength resource utilization. This can be also used in case of troubleshooting and maintenance to temporarily move a channel to a spare resource.

–   *Wavelength resource administration*: In an MW-PON system, wavelength becomes a key resource to arbitrate medium access. In both splitter-based and wavelength mux-based MW-PON systems, the OLT should be able to confirm the ONU wavelength assignment in the MAC layer. This supports regular wavelength maintenance. Information such as wavelength resource availability and wavelength assignment should be provided for resource administration. Traditional PON administration mechanisms are conducted in the TDM channel. Proper extension and enhancement should be investigated to address the issue of wavelength resource administration. Available timeslots and wavelengths should be used for dynamic wavelength and bandwidth assignment/allocation (DWBA), which manages both wavelength resources and timeslots in MW-PON. In an MW-PON system with a wavelength mux-based ODN, ONU wavelengths are determined by the physical infrastructure, and MW-PON should inventory all working wavelengths.

–   *Wavelength channel performance supervision*: Each wavelength channel should be monitored to maintain system health. Failures and defects related to wavelengths should be detected to facilitate troubleshooting. Two major issues associated with the use of wavelength are wavelength drift monitoring and wavelength stabilization supervision.

- *Wavelength drift monitoring*: Drift from the desired wavelength grid should be monitored. This function is especially important in the splitter-based MW-PON systems because wavelength drift may interfere with communications of other ONUs.

- *Wavelength stabilization supervision*: All working wavelengths should be stabilized around the desired wavelength grid. This function is especially important in the MW-PON systems with DWDM technologies.

8 Specifications for multiple-wavelength PON systems

8.1 Wavelength assignment

Wavelength assignment is an integral procedure of the ONU activation in an MW-PON system. The OLT makes the wavelength assignment decision and controls the ONU wavelengths by means of issuing function-specific bandwidth grants and/or exchanging wavelength management and control messages. The general ONU activation in PON consists of three phases: synchronization to the downstream signal, ONU identification and adaptation to the multiplexing technique. Wavelength assignment in MW-PON can be during, before or after any of the three phases depending on the implementation. This Recommendation specifies the general mechanism of wavelength assignment.

The wavelength assignment procedure consists of the steps given below:
−   Step 1: Communication on wavelength tuning capability (optional)
−   Step 2: Wavelength assignment decision
−   Step 3: OLT command ONU of the downstream and/or upstream wavelength
−   Step 4: ONU wavelength adjustment (optional)
−   Step 5: ONU response (optional)

The OLT optionally conducts Step 1 by issuing function-specific bandwidth grants or wavelength management and control messages to acquire the ONU tunability information. The ONU scans the downstream wavelength channel and responds with a wavelength management and control message. The ONU tunability information would include elements such as transmitter or receiver wavelength tuning range, tuning granularity, tuning time, channel spacing, calibrated or uncalibrated transmitter type.

The wavelength assignment decision in Step 2 can be made when connecting an ONU to the ODN, before an ONU activation or during an ONU activation, depending on the ODN architecture. In an MW-PON system with wavelength-splitter-based ODN, the ONU wavelength is determined by the connection between the ONU and ODN, and no further wavelength assignment is needed. In an MW-PON system with power-splitter-based ODN, the OLT makes wavelength assignment decisions either before or during an ONU activation, depending on factors such as ONU design, OLT design, PON traffic load, etc.

After deciding the wavelength assignment of a newly activated ONU, the OLT issues a wavelength management and control message to the ONU in Step 3. This message contains information to instruct the ONU of the wavelength assignment decision. The information elements include upstream wavelength ID, downstream wavelength ID, destination wavelength in nanometers or the corresponding frequency, wavelength tuning direction (longer or shorter wavelength), wavelength tuning start time. Note that there are several ways to issue the wavelength assignment message. The OLT can broadcast it to all downstream wavelengths, send it in a wavelength selected for system control and management, or issue it in the downstream wavelength of the new ONU. The new ONU scans the downstream wavelength channel and detects the wavelength assignment message if there is any.

Depending on the initial wavelengths, the ONU may or may not change its wavelengths in Step 4. Once the ONU confirms the downstream and upstream wavelengths following the OLT command, it optionally responds with a wavelength management and control message in Step 5.

An ONU joins MW-PON operations by the ONU activation process. Various types of ONUs can be employed. In the activation process, the working wavelengths of an inactive ONU (one for downstream, the other for upstream) can be a random pair of wavelengths or a default pair of wavelengths, depending on the ONU transceiver design and the protocol specification.
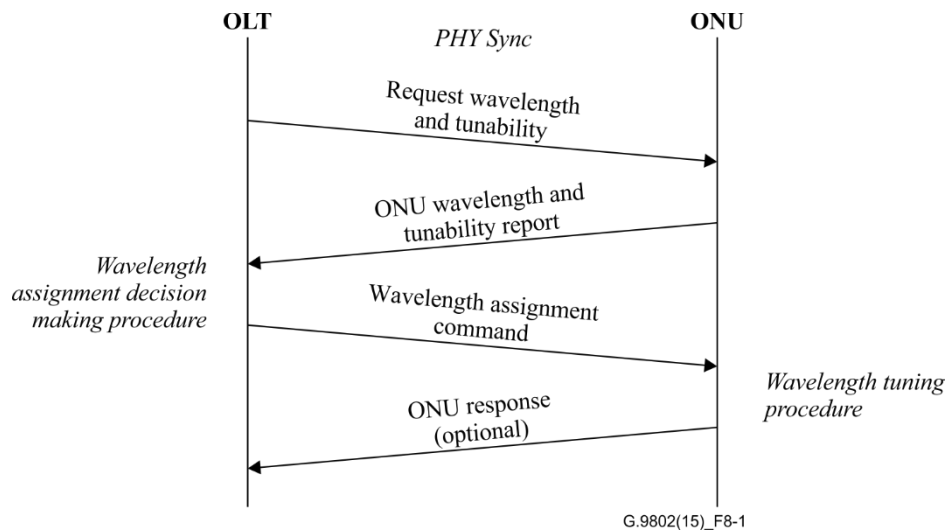
Figure 8-1 – Wavelength assignment message exchange in ONU activation

The OLT acquires the information of ONU working wavelengths and wavelength tunability after the ONU conducts PHY synchronization. Such information helps the OLT to make wavelength assignment. Once making the wavelength assignment decision, the OLT instructs the ONU to either maintain the current wavelengths or switch to the target wavelengths. Figure 8-1 shows the main information exchange between the OLT and an ONU in the activation process.

8.2 Wavelength tuning

Wavelength tuning is the procedure of changing the ONU wavelengths during regular operation. In the regular operation, due to purposes such as load balance or power saving, the OLT may direct ONUs to change wavelengths.

Note that wavelength tuning does not apply to the MW-PON system with a fixed wavelength configuration restricted by the ODN architecture.

The wavelength tuning procedure consists of the steps given below:
−	Step 1 Communication on wavelength tuning capability (optional)
−	Step 2 Wavelength tuning decision
−	Step 3 OLT command ONU of the downstream and/or upstream wavelength
−	Step 4 ONU wavelength adjustment
−	Step 5 ONU response (optional)

The OLT optionally conducts Step 1 by issuing a wavelength management and control message to acquire the ONU tunability information. The ONU sends a response message. Note that the wavelength management and control message can either broadcast to all ONUs or unicast to an ONU. The ONU tunability information would include elements such as transmitter or receiver wavelength tuning range, tuning granularity, tuning time, channel spacing, calibrated or uncalibrated transmitter type.

In Step 2 the OLT makes wavelength tuning decision based on requirements such as load balance or power saving.

The OLT issues a wavelength management and control message to the ONU in Step 3. This message contains information to instruct the ONU of the wavelength tuning decision. The information elements include upstream wavelength ID, downstream wavelength ID, destination wavelength in nanometers or the corresponding frequency, wavelength tuning direction (longer or shorter wavelength), wavelength tuning start time.

The ONU adjusts wavelengths in Step 4.

Once the ONU confirms its downstream and upstream wavelengths following the OLT command, it optionally sends a response message in Step 5.

A major reason of changing ONU wavelengths in operation is to balance MW-PON traffic among the available wavelengths. Another reason is to potentially facilitate power savings at the OLT by reducing the number of required "active" ports. Figures 8-2 and 8-3 show the message exchange between the OLT and an ONU to support wavelength tuning.
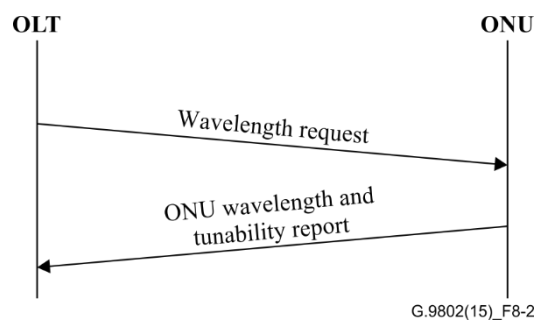
Figure 8-2 − Example of message exchange in wavelength tunability request

Figure 8-2 shows the OLT transmits a wavelength request to an ONU. The ONU reports its working wavelengths and its tunability. Such information helps the OLT to make the wavelength tuning decision.
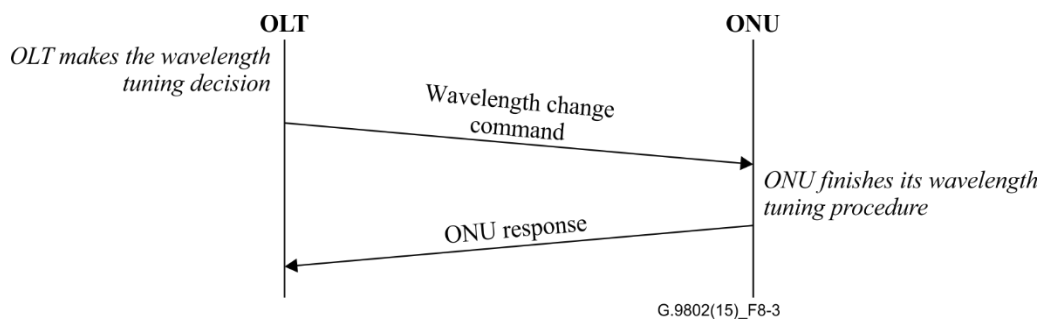
Figure 8-3 − Message exchange in wavelength tuning

When the OLT decides to change the ONU wavelengths, it instructs the assigned wavelengths to the ONU by transmitting a wavelength change command as shown in Figure 8-3. The ONU converts its wavelengths to the target wavelengths by following the command. After tuning its transceiver, the ONU transmits a response to confirm the completion of wavelength change.

The wavelength change command includes the destination wavelength. This command may include a start time when the ONU should start the wavelength tuning procedure to flush out the OLT-port's accumulated downstream buffer or to avoid the collision at the ONU between the period of wavelength tuning and the previously granted period of sending upstream data.

After sending the wavelength change command, the OLT waits for the ONU response. The OLT may periodically assign upstream grants to let ONUs to send responses. The ONU sends its response when completing the wavelength tuning procedure.

8.3   Wavelength resource administration

8.3.1   Channel ID

The channel ID is the wavelength connection indication in MW-PON. It is the logic ID of the MW-PON wavelength resource.

In an MW-PON system, the downstream wavelength received by an ONU is decided either by the ODN configuration or by the ONU receiver tunability. The channel ID of the downstream wavelength indicates the wavelength connection between an OLT port and its associated ONUs.

The channel ID of the upstream wavelength has several applications in MW-PON. For example, when the downstream and upstream wavelength channels have a fixed relationship, the OLT needs the upstream wavelength information to correlate the upstream transmission from the ONU with the downstream wavelength that the ONU receives. In this case, the ONU can feedback its downstream wavelength up through the upstream, and the OLT makes the key association. Another example is when the ONU transmits its upstream wavelength channel indication in the upstream frames. The OLT uses this as a confirmation to check the ONU upstream working wavelength.

8.4   Wavelength channel performance supervision

Wavelength channel performance supervision supports the management and troubleshooting of an MW-PON system. Traditional optical layer supervision, described in Appendix IV of [ITU-T G.984.2], is expected to be supported via an ONU management and control interface.

In an MW-PON system with the capability of channel calibration, the OLT obtains the channel calibration information from the ONUs. This information is for wavelength tuning in the process of ONU activation and/or system operation. The OLT may implement methods such as dithering for wavelength channel supervision. The OLT assigns an optical power value to each upstream wavelength channel. The dithering alarm is on when the difference between the measured optical signal power and the pre-configured value exceeds a threshold.

Annex A

Multiple-wavelength XG-PON enhancement

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

A.1 Wavelength assignment

For wavelength assignment, exchange of management and control messages is required. For this purpose, PLOAMs in XG-PON are extended for TWDM channels in NG-PON2 as described in [ITU-T G.989.3].

For enhancing multiple-wavelength system, downstream channel scanning process is required for a colourless ONU to decide initial downstream wavelength selection for ONU activation. The ONU activation process extended for TWDM channels in NG-PON2 is described in [ITU-T G.989.3].

A.2 Wavelength tuning

The wavelength tuning procedure is implemented in TWDM channels in NG-PON2 as described in [ITU-T G.989.3].

A.3 Wavelength resource administration

A logic ID that represents the wavelength connection indication is required in MW-PON systems. [ITU-T G.989.3] includes the description of TWDM downstream and upstream identifiers as well as other indicators.

A.4 Wavelength channel performance supervision

This requirement is implemented in TWDM channels of NG-PON2 as described in [ITU-T G.989.3].

Appendix I

Multiple-wavelength 10G-EPON enhancement

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

I.1 Wavelength assignment

For wavelength assignment, exchange of management and control messages is required. In EPON, MAC control extension is available for the ONU control. Another way is to add the wavelength information to the current MAC control messages (e.g., GATE message and REPORT message).

For colourless ONUs, a downstream channel scanning process is required to select the initial downstream wavelength in the ONU discovery process. The enhanced ONU discovery process for multiple-wavelength 10G-EPON is shown in Figure I.1.
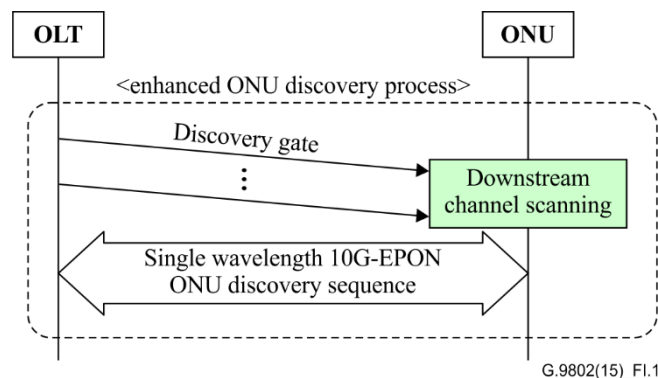

Figure I.1 – ONU discovery process for multiple-wavelength 10G-EPON

I.2 Wavelength tuning

A wavelength tuning procedure is implemented with the following mechanisms.

1) A mechanism to command the designation of the destination wavelength to ONUs and the tuning start timing – It may need to modify the Gate message of the MPCP or to utilize a MAC control extension to command wavelength change. The command may include a local time to schedule the start timing of the wavelength tuning procedure.

2) A mechanism to allow each ONU to have a different tuning time and to recover connection as fast as possible – It may be realized by sending a grant of Report message periodically right after commanding a wavelength change from the OLT and by sending a modified Report message as ONU responses at the grant right after completing the wavelength tuning procedure of the ONU. It may also be realized by utilizing a MAC control extension.

The wavelength tuning capability of the ONU can be transferred to the OLT via the OMCC.

I.3 Wavelength resource administration

A logic ID that represents the wavelength connection indication is required in MW-PON systems. In EPON, the ONU is able to recognize the OLT ports in the MAC layer by checking the OLT MAC address that is populated in the MAC control message received from the OLT. The ONU is also able to recognize the point-to-point connection between the OLT and the ONU by checking the LLID that is populated in the preamble of Ethernet frames. This information can be used for identifying the wavelength connection.

I.4 Wavelength channel performance supervision

This requirement is implemented as a physical layer function. In a multiple-wavelength EPON system, physical layer specification can be in common with TWDM-PON.

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