TECHNICAL REPORT

TR-287
PON Optical-Layer Management

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Issue History

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Executive Summary

A growing number of Broadband Forum Technical Reports is dedicated to the description of an Ethernet-based architecture optimized for multi-service PON networks catering to both residential and business customers. TR-287 extends this architecture by providing enhanced optical-layer management requirements. These requirements cover system architecture, use cases, functional requirements, and interoperability requirements. The specifications in TR-287 apply to both ITU-T and IEEE PON systems.

1 Purpose and Scope

1.1 Purpose

The rapid expansion of PON-system deployments throughout the world has brought into focus the need for improved physical-layer performance monitoring and fault-isolation capabilities. TR-287 contains optical-layer management requirements that meet carrier requirements, foster interoperability, and apply to both ITU-T [1], [2] and IEEE [3], [4] PON systems.

1.2 Scope

The requirements in TR-287 cover the following topics:

- The system architecture, main interfaces, and use cases of FTTx optical-link management functions;
- Functional and performance requirements for FTTx optical-link management functions;
- Implementation-dependent requirements (OTDR, RSSI-based optical-power monitoring, etc.);
- Interface requirements (ONU-OLT, EMS-OLT, etc.).

Fostering interoperability of equipment is one of the principal objectives of TR-287, including compatibility with existing PON standards. Finally, TR-287 has been developed in a protocol-neutral way so that the results are applicable to both ITU-T and IEEE PON systems.

2 References and Terminology

2.1 Conventions

In this Technical Report, several words are used to signify the requirements of the specification. These words are always capitalized. More information can be found be in RFC 2119 [5].

MUST	This word, or the term "REQUIRED", means that the definition is an absolute requirement of the specification.
MUST NOT	This phrase means that the definition is an absolute prohibition of the specification.
SHOULD	This word, or the adjective "RECOMMENDED", means that there could exist valid reasons in particular circumstances to ignore this item, but the full implications need to be understood and carefully weighed before choosing a different course.
SHOULD NOT	This phrase, or the phrase "NOT RECOMMENDED" means that there could exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications need to be understood and the case carefully weighed before implementing any behavior described with this label.
MAY	This word, or the adjective "OPTIONAL", means that this item is one of an allowed set of alternatives. An implementation that does not include this option MUST be prepared to inter-operate with another implementation that does include the option.

2.2 References

The following references are of relevance to this Technical Report. At the time of publication, the editions indicated were valid. All references are subject to revision; users of this Technical Report are therefore encouraged to investigate the possibility of applying the most recent edition of the references listed below. A list of currently valid Broadband Forum Technical Reports is published at www.broadband-forum.org.

Document		Title	Source	Year
[1]	G.984 Series	*Gigabit-capable Passive Optical Networks (G-PON)*	ITU-T	2004-Present
[2]	G.987 Series	*10-Gigabit-capable passive optical networks (XG-PON)*	ITU-T	2010-Present

[3]	Std 802.3-2012	*Standard for Ethernet*	IEEE	2012
[4]	Std 1904.1-2013	*Standard for Service Interoperability in Ethernet Passive Optical Networks (SIEPON)*	IEEE	2013
[5]	RFC 2119	*Key words for use in RFCs to Indicate Requirement Levels*	IETF	1997
[6]	SFF-8472, Revision 11.0	*Specification for Diagnostic Monitoring Interface for Optical Transceivers*	SFF Committee	2011
[7]	INF-8077i, Revision 4.5	*10 Gigabit Small Form Factor Pluggable Module*	XFP Promoters	2005
[8]	L.66	*Optical fibre cable maintenance criteria for in-service fibre testing*	ITU-T	2007
[9]	SR-4731, Issue 2	*Optical Time Domain Reflectometer (OTDR) Data Format*	Telcordia	2011
[10]	IEC 61746, Ed. 2.0	*Calibration of optical time-domain reflectometers (OTDR)*	IEC	2005
[11]	G.671	*Transmission characteristics of optical components and subsystems*	ITU-T	2012
[12]	60825-1 Ed.2	*Safety of laser products - Part 1: Equipment classification and requirements*	IEC	2007
[13]	Private Communication		Meir Bartur, Optical Zonu Corp.	2011
[14]	Proceedings of the 59th IWCS/IICIT (http://iwcs.omnibooksonline.com/data/papers/2010/12_4.pdf)	*Characterization of Losses in GPON Access Networks Using OTDR Measurements*	Svend Hopland	2010

[15]	Hewlett-Packard Journal **39**, #6, pp. 6-38. (http://www.hpl.hp.com/hpjournal/pdfs/IssuePDFs/1988-12.pdf)	Special Issue on Optical Time Domain Reflectrometry	Michael Fleischer-Reumann, et al	December 1988

2.3 Definitions

The following terminology is used throughout this Technical Report.

ODN Optical Distribution Network: The physical medium that connects an OLT to its subtended ONUs. The ODN is comprised of various passive components, including the optical fiber, splitter or splitters, and optical connectors.

OLT Optical Line Terminal (OLT): A device that terminates the common (root) endpoint of an ODN, implements a PON protocol, and adapts PON PDUs for uplink communications over the provider service interface. The OLT provides management and maintenance functions for the subtended ODN and ONUs.

ONU Optical Network Unit (ONU): A generic term denoting a functional element that terminates any one of the distributed (leaf) endpoints of an ODN, implements a PON protocol, and adapts PON PDUs to subscriber service interfaces. In some contexts an ONU supports interfaces for multiple subscribers.

PON Passive Optical Network. A PON includes the OLT, ONU, and Optical Distribution Network (ODN).

2.4 Abbreviations

This Technical Report uses the following abbreviations:

AN	Access Node
ADZ	Attenuation Dead Zone
CO	Central Office
DMI	Diagnostic Monitoring Interface
EMS	Element Management System
EPON	Ethernet Passive Optical Network
EDZ	Event Dead Zone
FDF	Fiber Distribution Frame
FFS	For Future Study
FTTH	Fiber To The Home
GPON	Gigabit-capable Passive Optical Network
OAM	Operations, Administration, and Maintenance
ODN	Optical Distribution Network
OLM	Optical-Layer Management
OLT	Optical Line Terminal
OMCI	ONT Management Control Interface
ONU	Optical Network Unit
OPM	Optical Parameter Measurement
OTDR	Optical Time Domain Reflectrometry
OTDS	Optical Test and Diagnostics Subsystem
OTF	Optical Test Function
OTMF	Optical Test-Management Function
PON	Passive Optical Network
RSSI	Received Signal Strength Indication
TR	Technical Report
WDM	Wavelength Division Multiplexing
WG	Working Group

3 Technical Report Impact

3.1 Energy Efficiency

TR-287 has no impact on Energy Efficiency.

3.2 IPv6

TR-287 has no impact on IPv6.

3.3 Security

TR-287 has no impact on Security.

3.4 Privacy

TR-287 has no impact on Privacy.

4 PON Optical-Layer Management (OLM) Architecture

The ability to remotely manage the PON optical layer is valuable in a wide variety of deployment scenarios and operational procedures. This Section describes the high-level architecture of PON OLM and Sections 5 through 9 contain detailed Requirements. Appendix A contains various use cases which illustrate the use of PON OLM. Appendix B contains an overview of optical time domain reflectrometry basics and fiber fault detection techniques.

Figure 1 shows the logical functional blocks of an OLM system. The Optical Test and Diagnostics Subsystem (OTDS) is responsible for initiating tests and performing diagnostics. The Optical Test-Management Function (OTMF) layer includes the link-monitoring management function and the OTDR controller function, thus performing centralized management and control of the Optical-Test Function (OTF) layer. The OTF layer includes the link-monitoring and Optical Time-Domain Reflectrometry (OTDR) functions and is responsible for receiving commands from OTMF layer, executing test commands, and reporting results back to the OTMF layer.

Optical-link monitoring is used in conjunction with OTDR to provide a complete solution for PON optical layer management. Here, optical-link monitoring refers to SFF-8472 [6] and INF-8077i [7] based optical parameter measurement (OPM), support for which is integrated into the OLT and ONU optical modules.

Functionality in the OTMF layer may be implemented in a variety of ways, including, but not limited to:

- The link-monitoring management function resides in the PON EMS, while the OTDR controller function resides in a separate and dedicated server that manages more than one OTDR function;
- The link-monitoring management function resides in the PON EMS, while the OTDR controller function and the OTDS reside in the same server;
- The link-monitoring management function and the OTDR controller functional reside in the PON EMS.

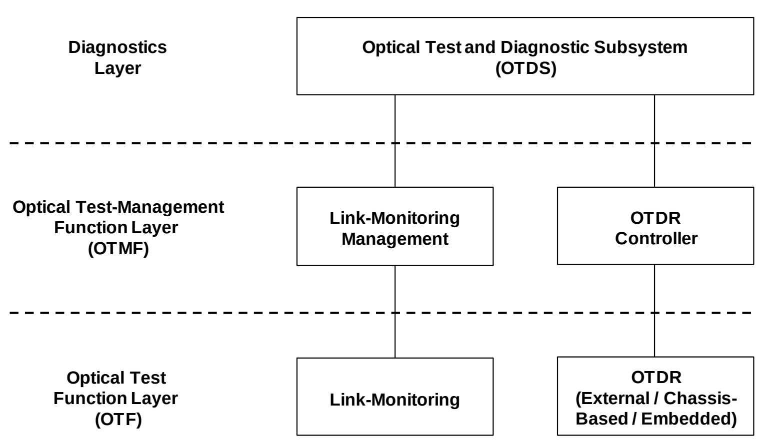

Figure 1 – Logical functional blocks of an OLM system.

Figure 2 shows the functional blocks and interfaces of the three model equipment configurations specified in TR-287. The left panel illustrates the external OLM architecture, the middle panel illustrates the chassis-based OLM architecture, and the right panel illustrates the dedicated OLM architecture. These configurations are described in more detail in Sections 5– 7, and definitions of all the interfaces are contained in Appendix C.

To improve OTDR sensitivity, a network operator may choose to enhance the reflectivity of ONUs by adding a wavelength-selective reflector at the ONU [8]. In this context wavelength selective means that the OTDR wavelength is reflected with high efficiency while the traffic wavelengths pass in both directions with minimal attenuation. This option can be used with any of the three architectures described in this Technical Report. Since the exact location of the wavelength-selective reflector varies depending upon implementation, it is not shown explicitly in any of the drawings. Wavelength-selective reflectors are described in Section 9.

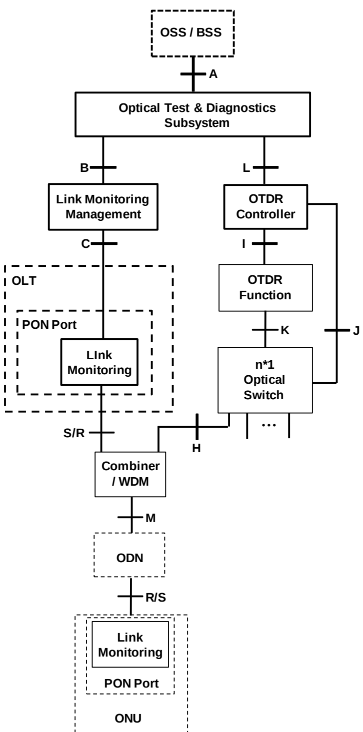

Figure 2 – Reference architectures for external, chassis-based, and dedicated OTDR (left to right).

4.1 External OTDR

As shown in the left panel of Figure 2, this configuration combines one or more OLTs and external equipment to provide a complete OLM solution. The external equipment consists of a test set that provides OTDR functionality and a multiport optical switch. The OTDR controller, which manages both the OTDR function and the n*1 optical switch, can be either a discrete, physical unit or can exist as a virtual functional block within the Optical Test and Diagnostics System (OTDS). The OLT generally contains multiple PON ports, each of which supports embedded optical link-monitoring functionality dedicated to that port. These functions, which are based on SFF-8472 [6] and INF-8077i [7], are described in detail in Section 8. The PON port on the ONU supports similar link-monitoring functions, which also are described in Section 8. Detailed Requirements for the optical-layer management system of this architecture, which is comprised of the functional elements and the interfaces shown in the left panel of Figure 2, are found in Section 5. Network operators who employ the external OTDR architecture typically require that such a solution satisfy the use cases described in Appendices A.2, A.3, and A.4.

4.2 Chassis-Based OTDR

For the configuration shown in the middle panel of Figure 2, an OTDR module or card is embedded in each OLT chassis and is used together with the per-PON port optical-link monitoring functions to provide a complete OLM solution. This embedded OTDR function consists of a test set that provides OTDR functionality and a multiport optical switch. The OLT generally contains multiple PON ports, each of which supports embedded optical link-monitoring functionality dedicated to that port. These functions are based on SFF-8472 [6] and INF-8077i [7] and are described in detail in Section 8. Detailed Requirements for the optical-layer management system of this architecture, which is comprised of the functional elements and the interfaces shown in the middle panel of Figure 2, are found in Section 6. Network operators who employ the chassis-based OTDR architecture typically require that such a solution satisfy the use cases described in Appendices A.2, A.3, and A.4.

4.3 Dedicated OTDR

For the configuration as shown in the right panel of Figure 2, an OTDR module is embedded in each OLT PON port which is used in conjunction with the optical-link monitoring functions to provide a complete OLM solution. The OLT generally contains multiple PON ports, each of which supports embedded optical link-monitoring functionality dedicated to that port. These functions are based on SFF-8472 [6] and INF-8077i [7] and are described in detail in Section 8. Detailed Requirements for the optical-layer management system of this architecture, which is comprised of the functional elements and the interfaces shown in the right panel of Figure 2, are found in Section 7. Network operators who employ the dedicated OTDR architecture typically require that such a solution satisfy the use cases described in Appendices A.2, A.3, and A.4.

5 Functional Requirements for External OTDR

The external OTDR architecture combines one or more OLTs with external equipment to provide a complete OLM solution, as illustrated in the left panel of Figure 2. The external equipment consists of a test set that provides OTDR functionality, a multiport optical switch, a combiner/WDM, and in some implementations a stand-alone OTDR controller. This section contains detailed Requirements for this architecture.

5.1 Optical Test and Diagnostics Subsystem

The Optical Test and Diagnostics Subsystem (OTDS), shown in Figure 2, left panel, manages the optical-link performance monitoring, manages OTDR testing, and analyzes the resulting information. This subsystem is responsible for generating alerts regarding optical link quality degradation and for diagnosing optical link fault conditions. ODN topology information and ODN reference data may be stored locally by the OTDS or alternatively accessed via the **A** interface.

R-1 The OTDS MUST support a north-bound interface to OSS/BSS (Figure 2, left panel, interface **A**). Supported functionality across this interface MUST include test initiation (downstream) and test result reporting (upstream).

R-2 The OTDS MUST support ODN topology retrieval from upstream OSS/BSS.

R-3 The OTDS MUST support the manual initiation of testing and diagnostic functions.

R-4 The OTDS MUST support the automatic initiation of testing and diagnostic functions upon triggering by a specific fault condition.

R-5 The OTDS MUST support the periodic initiation of testing and diagnostic functions.

R-6 The OTDS MUST support the ability to automatically generate test parameters, such as pulse width, measurement time, etc.

R-7 The OTDS MUST accept manually specified test parameters, such as pulse width, measurement time, etc.

R-8 The OTDS MUST support the collection of link-monitoring data, including but not limited to, SFF 8472-based optical-layer parameters, OLT alarms, ONU alarms, and BIP/FEC errors, via the **B** interface of Figure 2, left panel.

R-9 The OTDS MUST support the generation and archiving of ODN reference data for each ODN in its management domain.

R-10 The OTDS MUST support analysis of link-monitoring data and OTDR data, for the purpose of determining the ODN optical-loss budget and optical module operating parameters on a per-ONU basis.

R-11 The OTDS MUST support analysis of link-monitoring data and OTDR data, for the purpose of detecting degradation of the optical link quality and OLT/ONU optical modules over time.

R-12 The OTDS MUST be capable of distinguishing between OLT/ONU faults and ODN faults.

R-13 The OTDS MUST support identifying and locating optical-link faults.

5.2 OTDR Controller

The OTDR controller, which manages both the OTDR function and the n*1 optical switch, can be either a discrete, physical unit or can exist as a virtual functional block within the Optical Test and Diagnostics System (OTDS). One OTDR controller can manage multiple OTDR-function / n*1-optical-switch pairs.

R-14 The OTDR Controller MUST be capable of receiving commands from the OTDS via the **L** interface, transferring those commands to the OTDR function and receiving the results from the OTDR function via the **I** interface of Figure 2, left panel.

R-15 The OTDR Controller MUST be capable of receiving commands from the OTDS and controlling the n*1 optical switch via the **J** interface of Figure 2, left panel. Required functionality MUST include selection of the ODN to be placed under test.

R-16 The OTDR Controller MUST support the management of its subtended OTDR functions and optical switches. This management MUST include but is not limited to configuration management, status monitoring and alarm management.

R-17 The OTDR Controller MUST support the transfer of results from the OTDR Controller's subtended OTDR functions to the OTDS.

5.3 OTDR Function

The OTDR function, as shown in Figure 2, left panel, performs the optical-layer tests and provides the results to the OTDS via the OTDR Controller. This data is interpreted by the OTDS to determine fiber attenuation and identify reflection and attenuation events. It is assumed that the OTDR function includes basic data acquisition, signal-processing, data-processing, and SNR-improvement (for example, by signal averaging) capabilities.

There are many, equivalent ways to state performance requirements for PON OTDR. The external OTDR performance specifications in this Technical Report, contained in Requirements R-20 and R-21, are presented in a tabular format that explicitly shows the relationships among the interdependent variables (dynamic range, distance resolution, and detection time).

In real networks the measured reflectivity of a particular fiber break or attenuation event (e.g., a pinched fiber) can vary over a wide range, depending upon the microscopic details of the impairment. Accordingly, the external OTDR performance specifications contained in R-20 should be interpreted as statistical limits and not treated as universal values that cover all possible cases. For example, if a particular external OTDR solution conforms to R-20, it will be capable of detecting approximately 95% of the fiber breaks in a feeder where the fiber breaks obey the statistical distribution shown in Figure 15.

R-18 The OTDR function MUST support the reporting of test results to the OTDS via the OTDR Controller.

R-19 The OTDR function MUST conform to the operating and performance parameters shown in Table 1.

Item	Unit	Specification
Wavelength	nm	1640-1660
Pulse Width	ns	Configurable, Minimum Pulse Width ≤ 5
Peak Power	dBm	Configurable, Maximum ≤ 15
Measurement Range (Single Fiber)	km	Configurable, Maximum ≥ 20
Measurement Time	minutes	Configurable
Sampling Resolution	m	Configurable, Minimum Sampling Resolution ≤ 0.5
Distance Uncertainty	m	≤ 2.5
Attenuation Dead Zone†	m	≤ 10 (Pulse Width = 10 ns, Reflection Event with a Reflectivity = -45 dB)
Event Dead Zone†	m	≤ 3 (Pulse Width = 10 ns, Reflection Event with a Reflectivity = -45 dB)
† In all cases the pulse width should be ≥ 10 ns. If the OTDR doesn't support a 10ns pulse width, a pulse width >10ns may be used to determine the values of ADZ and EDZ.		

Table 1 – OTDR functionality subsystem parameters, external OTDR architecture.

Table 1 Parameter Definitions

Event Dead Zone (EDZ): As illustrated in the top of Figure 3, the event dead zone is defined as the distance between the two points on either side of the reflective peak that are -1.5dB below the reflective peak. If the distance between two connectors is greater than the event dead zone (Figure 3, bottom right), the OTDR is said to be capable of distinguishing between the two events.

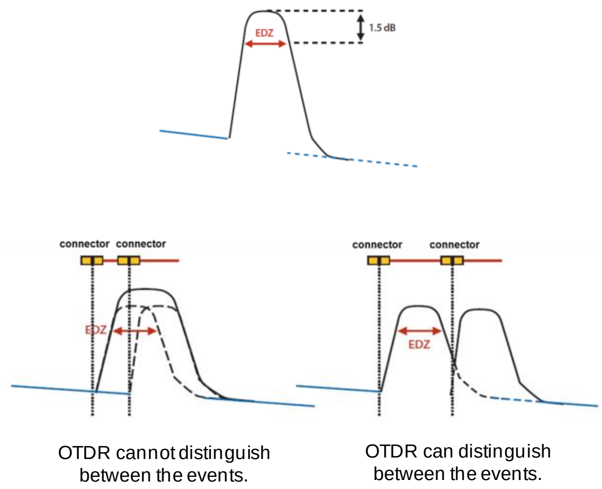

Figure 3 – Definition of event dead zone.

Attenuation Dead Zone: As illustrated in the top of Figure 4, the attenuation dead zone is defined as the distance from the start of a reflection event to the point where the reflection has recovered to within +/-0.5 dB of the undisturbed and averaged backscatter trace. If the distance between two events is greater than the attenuation dead zone (Figure 4, bottom right), the OTDR is said to be capable of detecting the second event.

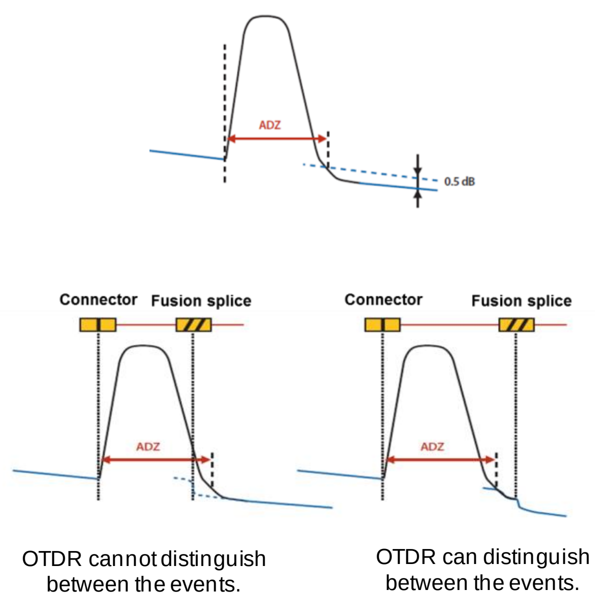

Figure 4 – Definition of attenuation dead zone.

R-20 For a reflection event within a 20 km fiber distance of the OLT, Table 2 specifies the maximum detection time allowed, minimum OTDR dynamic range, and required distance resolution that an External OTDR function MUST support, depending upon the use case.

Line	IEC Dynamic Range (dB)	Resolution (m)	Maximum Detection Time (minutes)	Use Case
1	10	3	0.5	A. Feeder-fiber reflection event with a reflectivity ≥ -60 dB or greater and an ODN loss of 10 dB (Appendix A.2). B. Distribution-fiber reflection event with a reflectivity ≥ -41 dB and an ODN loss of 21 dB (Appendix A.3). C. Drop-fiber reflection event with a reflectivity ≥ -15dB and an ODN loss of 32dB (Appendix A.4).
2	10	1.5	3	A. Feeder-fiber reflection event with a reflectivity ≥ -60 dB or greater and an ODN loss of 10 dB (Appendix A.2). B. Distribution-fiber reflection event with a reflectivity ≥ -41 dB and an ODN loss of 21 dB (Appendix A.3). C. Drop-fiber reflection event with a reflectivity ≥ -15dB and an ODN loss of 32dB (Appendix A.4).
3	21	20	3	Distribution-fiber reflection event with a reflectivity ≥ -51 dB and an ODN loss of 21 dB (Appendix A.3).
4	FFS	FFS	FFS	Drop Fiber Reflection Event (Appendix A.4)

Table 2 – OTDR performance requirements for reflection events, external OTDR architecture.

Table 2 Parameter Definition

Dynamic Range: The difference between the peak backscatter power and the noise power level, at a specified pulse width, averaging time, and maximum distance. As illustrated in Figure 5, the noise level can be specified as the either the level below which 98% of the data points lie [10] or as the RMS value of the data set (Gaussian distribution, SNR=1). Dynamic range is expressed in dB of one-way fiber loss.

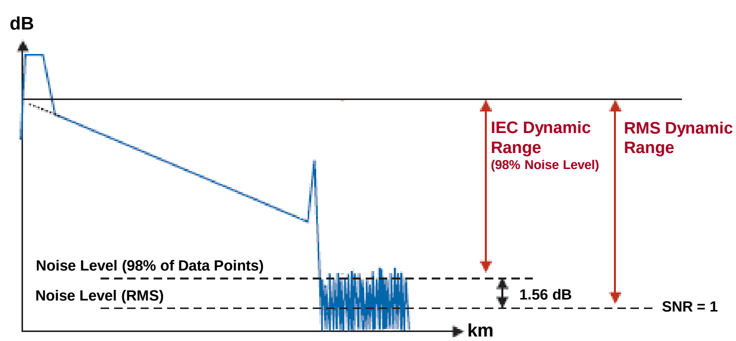

Figure 5 – Definition of dynamic range.

R-21 For an attenuation event within a 20 km fiber distance of the OLT, where the attenuation event results in a decrease of

- 0.3 dB or more in the Rayleigh backscatter signal of the affected feeder fiber, or
- 3 dB or more in the Rayleigh backscatter signal of the affected distribution fiber,

Table 3 specifies the maximum detection time allowed, minimum OTDR dynamic range, and required distance resolution that an External OTDR function MUST support, depending upon the use case.

Line	IEC Dynamic Range (dB)	Resolution (m)	Maximum Detection Time (minutes)	Use Case
1	10	5	3	Feeder Fiber Attenuation Event (Appendix A.2)
2	21	60	15	Distribution Attenuation Event (Appendix A.3)
3	FFS	FFS	FFS	Drop Fiber Attenuation Event (Appendix A.4)

Table 3 – OTDR performance requirements for attenuation events, external OTDR architecture.

5.4 n*1 Optical Switch

The n*1 optical switch is used to connect a common OTDR functionality subsystem to multiple ODNs, as shown in Figure 2, left panel.

R-22 The n*1 optical switch MUST conform with Section 5.14 of G.671 [11].

R-23 The n*1 optical switch MUST reconfigure to cross-connect the OTDR test signal and the target ODN upon receipt of the appropriate command from the OTDR Controller.

5.5 Combiner / WDM

The combiner/WDM is used to combine/split the downstream/upstream PON and OTDR test signals.

R-24 The addition of an external OTDR MUST have no impact on the optical-power budget, wavelength plan, or any other optical-layer characteristics of the PON between the **S/R** and **R/S** reference points shown in Figure 2, left panel.

R-25 The addition of an external OTDR MUST have no impact on the bandwidth or traffic-management characteristics (including DBA) of the PON.

R-26 For the external OTDR architecture with an EPON, GPON, or NGA system, the combiner/WDM ports MUST conform with Figure 6.

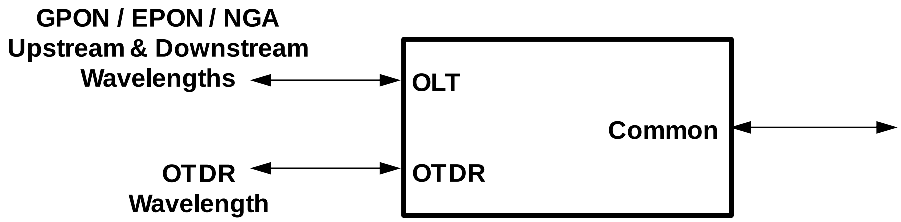

Figure 6 – Combiner/WDM ports for the external OTDR architecture, EPON, GPON, or NGA.

R-27 For ITU-T PON systems, the combiner/WDM MUST conform to the parameters specified in G.984.5 [1].

R-28 For ITU-T NGA-plus-GPON systems, the combiner/WDM ports MUST conform with ITU-T G984.5 and its Amendments.

6 Functional Requirements for Chassis-Based OTDR

In the chassis-based OTDR architecture, specialized OTDR functional blocks are embedded within an OLT to provide a complete OLM solution, as illustrated in the middle panel of Figure 2. These functional blocks consist of a single OTDR Function, which is shared by all of the PON ports in the chassis, a combiner/WDM, and a multiport optical switch, which is used to cross-connect the OTDR Function with the PON port under test. This Section contains detailed Requirements for this architecture.

6.1 Optical Test and Diagnostics Subsystem

The OTDS requirements for chassis-based OTDR systems are identical to those for external OTDR systems, as described in Section 5.1.

6.2 OTDR Controller

The OTDR controller, which manages both the OTDR Function and the n*1 optical switch embedded in the OLT chassis, can be either a discrete, physical unit, a virtual functional block within the Optical Test and Diagnostics System (OTDS), or a virtual functional block within the OLT. One OTDR controller can manage multiple chassis-based OTDR-function / n*1- optical-switch pairs.

R-29 The OTDR Controller MUST be capable of receiving commands from the OTDS via the **L** interface, transferring these commands to the OTDR function, receiving the result from the OTDR function, and controlling the n*1 optical switch via the **I** interface of Figure 2, middle panel. Required functionality MUST include selection of the ODN to be placed under test.

R-30 The OTDR Controller MUST support the management of its subtended OTDR functions and optical switches. This management MUST include but is not limited to configuration management, status monitoring and alarm management.

R-31 The OTDR Controller MUST support the transfer of results from the OTDR Controller's subtended OTDR functions to the OTDS.

6.3 OTDR Function

The OTDR function requirements for chassis-based OTDR systems are similar to those for external OTDR systems, as described in Section 5.3. As the OTDR function resides in the OLT chassis, the OLT is responsible for receiving test commands from the OTDR controller, parsing these commands if necessary, and sending test-initiation commands to the OTDR function.

Correspondingly, the OLT is responsible for retrieving test results from the OTDR function and forwarding them to the OTDR controller.

6.4 n*1 Optical Switch

The embedded n*1 optical switch is used to connect the common OTDR function to multiple ODNs, as shown in Figure 2, middle panel.

R-32 The n*1 optical switch MUST reconfigure to cross-connect the OTDR test signal and the target ODN upon receipt of the appropriate command from the OTDR Controller.

6.5 Combiner / WDM

The combiner/WDM, shown in the middle panel of Figure 2, is used to combine/split the downstream/upstream PON and OTDR test signals.

R-33 For ITU-T PON systems, the combiner/WDM MUST conform to the parameters specified in G.984.5 [1].

R-34 For ITU-T NGA-plus-GPON systems, the combiner/WDM ports MUST conform to Figure I.5/G984.5 Amendment1, Figure I.7/G984.5 Amendment1, Table I.5/G984.5 Amendment1, and Table I.6/G984.5 Amendment1 (“WDM1r” filter) [1].

7 Functional Requirements for Dedicated OTDR

In the dedicated OTDR architecture, a specialized OTDR functional block is embedded within each PON port to provide a complete OLM solution, as illustrated in the right panel of Figure 2. This Section contains detailed Requirements for this architecture.

7.1 Optical Test and Diagnostics Subsystem

The OTDS requirements for dedicated OTDR systems are identical to those for external OTDR systems, as described in Section 5.1.

7.2 OTDR Controller

The OTDR controller, which manages the OTDR Function embedded in each OLT PON port, can be implemented in a variety of ways, including but not limited to, a discrete, physical unit, a virtual functional block within the Optical Test and Diagnostics System (OTDS), a virtual block within the EMS, or a virtual functional block within the OLT. One OTDR controller can manage multiple dedicated OTDR-functions.

R-35 The OTDR Controller MUST be capable of receiving commands from the OTDS via the **L** interface, transferring these commands to the OTDR function, and receiving the results from the OTDR function via the **I** interface of Figure 2, right panel.

R-36 The OTDR Controller MUST support the management of its subtended OTDR functions. This management MUST include but is not limited to configuration management, status monitoring and alarm management.

R-37 The OTDR Controller MUST support the transfer of results from the OTDR Controller's subtended OTDR functions to the OTDS.

7.3 OTDR Function

The OTDR function, as shown in Figure 2, right panel, performs the optical-layer tests and provides the results to the OTDS via the OTDR Controller. This data is interpreted by the OTDS to determine fiber attenuation and identify reflection and attenuation events. It is assumed that the OTDR function includes basic data acquisition, signal-processing, data-processing, and SNR-improvement (for example, by signal averaging) capabilities. As the OTDR function resides in the OLT PON port, the OLT is responsible for receiving test commands from the OTDR controller, parsing these commands if necessary, and sending test-initiation commands to the OTDR function. Correspondingly, the OLT is responsible for retrieving test results from the OTDR function and forwarding them to the OTDR controller.

There are multiple options for the test wavelength in dedicated OTDR implementations. It can be in the 1640-1660 nm range using a separate laser diode inside the optical port. Alternately, it can be within the downstream wavelength range of the PON system by either applying a pilot-tone modulation to the downstream data or by adding a separate laser diode emitting at any unused wavelength within the downstream band. It also can be within the upstream wavelength range of the PON system by adding a separate laser diode emitting at the upstream wavelength and reusing the upstream receiver to receive the test signal.

There are many, equivalent ways to state performance requirements for PON OTDR. The dedicated OTDR performance specifications in this Technical Report, contained in R-44 through R-47, are presented in a tabular format that explicitly shows the relationships among the interdependent variables (dynamic range, distance resolution, and detection time).

In real networks the measured reflectivity of a particular fiber break or attenuation event (e.g., a pinched fiber) can vary over a wide range, depending upon the microscopic details of the impairment. Accordingly, the dedicated OTDR performance specifications in this Technical Report, contained in R-44 and R-45 should be interpreted as statistical limits and not treated as universal values that cover all possible cases. For example, if a particular dedicated OTDR solution conforms to R-44 or R-45, it will be capable of detecting approximately 95% of the fiber breaks in a network where the fiber breaks obey the statistical distribution shown in Figure 15.

R-38 The OTDR function MUST remain in a low-power mode until receiving a command, and MUST return it a low-power mode once all OTDR-related activity has been completed;

R-39 The OTDR function MUST support the reporting of test results to the OTDS via the OTDR Controller.

R-40 The OTDR function MUST conform to the operating parameters shown in Table 4.

Item	**Unit**	**Specification**
Pulse Width	ns	Configurable
Measurement Range (Single Fiber)	km	Configurable, Maximum ≥ 20
Measurement Time	minutes	Configurable
Sampling Resolution	m	Configurable, Minimum Sampling Resolution ≤ 1
Distance Uncertainty	m	≤ 3
Attenuation Dead Zone†	m	≤ 10 (Pulse Width = 10 ns, Reflection Event with a Reflectivity = -45 dB)
Event Dead Zone†	m	≤ 5 (Pulse Width = 10 ns, Reflection Event with a Reflectivity = -45 dB)
† In all cases the pulse width should be ≥ 10 ns. If the OTDR doesn't support a 10ns pulse width, a pulse width >10ns may be used to measure the values of ADZ and EDZ.		

Table 4 – OTDR functionality parameters, dedicated OTDR architecture.

R-41 For implementations that use a separate wavelength for OTDR, the OTDR function SHOULD conform to Class 1 laser requirements defined in IEC 60825-1[12].

R-42 OLT optical modules that support dedicated OTDR functionality must conform to existing standards for mechanical form-factor, electrical connectivity, and management connectivity. In other words, OLT optical modules that support dedicated OTDR functionality must be plug compatible with existing and otherwise equivalent OLT optical modules that do not support dedicated OTDR functionality.

R-43 OLT optical modules that support dedicated OTDR functionality must be implemented in such a way that upgrading existing OLTs to support dedicated OTDR requires only the replacement of the OLT optical module and an upgrade of the OLT software.

R-44 For a reflection event within a 20 km fiber distance of the OLT, Table 5 specifies the maximum detection time allowed, minimum OTDR dynamic range, and required distance resolution that a Dedicated OTDR function MUST support, depending upon the use case.

Line	IEC Dynamic Range (dB)	Resolution (m)	Maximum Detection Time (minutes)	Use Case
1	9	5	30	A. Feeder-fiber reflection event with a reflectivity ≥ -60 dB or greater and an ODN loss of 10 dB (Appendix A.2). B. Distribution-fiber reflection event with a reflectivity ≥ -41 dB and an ODN loss of 21 dB (Appendix A.3). C. Drop-fiber reflection event with a reflectivity ≥ -15dB and an ODN loss of 32dB (Appendix A.4).
2	FFS	20	20	Distribution-fiber reflection event with a reflectivity ≥ -51 dB and an ODN loss of 21 dB (Appendix A.3).
3	FFS	FFS	FFS	Drop Fiber Reflection Event (Appendix A.4)

Table 5 – OTDR performance requirements for reflection events, dedicated OTDR architecture.

R-45 For a reflection event within a 20 km fiber distance of the OLT, Table 6 specifies the maximum detection time allowed, minimum OTDR dynamic range, and required distance resolution that a Dedicated OTDR function SHOULD support, depending upon the use case.

Line	IEC Dynamic Range (dB)	Resolution (m)	Maximum Detection Time (minutes)	Use Case
1	10	5	3	A. Feeder-fiber reflection event with a reflectivity ≥ -60 dB or greater and an ODN loss of 10 dB (Appendix A.2). B. Distribution-fiber reflection event with a reflectivity ≥ -41 dB and an ODN loss of 21 dB (Appendix A.3). C. Drop-fiber reflection event with a reflectivity ≥ -15dB and an ODN loss of 32dB (Appendix A.4).
2	21	20	20	Distribution-fiber reflection event with a reflectivity ≥ -51 dB and an ODN loss of 21 dB (Appendix A.3).
3	FFS	FFS	FFS	Drop Fiber Reflection Event (Appendix A.4)

Table 6 – OTDR performance recommendations for reflection events, dedicated OTDR architecture.

R-46 For an attenuation event within a 20 km fiber distance of the OLT, where the attenuation event results in a decrease of

- 0.3 dB or more in the Rayleigh backscatter signal of the affected feeder fiber, or
- 3 dB or more in the Rayleigh backscatter signal of the affected distribution fiber,

Table 7 specifies the maximum detection time allowed, minimum OTDR dynamic range, and required distance resolution that a Dedicated OTDR function MUST support, depending upon the use case.

Line	IEC Dynamic Range (dB)	Resolution (m)	Maximum Detection Time (minutes)	Use Case
1	9	8	30	Feeder Fiber Attenuation Event (Appendix A.2)
2	FFS	FFS	FFS	Distribution Attenuation Event (Appendix A.3)
3	FFS	FFS	FFS	Drop Fiber Attenuation Event (Appendix A.4)

Table 7 – OTDR performance requirements for attenuation events, dedicated OTDR architecture.

R-47 For an attenuation event within a 20 km fiber distance of the OLT, where the attenuation event results in a decrease of

- 0.3 dB or more in the Rayleigh backscatter signal of the affected feeder fiber, or
- 3 dB or more in the Rayleigh backscatter signal of the affected distribution fiber,

Table 8 specifies the maximum detection time allowed, minimum OTDR dynamic range, and required distance resolution that a Dedicated OTDR function SHOULD support, depending upon the use case.

Line	IEC Dynamic Range (dB)	Resolution (m)	Maximum Detection Time (minutes)	Use Case
1	10	8	3	Feeder Fiber Attenuation Event (Appendix A.2)
2	FFS	FFS	FFS	Distribution Attenuation Event (Appendix A.3)
3	FFS	FFS	FFS	Drop Fiber Attenuation Event (Appendix A.4)

Table 8 – OTDR performance recommendations for attenuation events, dedicated OTDR architecture.

8 Functional Requirements for Optical-Link Monitoring

The functionality described in SFF-8472 [6] and INF-8077i [7] enables OLT and ONU optical modules to measure and report operational status and optical performance. Key parameters covered by SFF-8472 and INF-8077i include module temperature, supply voltage, transmitter bias current, transmitted optical power, and received optical power. This data is used by the OTDS in a variety of ways, including the detection of fault conditions, the detection of failing components, and the determination of the optical-link loss for individual ONUs.

Additional optical-module requirements for ITU-T PON systems are found in G.984.2, Amd 2, Table IV.1 [1]. Additional optical-module requirements for IEEE PON systems are found in IEEE Std 1904.1, Clause 9.1.3 – Clause 9.1.6 [4].

8.1 OLT Optical-Link Monitoring Requirements

The Requirements in this Section describe optical-link monitoring capable OLTs equipped with SFF-8472 or INF-8077i compliant optical modules.

R-48 The OLT optical module MUST conform to performance requirements of SFF-8472 [6] or INF-8077i [7], whichever is applicable.

R-49 The OLT MUST support management of ONU optical parameter measurement functions via the OAM/OMCI interface.

R-50 The OLT transceiver MUST support a diagnostic monitoring interface for reporting status and performance data.

R-51 The reporting format used on the OLT transceiver diagnostic monitoring interface MUST comply with SFF-8472 [6] or INF-8077i [7], whichever is applicable.

R-52 The OLT transceiver MUST be capable of measuring and reporting the received (upstream) optical power on a per ONU basis. The lower limit of the measurement range MUST be at or below the transceiver's sensitivity, and the upper limit of the measurement range MUST be as close to the transceiver's overload limit as practical.

R-53 The OLT MUST accept optical parameter measurement commands from the Link Monitoring Management function via the **C** interface. For commands pertaining to one of the subtending ONUs, the OLT MUST translate the command into the appropriate OAM/OMCI message and transmit it to the target ONU.

R-54 The OLT MUST be capable of retrieving test results from OLT and ONU transceivers and reporting them to the Link Monitoring Management function via the **C** interface.

R-55 The OLT MUST be capable of continuously monitoring the status of all of the OLT port and subtending ONU optical modules. Should the OLT detect that any of the monitored values within its management domain falls outside of the pertinent, pre-configured range, the OLT MUST generate a threshold-crossing alarm whenever any parameter pertaining to any of the optical modules within its management domain is found to be outside of a pre-configured range. This alarm MUST be forwarded to the Link Monitoring Management function via the **C** interface.

8.2 ONU Optical-Link Monitoring Requirements

The Requirements in this Section describe optical-link monitoring capable ONUs equipped with SFF-8472 or INF-8077i compliant optical modules.

R-56 The ONU optical module MUST conform to performance requirements of SFF-8472 [6] or INF-8077i [7], whichever is applicable.

R-57 The ONU MUST support management of ONU optical parameter measurement functions via the OAM/OMCI interface.

R-58 The ONU transceiver MUST support a diagnostic monitoring interface for reporting status and performance data.

R-59 The reporting format used on the ONU transceiver diagnostic monitoring interface MUST comply with SFF-8472 [6] or INF-8077i [7], whichever is applicable.

R-60 The ONU transceiver MUST be capable of measuring and reporting the received (downstream) optical power. The lower limit of the measurement range MUST be at or below the transceiver's sensitivity, and the upper-limit of the measurement range MUST be as close to the transceiver's overload limit as practical.

R-61 The ONU MUST accept optical parameter measurement commands from OLT via the OAM/OMCI interface.

R-62 The ONU MUST be capable of continuously monitoring its internal status and MUST be capable of generating a threshold-crossing alarm whenever any parameter is found to be outside of a pre-configured range. The ONU MUST transmit this alarm to the OLT via the OAM/OMCI interface.

R-63 The ONU MUST support internal calibration of the optical parameter measurement values.

8.3 Link Monitoring Management Function Requirements

For optical-link monitoring functions, the Link Monitoring Management function is responsible for relaying optical-layer test and diagnostics commands and results between the OTDS and the subtended OLTs.

R-64 The Link Monitoring Management function MUST support initiating optical-link tests upon receipt of the appropriate OTDS command via interface **B**.

R-65 The Link Monitoring Management function MUST support reporting the results of optical-link tests to the OTDS via interface **B**.

8.4 OTDS Optical-Link Monitoring Requirements

The Optical Test & Diagnostics Subsystem (OTDS) is responsible for managing the optical link-monitoring functions, collecting test results and alarms, and performing fault diagnostics and link-quality evaluation.

R-66 The OTDS MUST support sending optical parameter measurement commands to the Link Monitoring Management function via interface **B**. These commands may be initiated either manually or automatically.

R-67 The OTDS MUST support operator-defined policies for monitoring optical-layer performance and MUST include periodic monitoring capabilities.

R-68 The OTDS MUST support analysis of link-monitoring data for the purpose of determining the ODN optical loss on a per-ONU basis.

R-69 The OTDS MUST support higher-level analysis of the optical-parameter measurements it collects and MUST be capable of reporting the results of this analysis to an upstream OSS via interface **A**. Examples of such analysis may include fault location, optical-path attenuation that exceeds a pre-defined threshold, and optical-path disconnection. In the case of optical path disconnection, the OTDS SHOULD be capable of determining which portion of the ODN has been disconnected.

R-70 The OTDS MUST be capable of detecting and reporting to an upstream OSS via interface **A** the degradation of optical-link quality, based on analysis of historical optical parameter measurement data.

9 Functional Requirements for Wavelength-Selective Reflectors

Wavelength-selective reflectors, which selectively reflect the OTDR signal with high efficiency, can be added to the ODN to improve OTDR performance. Benefits of using wavelength-selective reflectors include enhancement of the ability to identify signals belonging to specific ONUs and improvement in link-health monitoring capabilities. Wavelength-selective reflectors can be integrated into the ONU (thus minimizing operational complexity during installation), or can be incorporated into other elements of the ODN, such as the drop-fiber pigtail or a specialized connector located on the customer premises. Additionally, an operator may choose to install fiber drops with unique lengths, thus further enhancing fault isolation capabilities.

For networks that require the use of wavelength selective reflectors, Requirements R-71 through R-73 apply:

R-71 The wavelength-selective reflector MUST provide reflection over the specified OTDR wavelength range.

R-72 The wavelength-selective reflector MUST allow traffic-bearing wavelengths to pass with minimal impairment.

R-73 When unique drop-fiber lengths are used in combination with wavelength-selective reflectors located at the ONUs for the purpose of enabling the unambiguous identification of individual ONUs, the difference in length between any two drops MUST be larger than the OTDR's reflection-event resolution.

Appendix A: OLM Use Cases

The PON architecture is very flexible in terms of fiber lengths, split ratios, splitter locations, wavelength selection, etc., and many ODN configurations are found in commercial networks. Since it is not possible to describe and develop requirements for every ODN of current or potential interest, TR-287 is restricted to a set of Use Cases that (1) describe OLM scenarios of widespread relevance to the industry, (2) challenge suppliers in terms of OLM performance, and (3) are readily translated into test cases. All of the Use Cases described in TR-287 assume a 1x64 split-ratio and a 20 km maximum reach, and for drop-fiber OLM both single-splitter and cascaded-splitter configurations are considered. While the ODNs described in this Annex are not normative themselves, the discussion of the Use Cases that follows is intended to illustrate the key constraints and trade-offs that shaped the requirements of TR-287. Finally, it is hoped that Requirements in this Technical Report are sufficiently complete and self-consistent that operators and suppliers can extend them in a straightforward manner to ODNs and OLM scenarios beyond those described herein.

A.1 Link-Monitoring Use Case

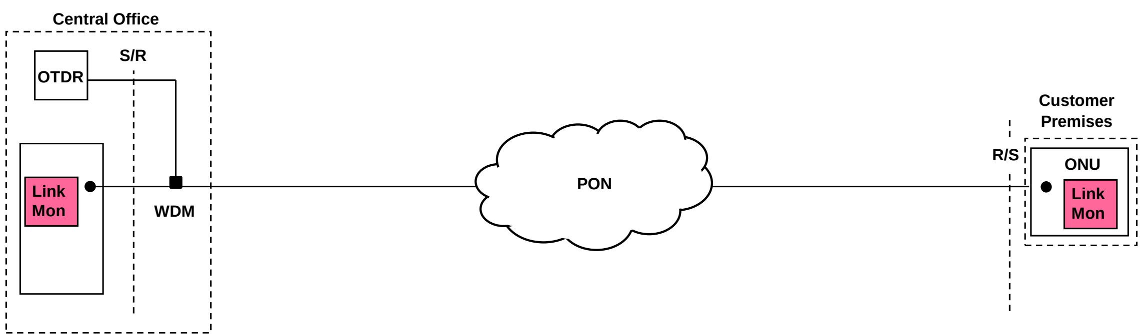

Figure 7 – Application of link-monitoring functions for PON optical-layer management.

In many PON systems, the optical transceivers in the OLTs and ONUs support digital Diagnostic Monitoring Interfaces (DMI) based on SFF-8472 [6] or INF-8077i [7]. This functionality, illustrated in Figure 7, allows operators to monitor various optical-layer parameters, including the operating temperature of the optical module, supply voltage, bias current, transmitted power, received power, etc.

In a PON system with DMI capabilities the OLT retrieves each ONU's optical transceiver status via OAM/OMCI, either periodically or in response to some event, such as an alarm. By comparing the OLT’s local DMI values with the ONU reported DMI values (e.g., the OLT's transmitted optical power with ONU's received optical power), the OLT can determine the optical-link status. Optical-link performance evolution can be determined by comparing current DMI readings with historical data, thus allowing the detection of component degradation, ODN impairments, etc. Finally, when a transceiver parameter exceeds a provisioned threshold, the system can be configured to generate an alarm or warning. ONU alarms and warnings are carried via OAM/OMCI.

A.2 Trunk-Fiber Fault Location

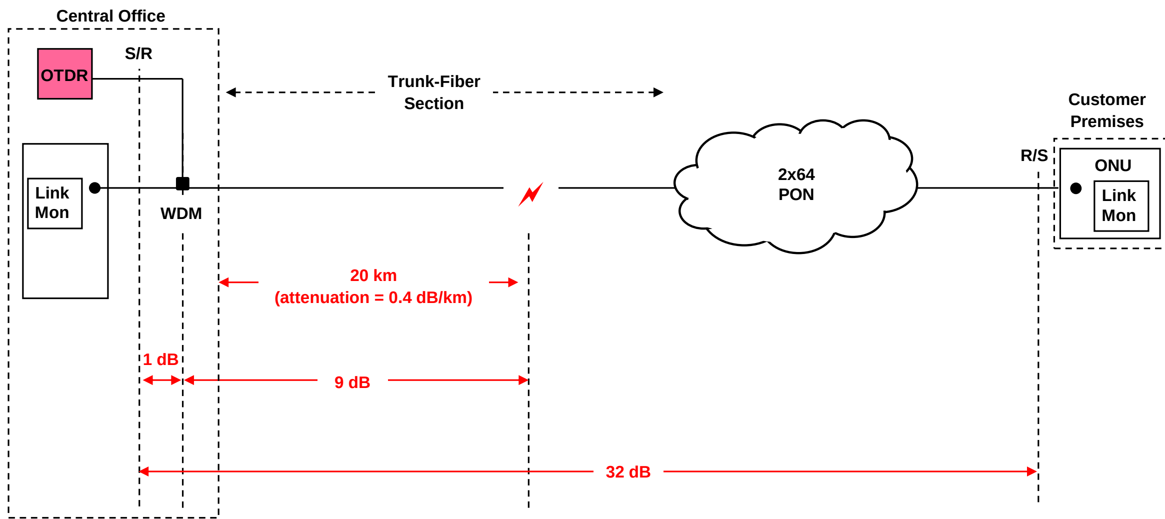

Figure 8 – Use of OTDR to locate a trunk-fiber impairment.

In PON systems equipped with OTDR functionality, remote detection of some classes of trunk-fiber impairment is possible. For illustrative purposes, example values are shown in Figure 8 for the split ratio, total one-way attenuation budget, fiber-attenuation coefficient, distance between the OTDR function and the impairment, and WDM attenuation. In real networks other values for these parameters are possible.

OTDR, regardless of its implementation details, can provide excellent diagnostic capabilities for the trunk-fiber section of the ODN for a wide range of PON deployments.

A.3 Distribution-Fiber Fault Location

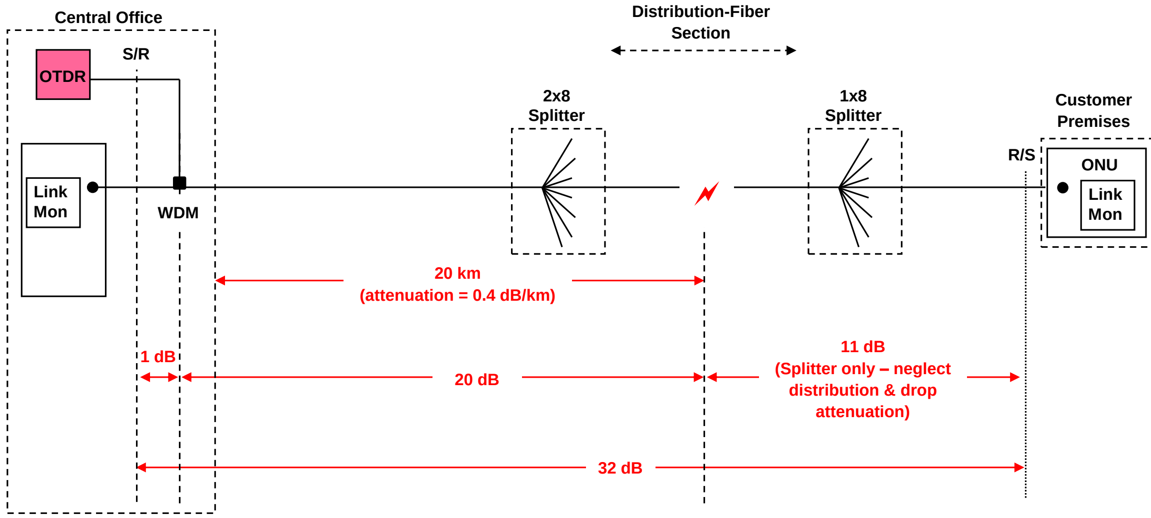

Figure 9 – Use of OTDR to locate a distribution-fiber impairment.

In PON systems equipped with OTDR functionality, remote detection of some classes of distribution-fiber impairment is possible. For illustrative purposes, example values are shown in Figure 9 for the split ratio, total one-way attenuation budget, fiber-attenuation coefficient, distance between the OTDR function and the impairment, splitter attenuation, and WDM attenuation. In real networks other values for these parameters are possible.

External and chassis-based OTDR can provide useful diagnostic capabilities for the distribution-fiber section of the ODN for a wide range of PON deployments. The utility of OTDR for this scenario typically depends on the split-ratio of the primary splitter, which usually represents a large component of the attenuation between the OTDR function and the fiber impairment.

A.4 Drop-Fiber Fault Location

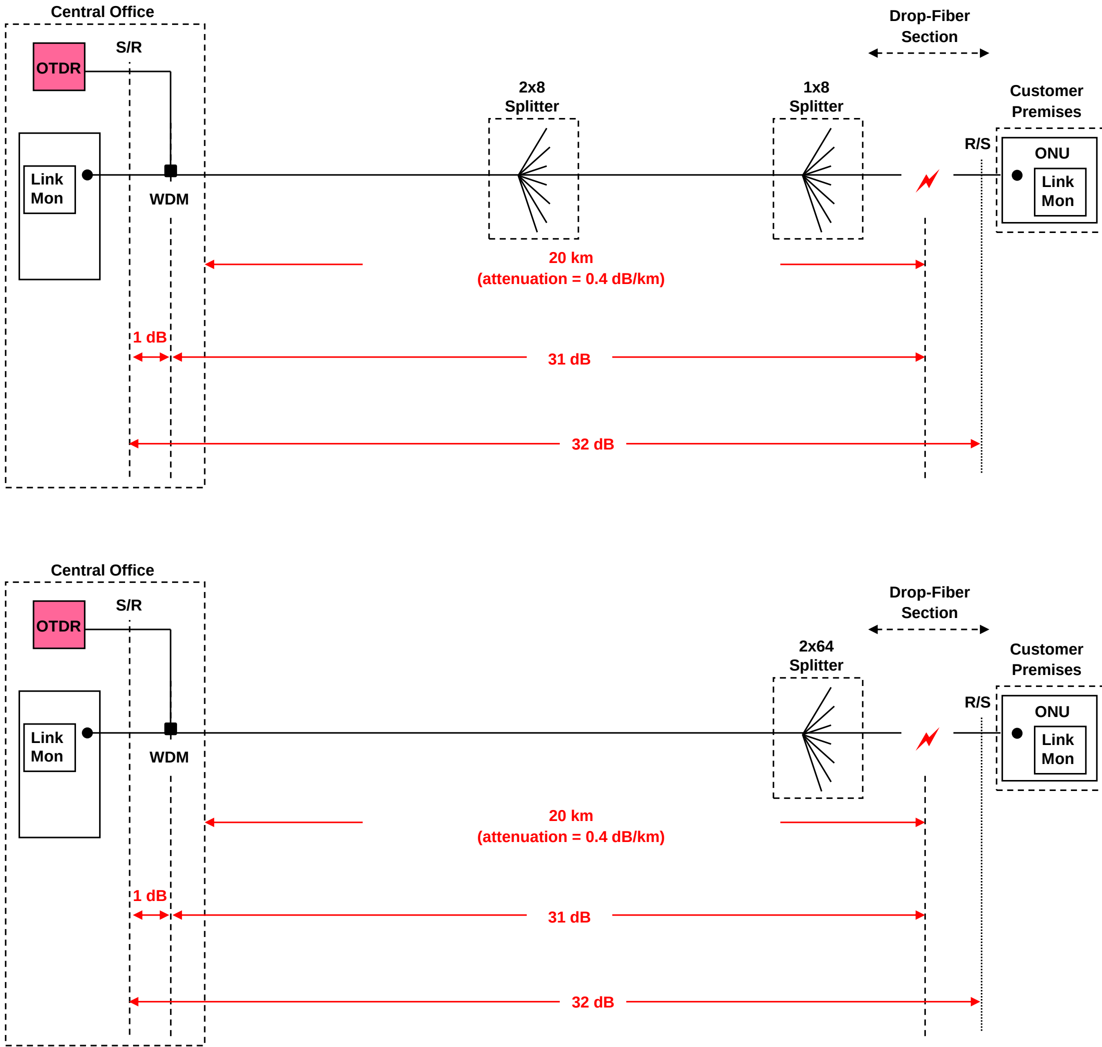

Figure 10 – Use of OTDR to locate a drop-fiber impairment.

In PON systems equipped with OTDR functionality, at the time of publication remote detection of drop-fiber impairment typically is not possible in commercial networks with high split ratios [13]. For illustrative purposes, example values are shown in Figure 10 for the split ratio, total one-way attenuation budget, fiber-attenuation coefficient, distance between the OTDR function and the impairment, splitter attenuation, and WDM attenuation of two common ODN architectures. In real networks other values for these parameters are possible.

OTDR, regardless of its implementation details, at the time of publication typically cannot provide useful diagnostic capabilities for the drop-fiber section of the ODN for PON deployments with attenuations between the OTDR function and the fiber impairment comparable to those of the examples shown in Figure 10.

Appendix B: Overview of Optical Time Domain Reflectrometry

B.1 Physics of OTDR

The principles of OTDR operation are similar to those of radar and sonar. In its most common form, a specialized instrument launches a pulse of light into one end of the fiber plant under test. Subsequent reflections from refractive-index discontinuities are detected and recorded as a function of time, thus producing a plot of optical-event intensity versus distance (reflectogram). Reflections arise from a variety of sources, both macroscopic and microscopic. Common macroscopic sources include connectors, splices, and fiber-cuts. On the microscopic scale, Rayleigh scattering from atomic-scale inhomogeneities in the fiber accounts for the principal component of the background signal. Figure 11 depicts the basic OTDR process for a point-to-point link (top) and the resulting reflectogram showing the locations of the various reflection events as a function of round-trip time (distance). OTDR is a well-established and valuable tool for a wide variety of point-to-point links, and is used both during construction and for fault isolation in commissioned systems.

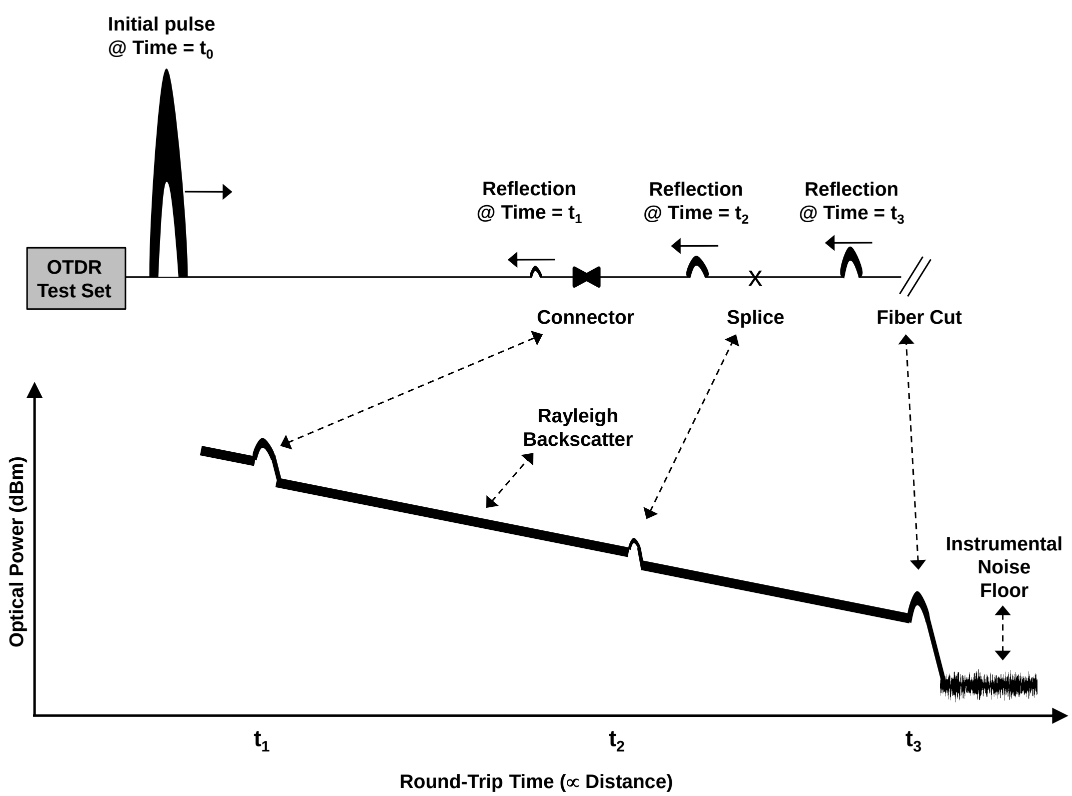

Figure 11 – OTDR characterization of a point-to-point link.

OTDR characterization of a PON ODN is much more challenging for two reasons. First, the presence of one or more power splitters results in reflection amplitudes that are much lower than those typical of point-to-point networks, and because of this it is not possible in most cases to use OTDR to probe the portion of the ODN near the customer [13]. Second, independent reflectors on two or more splitter legs can be at the same optical distance from the OLT, hence the reflected signals will arrive at the OTDR test-set simultaneously, thus making unambiguous interpretation of the reflectogram impossible. Figure 12 depicts the scenario for OTDR characterization of an idealized 1x64 PON ODN without ONUs (top) and the resulting reflectogram showing the locations of the various reflection events as a function of round-trip time (distance). In this ideal case all of the distribution-sections have sufficiently unique lengths (i.e., the length differences exceed the minimum resolution limit of the instrument), as do all of the drop fibers, hence each of the reflection events is distinguishable. In the non-ideal case, multiple reflectors share one or more common optical distances and the resulting reflectogram typically is much more complex.

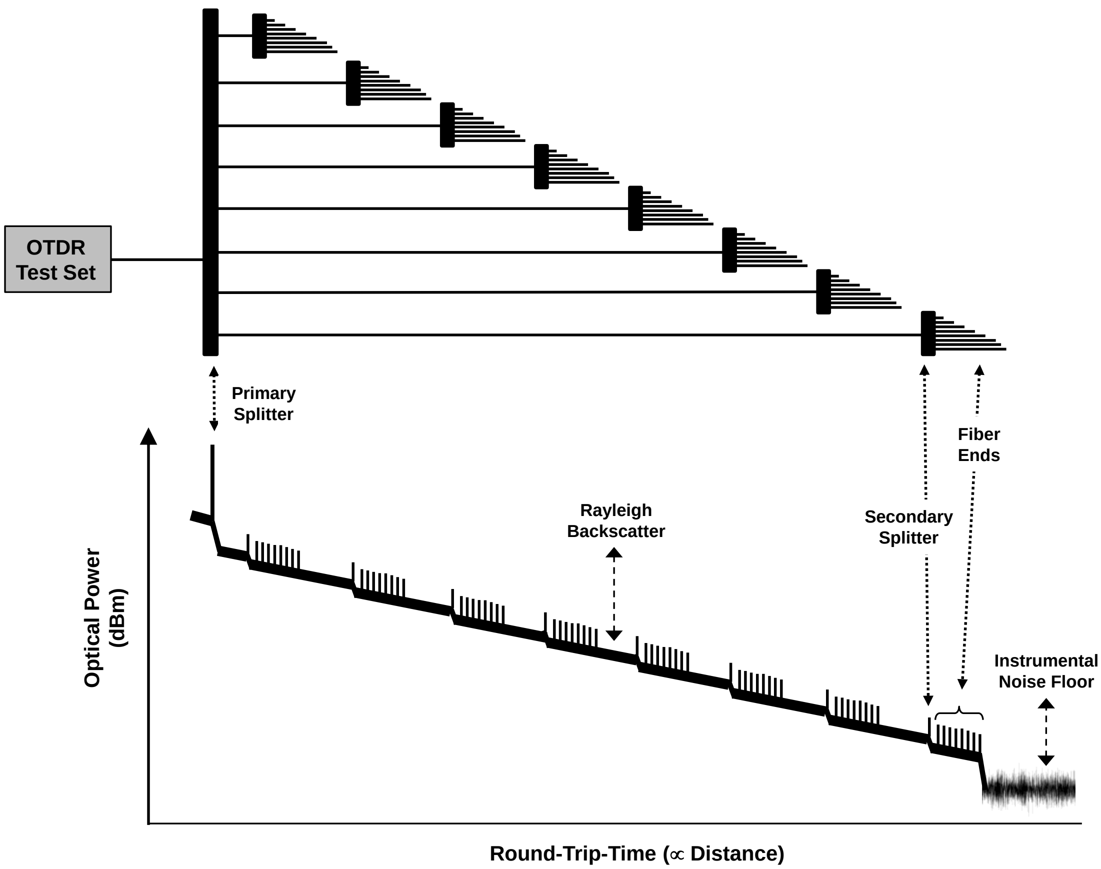

Figure 12 – OTDR characterization of a 1x64 PON.

Because the optical power of a single reflection typically is small compared to the noise environment, commercial OTDR instruments rely on signal averaging to produce useful results. It is not uncommon that tens of thousands of individual reflectograms must be averaged, which for a 20 km fiber span results in a measurement time of several minutes. Some instruments employ additional signal processing techniques to improve performance, including the use of advanced modulation schemes. The requirements in TR-287 do not specify the details of OTDR implementation and are intended to apply to all solutions.

B.2 Fiber Fault Detection

Most fiber faults of interest in access ODNs can be classified as either reflection events or attenuation events. As described in this Section, the characteristic signatures of these two classes of events are quite different, thus leading to separate modeling and detection criteria. The issues discussed below were taken into consideration during the development of the requirements of TR-287.

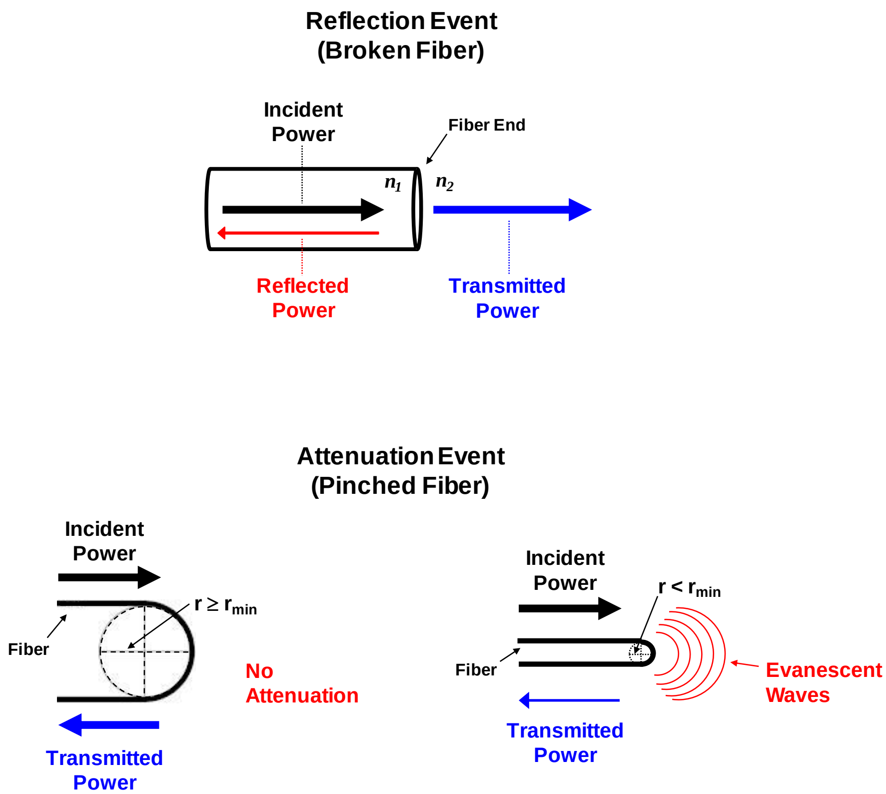

Figure 13 – Example ODN impairments.

Reflection Events

A reflection event is caused by a step change in the index of refraction *n* at a specific point in the ODN. This phenomenon is called Fresnel reflection and is illustrated in the top panel of Figure 13. Common sources of Fresnel reflection include connectors, splices, and fiber breaks. The optical performance of connectors and splices typically are of most interest during acceptance testing of a newly built or modified ODN. Fiber breaks, which have many causes and result in the loss of service to one or more customers, usually are of most interest in operating networks.

The top panel of Figure 14 shows an idealized representation of an OTDR measurement of an ODN with a broken, out-of-service fiber. The reflected signal of the break appears as a sharp peak rising out of the noise / background floor, and to be detectable, the reflected signal must rise a specified minimum distance (the "detection threshold") above the floor. The noise component of the floor typically is due to instrumental noise, and in PON ODNs Rayleigh backscattering from adjacent distribution fibers often contributes to the background signal.

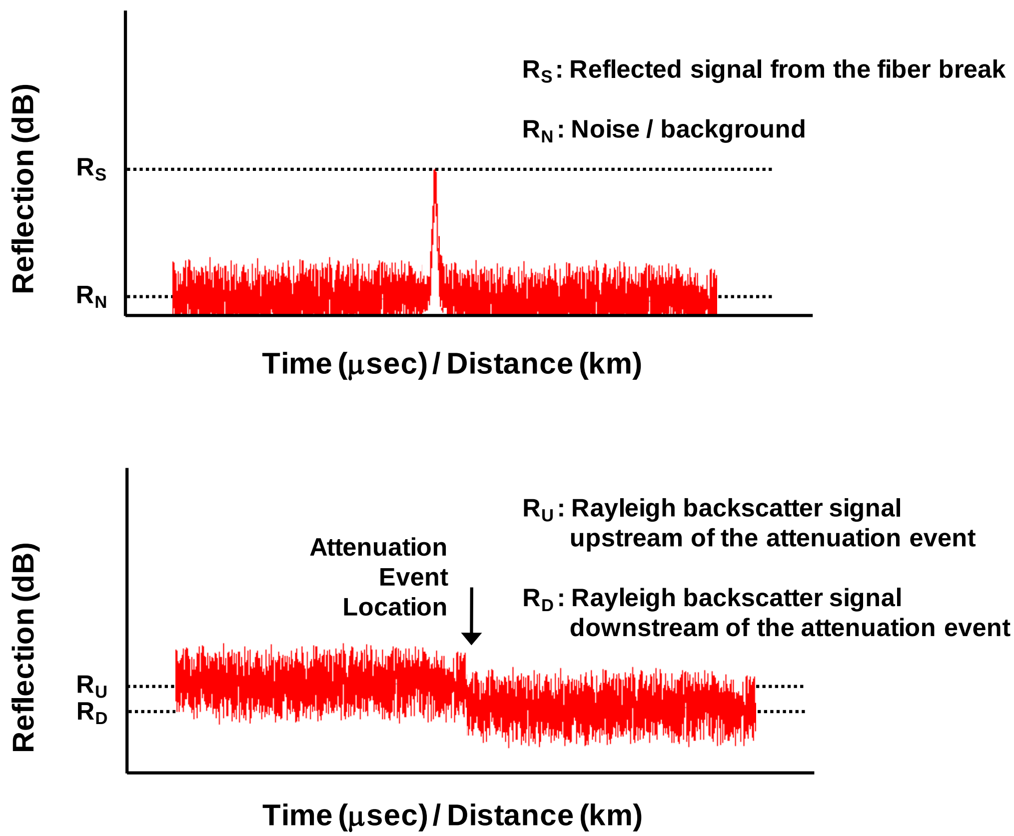

Figure 14 – Detection criteria for fiber faults.

The reflective power of a fiber break depends very sensitively on the physical details of the break and the wide variety of broken-fiber morphologies occurring in real networks results in an extensive range of reflected signal strengths. Figure 15 shows the results of laboratory OTDR measurements of a large sample of broken fibers. For comparison, the reflective power of an unconnected, polished fiber end (UPC connector) also is shown.

Realistic received-power signals for broken and unconnected fibers can vary by more than 45 dB (15 dB to 60 dB), which on a linear power scale corresponds to a difference of nearly 32,000 between the strongest and weakest signals. Consequently, it is not possible to design a cost-effective OTDR capable of detecting all cases and instead detection criteria must be stated in terms of probabilities. For example, an OTDR capable of detecting all reflection events with a received power of 41 dB (60 dB) or greater is capable of detecting at least 50% (95%) of all fiber breaks that obey the distribution shown in Figure 15.

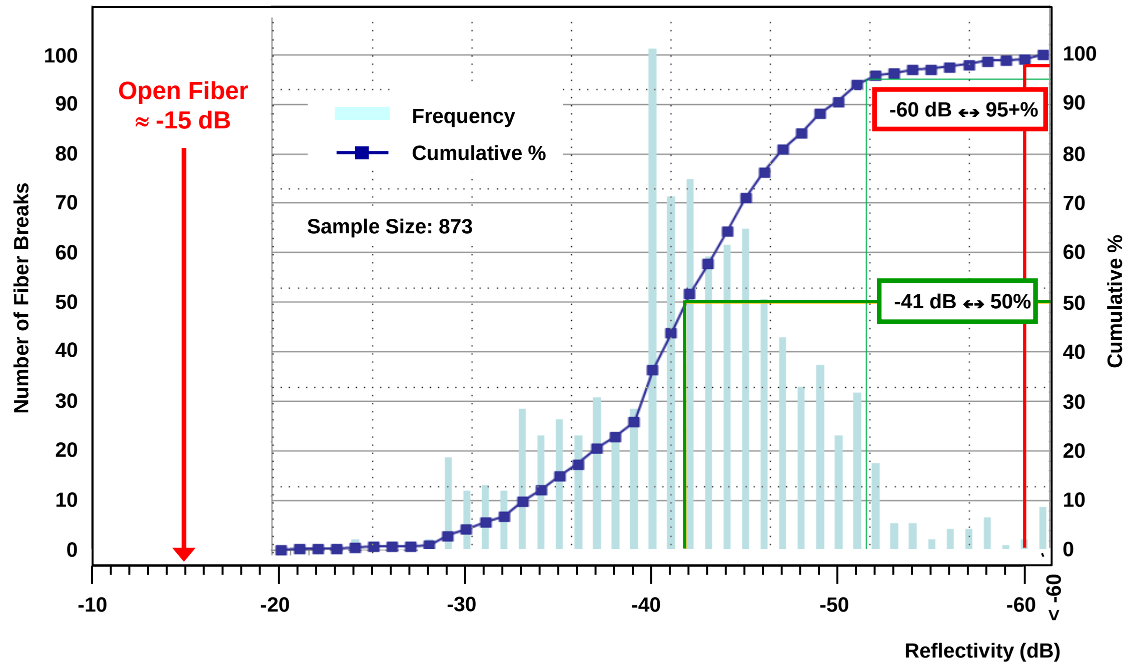

Figure 15 – Statistical distribution of fiber-break optical-return-loss values (adapted from [12], used with permission).

Attenuation Events

An attenuation event typically is caused by pinching or bending a fiber beyond the minimum bend radius specified by the manufacturer (Figure 13, bottom). When the fiber bend-radius is reduced below the minimum bend-radius, the wave-guide properties of the fiber are compromised and energy is lost through a near-field effect known as evanescent-wave coupling.
Attenuation events typically are detected by examining an OTDR trace for evidence of a localized change in the Rayleigh backscattering signal of the ODN. The bottom panel of Figure 14 shows an idealized representation of an OTDR measurement of an ODN with an attenuation event. To be detectable, an attenuation event must be large enough that the difference between the Rayleigh backscattering signals upstream and downstream of the event (marked $\mathbf{R_U}$ and $\mathbf{R_D}$, respectively, in the bottom panel of Figure 14) is greater than some specified minimum detection threshold.

Further complicating the attenuation-event detection problem in PONs is the parallel-path effect (Figure 16), wherein the signal from an event on one splitter leg is obscured, either partially or wholly, by the Rayleigh scattering signals from adjacent splitter legs. Although parallel path effects can be significant for any class of impairment-detection problem, they are especially important in the detection of attenuation events.

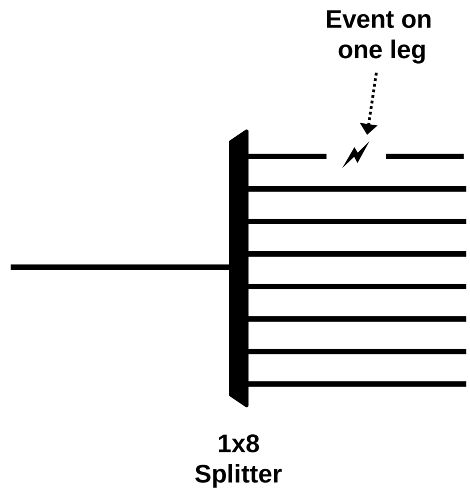

Figure 16 – Parallel-path effect.

Appendix C: Management Parameters, Commands, and Reports

C.1 A Interface

The **A** Interface is a north-bound interface between the OTDS and the OSS. The OSS sends test initiation to the OTDS and gets the test result report from the OTDS via the **A** interface. The OTDS may retrieve ODN topology data and ODN reference data from the OSS via the **A** interface. Furthermore, via the **A** interface the OTDS is capable of reporting to the OSS the degradation of optical-link quality. The file format for communication on the **A** interface is specified in SR-4731[9].

C.2 B Interface

The **B** Interface is an interface between the OTDS and the link-monitoring management function. Via the **B** interface, the OTDS retrieves OLT/ONU information including but not limited to, SFF 8472-based optical-layer parameters, OLT alarms, ONU alarms, and BIP/FEC errors from the link-monitoring management function (Table 9). The link-monitoring management function may report OLT/ONU alarms actively to the OTDS via the **B** interface.

Actions	Initiated by	Data elements	Responses
Get link monitoring information	OTDS	OLT ID, PON port ID, ONU-ID, Associated parameter index	Specified link monitoring results
Report alarms	Link-monitoring management	Relevant information (OLT ID, PON port ID, ONU-ID, types, parameters of alarms, etc.)	--

Table 9 – Parameters, commands, and results for Interface **B**.

C.3 C Interface

The **C** interface is an interface between the link-monitoring management function and the link-monitoring function. Via the **C** interface, the link-monitoring management function sets link monitoring parameters, and retrieves OLT/ONU information including but not limited to, SFF 8472-based optical-layer parameters, OLT alarms, ONU alarms, and BIP/FEC errors from the link-monitoring function (Table 10). The link-monitoring function may report OLT/ONU alarms actively to the link-monitoring management function via the **C** interface.

Actions	Initiated by	Data elements	Responses
Get link monitoring information	Link-monitoring management	OLT ID, PON port ID, ONU-ID, Associated parameter index	Specified link monitoring results
Set link monitoring parameter	Link-monitoring management	Specific parameter index, Associated value	Execution result
Report alarms	Link-monitoring	Relevant information (OLT ID, PON port ID, ONU-ID, types, parameters of alarms, etc.)	--

Table 10 – Parameters, commands, and results for Interface **C**.

C.4 H Interface

The **H** interface is a physical interface, connecting the combiner/WDM and the optical switch.

C.5 I Interface

The **I** interface is an interface between the OTDR controller and the OTDR function. Via the **I** interface, the OTDR controller configures the OTDR function and controls it to perform the test and report the test results (Table 11). Furthermore the OTDR controller may retrieve the OTDR function capability from the OTDR function via the **I** interface. The OTDR function may report its alarms actively to the OTDR controller via the **I** interface.

In the Chassis-based OTDR architecture, the OTDR controller controls the optical switch to send relevant information, to report its alarms actively, and to select the ODN to be placed under test through the OTDR function via the **I** interface.

At present there is no standard that defines a file format for the exchange of data on the **I** interface. The BBF believes that such a standard would benefit the industry and encourages its development by the appropriate SDO or other external group.

Actions	Initiated by	Data elements	Responses
Get OTDR function capability	OTDR Controller	OTDR ID	Functional capability
Configure OTDR function	OTDR Controller	OTDR ID, Configuration parameters	Configuration results
Get Optical Switch information (only applicable in chassis-based OTDR)	OTDR Controller	Optical Switch ID	Relevant information (configuration, status, alarms)
Configure Optical Switch (only applicable in chassis-based OTDR)	OTDR Controller	Optical Switch ID, Configuration parameters	Configuration results
Adjust Optical Switch (only applicable in chassis-based OTDR)	OTDR Controller	Optical Switch ID, PON port ID	Adjustment results
Start OTDR Test	OTDR Controller	PON port ID, OTDR ID ,	Start OTDR Test
Report alarms	OTDR Function / OTDR Controller	Relevant information regarding OTDR Function or Optical Switch (OTDR ID, Optical Switch ID, types, parameters of alarms, etc.)	--
Report OTDR Test Results	OTDR Function / OTDR Controller	OTDR Test Results	--

Table 11 – Parameters, commands, and results for Interface **I**.

C.6 J Interface

The **J** interface is an interface between the OTDR controller and the optical switch. Via the **J** interface, the OTDR Controller is capable of controlling the optical switch to select the ODN to be placed under test. Furthermore, the OTDR controller may retrieve the optical switch information and configure the optical switch via the **J** interface (Table 12).

Actions	Initiated by	Data elements	Responses
Get Optical Switch information	OTDR Controller	Optical Switch ID	Information of the specific optical switch (configuration, status, alarms)
Configure Optical Switch	OTDR Controller	Optical Switch ID, configuration parameters	Configuration results
Adjust Optical Switch	OTDR Controller	Optical Switch ID, PON port ID	Adjustment results
Report alarms	Optical Switch	Relevant information (Optical Switch ID, types, parameters of alarms, etc.)	--

Table 12 – Parameters, commands, and results for Interface **J**.

C.7 K Interface

The **K** interface is a physical interface, connecting the optical switch and the OTDR function.

C.8 L Interface

The **L** interface is an interface between the OTDS and the OTDR Controller. Via the **L** interface, the OTDR controller is capable of receiving test commands from the OTDS and reporting test results to the OTDS accordingly (Table 13). Furthermore the OTDS may retrieve the OTDR function capability from the OTDR controller via the **L** interface.

Actions	Initiated by	Data elements	Responses
Get OTDR function capability	OTDS / OTDR Controller	OTDR ID	Capability of the specific OTDR function
Start OTDR Test	OTDS / OTDR Controller	PON port ID, OTDR ID, Parameter set of OTDR test	OTDR test results, OTDR events identification
Provides Test Parameters to OTDR Controller.	OTDS / OTDR Controller	Test Parameters	Acknowledgement
Report OTDR Test Results	OTDS / OTDR Controller	OTDR Test Results	Test results

Table 13 – Parameters, commands, and results for Interface **L**.

C.9 M Interface

The **M** interface is an interface connecting the combiner/WDM and the ODN, for transmitting downstream PON signal and OTDR test signal to the ODN, and receiving upstream PON signal and reflected OTDR test signal from the ODN.

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