XENA NETWORKS

WHITE PAPER

GPON TESTING

OVERVIEW

ITU-T has defined the Gigabit-capable Passive Optical Network (GPON) to support digital communication to end customers at rates up to 2.4 Gbps downstream and 1.2 Gbps (optionally 2.4 Gbps) upstream.

A GPON requires active transmission equipment at its borders, and this equipment will of course need to be tested. Verifying the interoperability and conformance of the equipment is essential.

The Broadband Forum has defined the TR-255 GPON Interoperability Test Plan and the TR-247/ATP-247 Abstract Test Plan for GPON ONU Conformance (the ONU - Optical Network Unit - is the GPON transmission equipment closest to the customer premises).

The Xena Odin-1G-3S-6P 6-port 1Gbps test module provides powerful testing capabilities for testing and verifying GPON transmission equipment including mandatory interoperability and conformance test cases in accordance with TR-255 and TR-247/ATP-247.

The ValkyrieBay or ValkyrieCompact chassis equipped with Xena Odin-1G-3S-6P gives the user an easy to use, efficient test solution, which is able to handle complex scenarios without breaking the budget.

“Test of GPON transmission equipment, including verification of interoperability and conformance, is required to ensure the quality and proper functioning.”

GPON TESTING

Contents

WHITE PAPER

INTRODUCTION

Communication services have evolved dramatically over the last couple of decades. For many years residential customers used telephony as their only communication service, but many more services are now available. The telecom operators that provide the analog telephony (POTS – Plain Old Telephone Service) also wanted to provide access to the new communication services to their customers. DSL (Digital Subscriber Line) technology used in the access network between the telephone exchange and the customer premises was sufficient in some cases, but the reach of the DSL solutions could be a limitation.

Fiber optics has been used for many years in long distance communication. From that access network solutions based on fiber optics were developed allowing very high speed connections to the end customers. However installing new optical fibers to every customer would be quite costly, so various FTTx (Fiber To The "something") solutions have been invented. FTTx provides a fiber optic network to a point close to a group of customers and then use existing copper local loops the rest of the way. Even in cases where the fibers go all the way to the end customers optical signals are typically brought to position close to a group of customers and from there split to each individual customer. Such systems are normally implemented as Passive Optical Networks (PON) meaning that there are no active components (like amplifiers and repeaters) between the end points of the optical network but only passive components like splitters and combiners. This simplifies the network and maintenance of it significantly but at the same time limits the reach of a PON to approx. 20 km – an active optical network (AON) will typically have a reach up to 100 km. The split of a fiber in a PON is typically 1:32 or 1:64 (i.e. each PON can serve up to 32 or 64 customers). Some systems support splits up to 1:128.

ITU-T has defined a PON technology: the Gigabit-capable Passive Optical Network (GPON) to support digital communication to end customers at rates up to 2.4 Gbps downstream (from network to customer) and 1.2 Gbps (optionally 2.4 Gbps) upstream (from customer to network). GPON is designed to support a number of communication services and applications targeting private and business customers. The services and applications include digital broadcast services, Video On Demand (VOD), file download, e-mail, file exchange, distance learning, telemedicine, online-gaming, POTS, ISDN etc.

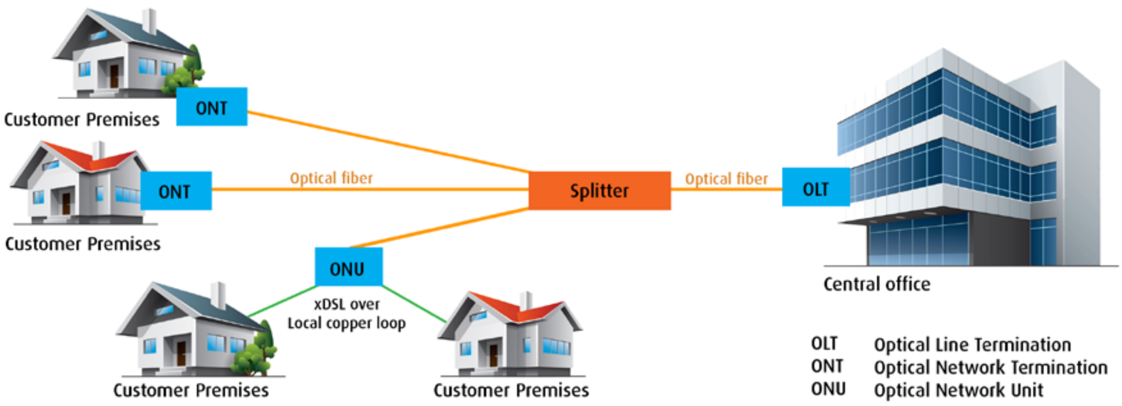


Figure 1: GPON network terminated with OLT and ONT/ONU

Figure 1 shows the main components of a GPON network. The passive component in the GPON – the optical splitter – is actually bi-directional: It divides the downstream signal from the OLT to the ONUs/ONTs and combines the upstream signals from the ONUs/ONTs into one signal, which is sent to the OLT. The splitter is therefore sometimes called a splitter/coupler. As there are no amplifiers inside the optical part of the network a GPON with N ONUs/ONTs will ideally send 1/Nth of the optical power from the OLT to each ONU/ONT – in reality they will receive less than that due to loss in the splitter and the optical fibers. As there has to be sufficient signal for the ONU/ONT to detect the signals this limits the number of ONUs/ONTs in the GPON as well as the reach of the GPON.

The PON and GPON market will grow in the coming years driven by the increasing number of internet based applications used by private and small business internet customers and the wide spread use of smart phones. In a market research report Radiant Insights estimates the PON market to grow at a CAGR of 3.6% until 2018 with GPON having a larger market share and growth than another PON technology – the Ethernet Passive Optical Network (EPON). In another report Global Industry Analysts projects the global GPON market to reach US$10.5 billion by 2020 with Asia Pacific being the largest market.

GPON STANDARDIZATION

Work on fiber to the home architectures began 1995 in the Full Service Access Network (FSAN) working group, formed by major telecom service providers and vendors. ITU-T did further work on the topic and GPON is now standardized by the ITU-T Study Group 15 in the G.984 series of recommendations:

	Title *	First approved	Current version
G.984.1	General characteristics	March 2003	March 2008
G.984.2	Physical Media Dependent (PMD) layer specification	March 2003	No updates
G.984.3	Transmission convergence layer specification	February 2004	January 2014
G.984.4	ONT management and control interface specification	June 2004	February 2008
G.984.5	Enhancement band	September 2007	May 2014
G.984.6	Reach extension	March 2008	No updates
G.984.7	Long reach	July 2010	October 2012

Table 1: G.984 series of recommendations

* All titles also include the text "Gigabit-capable passive optical networks (GPON)"

In addition to the updates shown in table 1 amendments and corrigenda have been issued for some of the recommendations in the G.984 series.

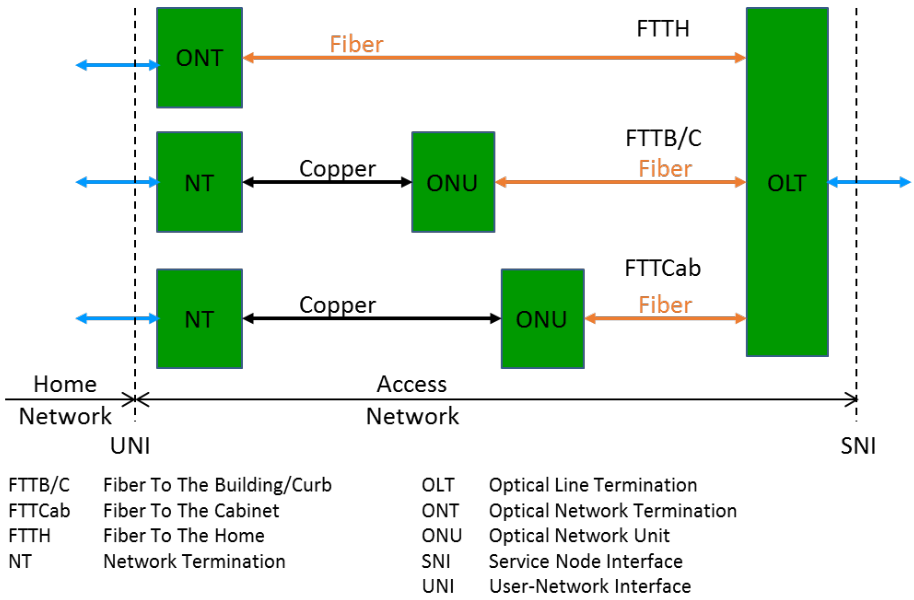


Figure 2: Network architecture defined in G.984.1

G.984.1 defines the network architecture shown in figure 2. The optical fiber section of the access network system can be point-to-point or point-to-multipoint. The copper part of the access network is outside the scope of the G.984 series; it will typically be a DSL (Digital Subscriber Line) solution.

A split ratio up to 1:64 is considered to be realistic according to G.984.1. Future technology may allow a split ratio up to 1:128.

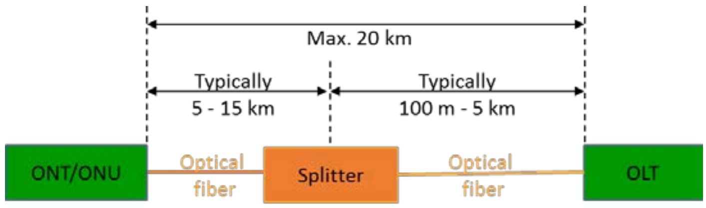


Figure 3: Distances in a GPON network

GPON can be sent as optical signals in 2 ways:

- Over a single bidirectional fiber – in this case GPON use Wavelength Division Multiplexing (WDM) with 1490 nm wavelength for downstream traffic and 1310 nm wavelength for upstream traffic
- Over two unidirectional fibers. Both downstream and upstream traffic use 1310 nm wavelength

G.984.2 lists the possible GPON downstream/upstream speed combinations (see table 2). 2488.32 Mbps downstream and 1244.16 Mbps upstream is most important; this combination is used in the vast majority of existing and planned GPON systems.

Downstream	Upstream
1244.16 Mbps	155.52 Mbps
1244.16 Mbps	622.08 Mbps
1244.16 Mbps	1244.16 Mbps
2488.32 Mbps	155.52 Mbps
2488.32 Mbps	622.08 Mbps
2488.32 Mbps	**1244.16 Mbps**
2488.32 Mbps	2488.32 Mbps

Table 2: GPON speeds

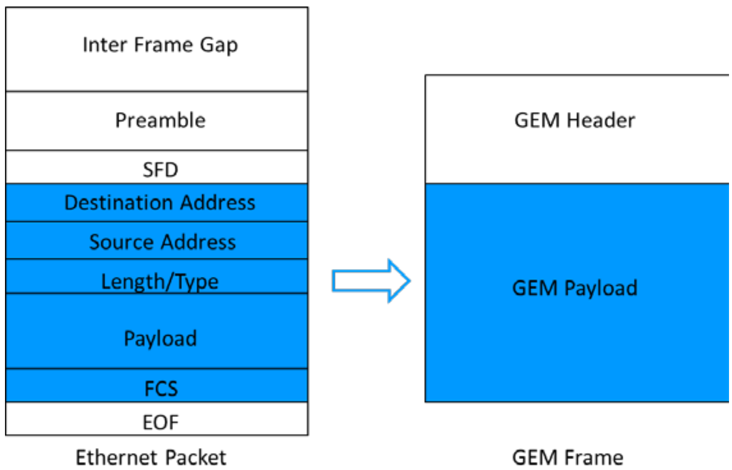
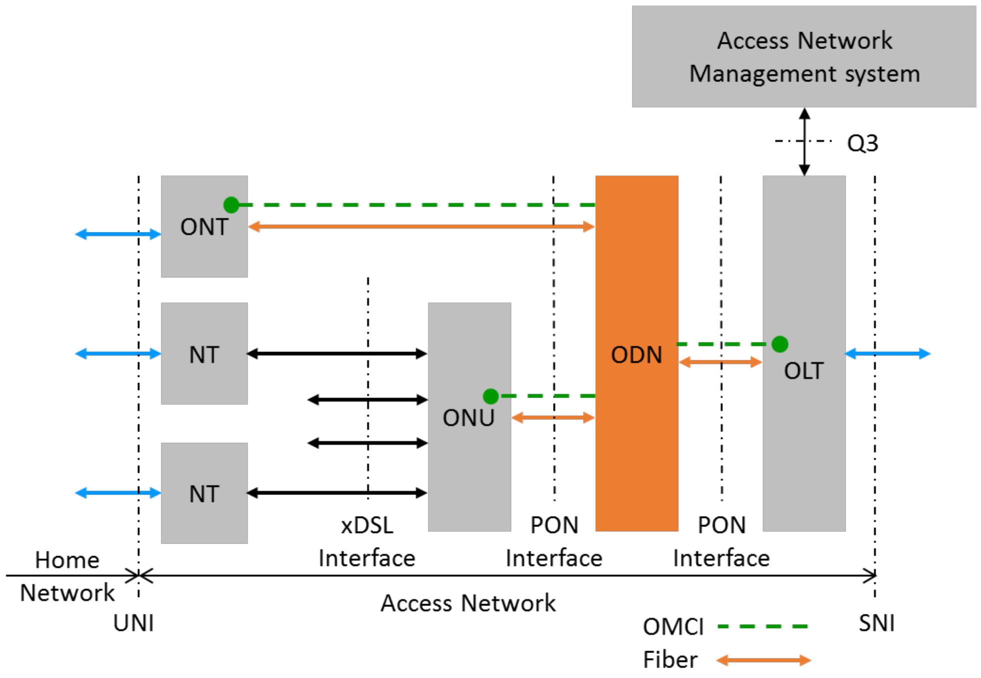


Figure 4: Mapping Ethernet traffic into GEM Frames

G.984.3 defines the GPON Transmission Convergence (TC) layer including the GPON TC (GTC) frame format. The GTC frames carry traffic between OLT and ONUs/ONTs. The end-user traffic is encapsulated in GEM (GPON Encapsulation Method) frames, which are carried over the GTC protocol transparently. In addition G.984.3 defines how to map various types of user traffic

(Ethernet, IP, MPLS, SDH and TDM) into GEM frames. Figure 4 shows how Ethernet traffic is mapped into GEM frames and that the Ethernet overhead is removed by the GEM encapsulation. Downstream data are sent as broadcast (i.e. to all users on the GPON). The Advanced Encryption Standard (AES) ensures that data is only accessible for the intended recipient on the GPON as each ONT/ONU gets a unique encryption key. For upstream data Time Division Multiple Access (TDMA) is used: Data from the users are divided into different time slots. Dynamic Bandwidth Allocation (DBA) ensures that the users get the bandwidth they currently need. DBA is managed by the OLT, which allocate bandwidth to the users.

G.984.3 also describes Forward Error Correction (FEC), which optionally can be used in the GPON system to increase the reach of the system or increase the number of ONUs/ONTs in the GPON.



DSL	Digital Subscriber Line	ONT	Optical Network Termination
ODN	Optical Distribution Network	ONU	Optical Network Unit
NT	Network Termination	PON	Passive Optical Network
OLT	Optical Line Termination	SNI	Service Node Interface
OMCI	ONT Management and Control Interface	UNI	User-Network Interface

Figure 5: G.984.4 reference model showing the path for OMCI signals between OLT and ONT/ONU

G.984.4 specifies the ONT Management and Control Interface (OMCI) for GPON systems to enable multivendor interoperability between the OLT and the ONT. G.984.4 defines the exchange of information between the OLT and the ONT and the ONT management and control channel, protocol and detailed messages needed to manage the ONT in the following areas:

- Configuration management
- Fault management
- Performance management
- Security management

The ONT management and control protocol packets are encapsulated directly in GEM packets. The OMCI allows an Access Network Management system that interfaces to the OLT to manage both the OLT and the ONTs/ONUs in the GPON system.

VLAN AND IGMP

A GPON system can use several standard Ethernet functions to convey information to and from the end customers. Virtual Local Area Network (VLAN) tagging can be used to group traffic flows in different VLANs distinguished by their VLAN ID (VID) and to separate customer connected to an ONU in the GPON network. The 3 priority bits of the VLAN tag allow marking of the traffic's Class of Service (CoS). This can be used to ensure sufficient Quality of Service (QoS) for traffic types to/from the customers (e.g. video, voice and data) through the GPON, which has a number of logical channels supporting different QoS. VLAN is defined in IEEE 802.1q and enhanced in 802.1ad. The Broadband Forum document TR-156 "Using GPON Access in the context of TR-101" defines 3 VLAN profiles to be used for GPON: 1:1, N:1 and VBES (VLAN Business Ethernet Service). These profiles involve single tagging and double tagging ("QinQ") and require the ONUs/ONTs/OLTs to add or change VLAN tags in some cases. Therefore the ONUs/ONTs and the OLTs must be able to process and manipulate the VLAN tags.

The Internet Group Management Protocol (IGMP) supports one-to-many communication and is used in GPON systems to send identical information like broadcast of entertainment video to many end customers connected to the GPON system. The Internet Engineering Task Force (IETF) has defined 3 versions of IGMP in Request For Comments (RFC) documents. IGMPv1 is defined in RFC 1112. IGMPv2 defined in RFC 2236 is an improved version; IGMPv3 provides further improvements and is defined in RFC 3376 and RFC 4604. IGMP is used in IPv4 networks. In IPv6 networks multicast management is handled by the Multicast Listener Discovery (MLD).

OTHER PON SYSTEMS

GPON is not the only system defined for PON access networks. Prior to GPON ITU-T defined APON/BPON (ATM PON/Broadband PON) in the G.983 series of recommendations. APON/BPON is based on the Asynchronous Transfer Mode (ATM). APON/BPON typically provides 622 Mbps downstream and 155 Mbps upstream data capacity.

After GPON ITU-T has defined PON systems supporting data rates higher than 2.4 Gbps:

- XG-PON (or 10G PON) provides 10 Gbps downstream data capacity and upstream 2.5 Gbps (XG-PON1) or 10 Gbps (XG-PON2). XG-PON2 is also known as XGS-PON (S for Symmetrical). XG-PON is defined in the G.987 series of recommendations. First recommendation in this series was approved in 2010.
- NG-PON2 – a 40 Gbps Time and Wavelength Division Multiplexed Passive Optical Network (TWDM-PON) system defined in the G.989 series of recommendations. First recommendation in this series was approved in 2013. Work is currently going on in ITU study group 15 to extend the bandwidth to 80 Gbps downlink and uplink.

IEEE has also defined PON systems; these systems are based on transmitting Ethernet frames:

- EPON (or GEPON) supporting 1 Gbps downlink and uplink. This was ratified in 2004 as amendment 802.3ah to 802.3.
- 10G EPON supporting 10 Gbps downlink and 1 or 10 Gbps uplink. This was ratified in 2009 as amendment 802.3av to 802.3.
- The P802.3ca 100G-EPON Task Force works on PON systems supporting up to 100 Gbps downlink and uplink. This is expected to be ratified in 2019.

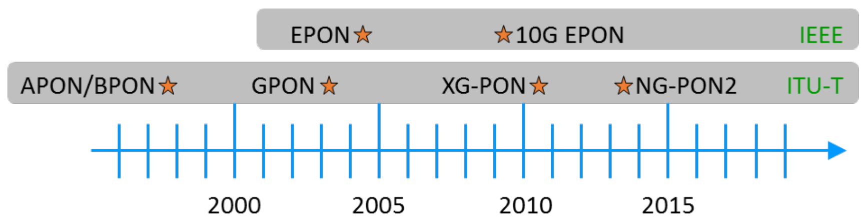


Figure 6: PON system time line (first document approved)

GPON TEST REQUIREMENTS

At the borders of the Optical Distribution Network (ODN) GPON systems include active transmission equipment (OLT and ONU/ONT), which of course will need to be tested. This will be relevant for Development, Quality Assurance and Production at Network Equipment

Manufacturers and GPON equipment manufacturers. Fundamental Ethernet performance testing of an OLT/ONU/ONT includes verification of:

- Throughput – maximum data rate that can be transferred through the DUT
- Latency – time it takes to transfer data through the DUT (also known as Frame Transfer Delay)
- Frame loss – data frames lost during the transfer of data through the DUT
- Back-to-back frames – identifies the longest burst of frames with minimum inter-frame gaps that can be sent through the DUT without frame loss
- Jitter – the variation in delay of transferred data packets (also known as Frame Delay Variation)

Testing is in typically done in accordance with the RFC 2544 Benchmarking Methodology for Network Interconnect Devices, which specifies throughput, latency, frame loss and back-to-back testing. Most Ethernet testers also include jitter testing in their RFC 2544 test suite.

Network Operators' verification/certification labs will also require testing of GPON equipment: As OLTs through the OMCI can control certain functions in the ONU/ONT, interoperability between these devices is essential. This includes interoperability between OLT and ONUs from different vendors, which is very important for the network operators. To verify the interoperability the Broadband Forum has defined the TR-255 GPON Interoperability Test Plan, which was approved February 2013. TR-255 describes 86 test cases covering items like:

- VLAN Manipulation
- Quality of Service Functions
- IGMP Controlled Multicast
- Non-IGMP Controlled Multicast and Broadcast.

Optional test cases cover:

- Security
- Filtering
- Port Identification and Characterization.

These test cases will typically include an Ethernet traffic generator that can provide traffic relevant for the test case. In many cases this includes generation of a number of parallel traffic streams with different characteristics. However, for some test cases an Ethernet traffic generator is not needed. Such test cases cover:

- Initial provisioning of ONU
- ONU bring-up
- Alarms
- Software download

TR-255 defines test setups for the interoperability tests - see figures 7 and 8 (the interfaces to and from the OLT and ONU are named V, S/R, R/S and U as shown in the following figures).

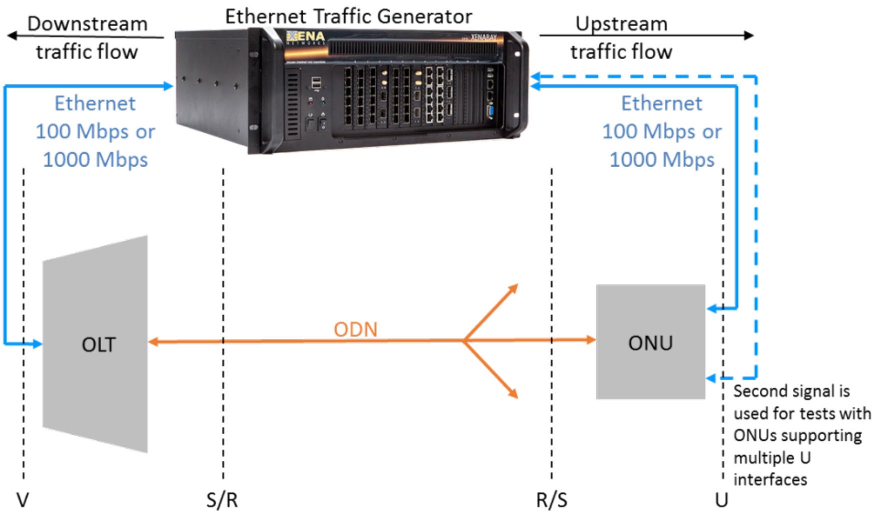


Figure 7: Basic setup for interoperability testing

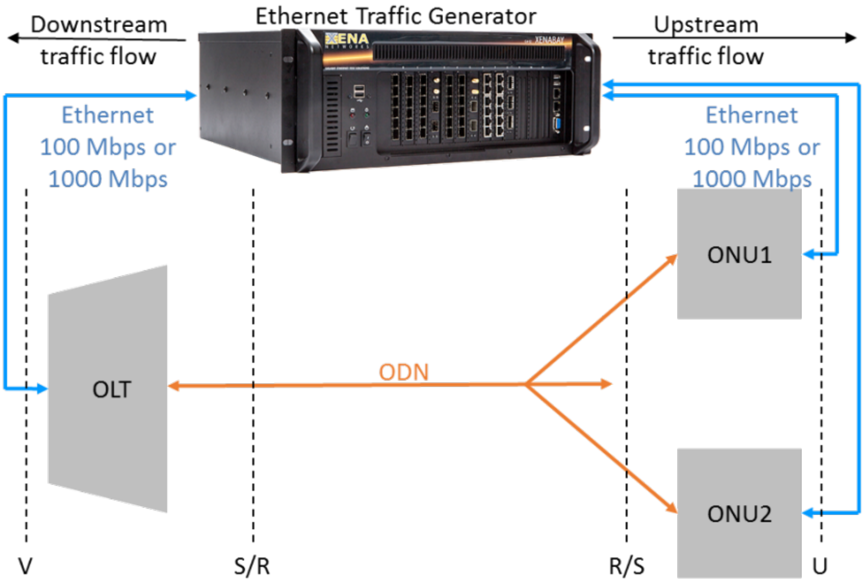


Figure 8: Setup for interoperability tests requiring multiple ONUs

In addition to TR-255 the Broadband Forum has also defined the TR-247/ATP-247 Abstract Test Plan for GPON ONU Conformance. With this the network operators can verify that ONUs/ONTs conform to the GPON standard before they are deployed in the network. ONUs (/ONTs) to be tested with TR-255 must first pass a 247/ATP-247 test. TR-247/ATP-247 was issued in October 2011.

TR-247/ATP-247 defines 95 test cases – some are however reserved for future use! The test cases cover:

- Classification and Tagging
- Frame Mapping and QoS
- IGMP Controlled Multicast
- Non-IGMP Controlled Multicast and Broadcast
- Initial Provisioning of ONU
- ONU Bring-Up
- Management Information Base (MIB) and Alarm Synchronization
- Software Image Download

247/ATP-247 test setups are similar to the TR-255 test setups in figures 7 and 8, however with the OLT substituted by an OLT emulator.

For the IGMP functionality in the GPON system further testing may be required. The IGMP tests in TR-255 and 247/ATP-247 verifies the basic IGMP functions. To verify the IGMP performance, testing in accordance with RFC 3918 "Methodology for IP Multicast Benchmarking" of multicast IP forwarding devices can be conducted. RFC 3918 testing includes:

- Forwarding and throughput: Mixed class throughput, scaled group forwarding matrix and aggregated multicast throughput
- Forwarding Latency: Multicast latency and min/max multicast latency
- Overhead: Group join delay and group leave delay
- Multicast Group capacity
- Interaction: Forwarding burdened multicast latency and forwarding burdened group join delay

GPON EQUIPMENT

GPON equipment is available from several vendors. Available ONUs/ONTs include:

- Adtran: 508VP MDU GPON Outdoor ONU
- Calix/Ericsson: Home Gateway Unit (HGU) ONT T077G; supports 4 GE + 2 POTS + RF + USB + Wi-Fi

- FiberHome: AN5506-04-F GPON Optical Network Unit
- FOT: GONT-420G 4GE+2FXS GPON home gateway unit
- Huawei: SmartAX MA5871; supports 10G GPON/GPON
- Nokia: 7342 ISAM ONT
- ZTE: ZXHN F660; supports 4GE+2POTS+Wi-Fi+1USB Bridge/Router+Voice

The Broadband Forum BBF.247 G-PON Products web page lists a number of GPON ONU certified products including components for ONUs and show whether they support multicast and the 3 VLAN profiles defined in TR-156.

Many GPON capable OLTs can be configured to support several access network technologies. Available OLTs include:

- Adtran: Total Access 5000; provides converged POTS and enhanced broadband services using the ADSL2+, VDSL2 and GPON technologies
- Calix/Ericsson: E3-8G GPON OLT
- FiberHome: AN5516-06 OLT; supports GPON/EPON/10G PON/P2P
- FOT: GOLT1008; a 1U, 8PON ports pizza box GPON OLT
- Huawei: SmartAX MA5600T; supports multiple access methods – VDSL2/ADSL2+/G.SHDSL/POTS/ISDN/ GPON/Ethernet P2P/Cable
- Nokia 7360 ISAM FX
- ZTE: ZXA10 C320: Compact-design PON OLT; supports GPON/EPON, 10G PON (XG-PON1/XGS-PON/10G EPON), P2P

Passive Optical Splitters are available from companies like:

- 3M™
- FS.com
- OFS (Furukawa)
- Senco Advanced Components
- Shenzhen UT-King Technology
- Sopto
- Sumitomo Electric

XENA NETWORKS GPON TEST SOLUTIONS

The Xena Odin-1G-3S-6P 6-port 1Gbps test module is ideal for testing of GPON OLTs and ONUs/ONTs including mandatory and most of the optional interoperability and conformance test cases in accordance with TR-255 and TR-247/ATP-247. Equipped with appropriate transceivers Odin-1G-3S-6P supports 100 Mbps and 1000 Mbps optical and electrical Ethernet interfaces. In a ValkyrieBay chassis up to 12 Odin-1G-3S-6P test modules can be available for testing of GPON OLTs and ONUs/ONTs.

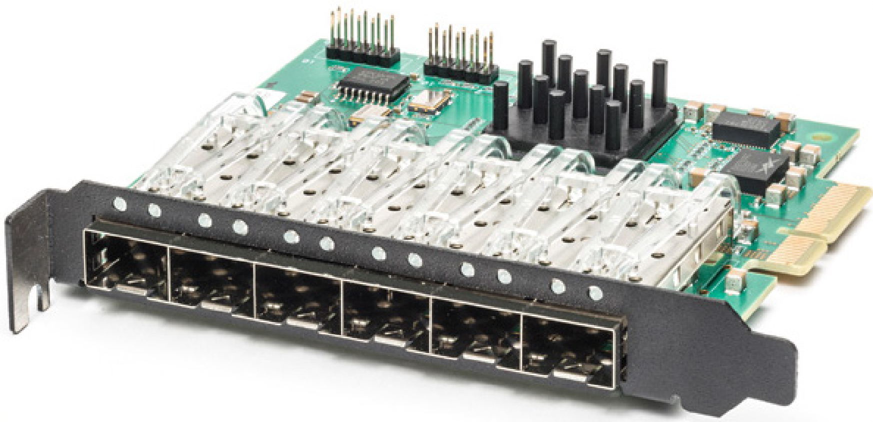


Figure 9: The powerful and versatile Xena Odin-1G-3S-6P 6-port 1Gbps test module

TESTING UP TO LAYER 3

Based on Xena's advanced architecture, the Odin-1G-3S-6P is a proven solution for Ethernet testing at layers 2 and 3. Advanced test scenarios can be performed using the free test applications for the test module:

ValkyrieManager test software is used to configure and generate streams of Ethernet traffic between Xena test equipment and Devices Under Test (DUTs) and analyze the results. Test functions include:

- Multistream traffic generation at line rate
- Flexible MAC address generation
- Generation of unicast, multicast and broadcast frames
- Generation of frames without VLAN tags, with one VLAN tag and double tagged frames
- Configurable VLAN priority
- Generation of IGMPv1, IGMPv2 and IGMPv3 frames

Valkyrie2544 offers full support for the 4 test types specified in RFC 2544: Throughput, Latency, Frame loss and Back-to-back frames; Jitter (Frame Delay Variation) is also supported. Valkyrie2544 lets you partially enable one or more test types and supports different network topologies and traffic flow directions on both Layer 2 and Layer 3.

Valkyrie3918 makes it easy to create, edit and execute all test types specified in RFC 3918. RFC 3918 describes tests for measuring and reporting the throughput, forwarding, latency and Internet Group Management Protocol (IGMP) group membership characteristics of devices that support IP multicast protocols.

Valkyrie1564 provides full support for both the configuration and performance test types described in Y.1564 for complete validation of Ethernet Service Level Agreements (SLAs) in a single test.

Valkyrie2889 is an application for benchmarking the performance of Layer 2 LAN switches. The following RFC 2889 test types are supported:

- All Throughput and Forwarding rate tests (both Fully and Partially meshed)
- Congestion Control
- Address Caching Capacity
- Address Learning Rate
- Broadcast Frame Forwarding and Latency
- Forward Pressure and Maximum Forwarding Rate

TEST AUTOMATION

GPON products require testing during development, production and interoperability/conformance verification. In these cases test scenarios are executed repeatedly to verify the quality and stability of the products. This is normally automated to ensure uniformity and reduce labor cost.

ValkyrieCLI is another free application for the Odin-1G-3S-6P in a ValkyrieBay or ValkyrieCompact chassis. It is a powerful and easy-to-use command-line-interface (CLI) scripting API that makes test automation easier for test engineers:

- Ideal for test automation of e.g. production environments
- Controls ValkyrieBay and ValkyrieCompact chassis with installed test modules
- Powerful CLI approach from any TCP/IP capable tool environment
- Unified syntax for CLI- and GUI-generated test port configurations makes it easy to learn
- Script examples of Tcl, Perl, Java, Ruby, BASH and Python available
- Intelligent console tool bundled free with ValkyrieManager

The ValkyrieBay and ValkyrieCompact chassis are typically controlled using ValkyrieManager, the free GUI application provided by Xena Networks. Everything you can do with ValkyrieManager can also be done via ValkyrieCLI, using simple CLI text commands.

CONCLUSION

GPON systems have been implemented by many operators to provide affordable digital communication services to their customers. More systems will be installed in the coming years to provide increased bandwidth to fulfill customer demands for access to a growing number of internet based applications and support the wide spread use of smart phones.

Test of GPON transmission equipment is required to ensure the quality and proper functioning. This includes verification of interoperability and conformance of the equipment in accordance with the Broadband Forum the TR-255 GPON Interoperability Test Plan and the TR-247/ATP-247 Abstract Test Plan for GPON ONU Conformance.

With the Xena Odin-1G-3S-6P 6-port 1Gbps test module the user gets powerful and versatile Ethernet test capabilities up to layer 3 to test and verify GPON equipment including mandatory interoperability and conformance test cases in accordance with TR-255 and TR-247/ATP-247. Controlling tests with ValkyrieCLI adds repeated testing of the GPON products required in development, production and interoperability/conformance verification. The ValkyrieBay or ValkyrieCompact chassis equipped with Xena Odin-1G-3S-6P gives the user an easy to use, efficient test solution, which is able to handle complex scenarios without breaking the budget.