Technical Report

TR-476

G.hn Access Performance Test Plan

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Issue History

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Executive Summary

This Technical Report defines a performance test plan for the G.hn Access broadband network solution based on the ITU-T G.996x “Unified high-speed wire-line based home networking transceiver system architecture” Recommendations [1]-[5]. This solution is also known as GiGAWire™. G.hn Access leverages G.hn technology through existing access wires to provide last mile infrastructure in areas where optical fiber cannot be deployed all the way to the customer premises.

G.hn supports broadband connectivity within the home. However, G.hn Access extends the applicability of G.hn to the Broadband Forum’s Fiber-to-the-extension point (FTTep) architecture [11] - [12], also known as Fiber-to-the-mosteconomical-point. With FTTep the fiber is extended over copper-based Point-to-Point (P2P) and Point-to-Multipoint (P2MP) infrastructure bringing broadband connectivity closer to the subscriber network infrastructure (home network) by using phonelines and/or coaxial cables, without significant degradation in QoE compared to the FTTH. G.hn Access provides crosstalk mitigation and auto pairing features to support multiple users using bundled cables.

Fiber-to-the distribution point (FTTdp) [14], Multi Dwelling Units (MDUs) environment, including large apartment complexes and office buildings, Single Family Units (SFUs) and Fiber Extension in the home (FE) are four FTTep deployment scenarios [15] considered in this Technical Report.

For each of the four deployment scenarios, TR-476 defines test cases and performance requirements for a system under test (SUT) comprised of a G.hn Aggregation Multiplexer (GAM) and one G.hn Network Termination (GNT) connected in a point-to-point topology.

1 Purpose and Scope

1.1 Purpose

G.hn Access is based on the ITU-T Recommendations G.996x for G.hn, which is a technology for broadband data transmission over in-premises wiring. When used in a Fiber-To-The-extension-point architecture [11] it can deliver fiber-grade services to the customer premises.

The purpose of this Technical Report is to provide a performance test plan for G.hn Access equipment, over twisted pair and coaxial cables, that complements the Conformance and Interoperability testing program of HomeGrid Forum [18]. The focus is on the physical layer testing, similar to the TR-380 [13], in that both test plans are defined on a common basis, including the test setup requirements, test loop topologies, and the noise models.

This Technical Report defines performance requirements for a system comprised of a G.hn Aggregation Multiplexer (GAM) and one G.hn Network Termination (GNT) connected in a point-to-point topology.

Technical content in this Technical Report includes test setup information, equipment configuration requirements, test procedures, and pass/fail requirements for each test case.

1.2 Scope

This Technical Report provides a performance test plan for G.hn Access equipment based on the ITU-T G.996x "Unified high-speed wire-line based home networking transceiver system architecture" Recommendations.

As the access network topologies and deployment practices vary greatly amongst service providers, the access network conditions (loop models, noise models, loop lengths, etc.) and test scenarios are selected to represent nominal conditions under which the performance is tested. This Technical Report is focused on assuring laboratory repeatability such that equipment from different vendors can be validated and compared.

This Technical Report is applicable to G.hn Network Terminations (GNTs) and a single-port or a multi-port G.hn Aggregation Multiplexer (GAM), connected in a point-to-point topology.

The test cases provide test setup information, equipment configuration requirements, test procedures, and performance requirements.

Operators' specific deployment scenarios, involving specific loop types, lengths, or noise scenarios, as well as performance testing of systems in the presence of crosstalk, of reversely power feed GAMs, on very short loop lengths and in point-to-multipoint topology are out of scope of this issue of TR-476.

1.3 Test Plan Passing Criteria

The tests contained in this document are each marked with a test status, indicating: "mandatory," "conditional mandatory," or "optional." These terms are defined in section 2.3.

This Technical Report defines a set of performance requirements for each of four deployment scenarios (use cases):

1. Fiber to the distribution point: FTTdp Use Case
2. Multi dwelling units: MDU Use Case
3. Single family units: SFU Use Case
4. In-home/In-room fiber extension: FE Use Case

This Technical Report also defines five (5) testing profiles in section 5.3.1, which are applicable to all of the above use cases.

Each of the five (5) testing profiles is defined by three (3) parameters:

1. Medium type: twisted pair or coax
2. Operating frequency band (OFB): 100MHz or 200MHz
3. Operating type: SISO or MIMO

For each system under test (SUT), a combination of a GAM and GNT, the information about the supported Use Case and the testing profile SHALL be declared and provided to the test engineer by the equipment vendor prior to the start of the testing. This declaration SHALL be included as part of the test report.

A SUT may support multiple Use Cases. A SUT may support multiple testing profiles.

For the purpose of determining a summary result, such as indicating that a system “passes TR-476 testing”, the system SHALL pass all “mandatory” tests and all applicable “conditional mandatory” tests, according to the declaration made. “Optional” tests SHALL not impact the summary result.

In some tests, parameters may be recorded for reporting purposes only. These parameters might be useful for debugging purposes.

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 [17].

SHALL	This word, or the term "REQUIRED", means that the definition is an absolute requirement of the specification.
SHALL NOT	This phrase means that the definition is an absolute prohibition of the specification.
SHOULD	This word, or the term "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 term "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.9960 (2018) Amendment 2	Unified high- speed wire-line based home networking transceiver System architecture Foundation	ITU-T	2020
[2] G.9961 (2018) Amendment 2	Unified high-speed wire-line based home networking transceiver System architecture Data Link Layer Specification	ITU-T	2020
[3] G.9962 (2018) Amendment 2	Unified high-speed wire-line based home networking transceiver System architecture Management Specification	ITU-T	2020
[4] G.9963	Unified high-speed wire-line based home networking transceiver System architecture Multiple-Input Multiple-Output Specification	ITU-T	2018
[5] G.9964 (2011) Amendment 3	Unified high speed wire-line based home networking transceiver System architecture Power Spectral Density Specification	ITU-T	2020
[6] TS-002 (R13)	HGF L2 Configuration and Management Protocol (LCMP) – Technical Specification	HGF	2015
[7] TS-003 (R17)	HGF L2 Configuration and Management Protocol (LCMP) – Data Model – Technical Specification	HGF	2015
[8] TR-069 Issue 1 Amendment 6 Corrigendum 1	CPE WAN Management Protocol	BBF	2020
[9] TR-181 Issue 2 Amendment 15	Device Data Model for CWMP Endpoints and USP Agents (tr-181-2-15-1-usp.xml)	BBF	2022
[10] TR-285 Issue 2	Broadband Copper Cable Models	BBF	2019
[11] TR-419 Issue 2	Fiber access extension over existing copperinfrastructure	BBF	2022

[12] MD-419	Utilizing Existing Copper Infrastructure for Deployment of Fiber-grade Services	BBF	2020
[13] TR-380 Issue 2	G.fast Performance Test Plan	BBF	2021
[14] TR-301 Issue 2 Amendment 1	Architecture and Requirements for Fiber to the Distribution Point	BBF	2020
[15] White paper	Using G.hn in access networks (https://homegridforum.org/wp-content/uploads/2020/07/Ghn-in-access-network_v2-FINAL-June-2020.pdf)	HGF	2020
[16] RFC 791	Internet Protocol	IETF	1981
[17] RFC 2119	Key words for use in RFCs to Indicate Requirement Levels	IETF	1997
[18] Technical paper	Introduction to GiGAWire™ (G.hn Access) (https://homegridforum.org/giga-wire-access/)	HGF	2022
[19] TR-369 Issue 1 Amendment 2	User Services Platform (USP) (https://usp.technology/specification/)	BBF	2022

2.3 Definitions

The following terminology is used throughout this Technical Report.

Term	Definition
Conditional mandatory	Tests marked as “conditional mandatory” also include a conditional statement, which if met, indicates the test SHALL be considered as “mandatory.” If the conditional statement is not met, the test SHALL be considered as “optional” or “not applicable.”
Device	Any type of system used for an application using a networking transceiver.
Domain Master	G.hn Domain Master (DM) as defined in G.9960.
End Point	G.hn End Point (EP) as defined in [1].
G.hn Aggregation Multiplexer	It represents the device that implements DM and GDM functionalities as defined in G.9960 architecture. The GAM usually includes an additional switching function to connect it to a broadband backbone.
G.hn device	A device using a G.996x transceiver.
G.hn transceiver	A node in a G.996x domain that conforms with G.996x family of recommendations.
G.hn network	A group of interconnected G.hn domains”.
G.hn Network Termination	The device that implements EP functionalities as defined in G.9960 architecture.
Mandatory	Tests marked as “mandatory” SHALL be performed when completing testing according to this Technical Report.
MIMO transceiver	As defined in [4], MIMO transceiver is an [ITU-T G.9963] compliant transceiver that is fully compliant with [ITU-T G.9960] and [ITU-T G.9961], and as such is able to operate based on functional models described in clause 7.1.1 (general PHY model), clause 7.1.2 (PCS), clause 7.1.3 (PMA) and clause 7.1.4 (PMD) of ITU-T G.9960 [1].
MIMO transmission	As defined in 10[4], transmission where one or two spatial streams are converted into two transmit streams.
Node	As defined in [4], any network device that contains an ITU-T G.9960 transceiver. In the context of TR-476, use of term “node” means “G.hn Aggregation Multiplexer” (GAM) in the Optical-to-Electrical entity (O2E, as defined in TR-419 [11]) and “G.hn Network Termination” (GNT) i.e., the Network Termination entity (NTE, as defined in TR-419 [11]).
OFB Profile	As defined in [1], categorization of OFBs depending on the PHY frame format they use. The Profile 1 OFB uses a normal ITU-T G.9600 PHY frame format for transmission of frames and both minimum and maximum frequencies available for communication are defined in the OFB.

Operational Frequency Band (OFB)	As defined in [1], range of frequencies that is allowed to be used by a node to communicate with another node of the domain
Optional	Tests marked as “optional” MAY be completed at the request of the tester or equipment manufacturer.
System Under Test	Any combination of two nodes, GAM and GNT, of the same domain type.
VectorBoost	VectorBoost™ is the feature of G.hn Access that allows twisted pair copper telephone wire to reach its maximum capacity, even under crosstalk from other subscribers in the same binder. It can ensure the optimal allocation of resources between the neighboring lines in accordance with their real-time traffic needs and can run locally on a GAM (G.hn Access Multiplexer) or in the cloud. In addition to mitigating crosstalk between pairs of a copper binder, VectorBoost™ optimizes the allocation of spectrum by boosting the spectrum only for subscribers needing extra bandwidth. Open-source software for VectorBoost™ can be accessed at https://github.com/HomeGrid/GigaWireVB.

2.4 Abbreviations

This Technical Report uses the following abbreviations:

Term	Definition
AGN	Additive Gaussian Noise
BLER	Block Error Rate
EP	End Point
FE	In-home/In-room fiber extension
FLR	Frame Loss Ratio
FLOWMONITOR.INFO.XPUT_ INDICATOR	Estimated application-layer throughput
FTTep	Fiber to the extension point
FTTdp	Fiber to the distribution point
GAM	G.hn Aggregate Multiplexer (i.e., ”mini Distribution Point Unit (DPU))
GNT	G.hn Network Termination (i.e., Customer Premises Equipment)
HGF	HomeGrid Forum
LAN	Local Area Network
LCMP	Layer 2 Configuration and Management Protocol
LPDU	Link Protocol Data Unit
MAC	Media Access Control
MAE	Mean Absolute Error
MIMO	Multiple Input, Multiple Output
ME	Mean Error
MDU	Multiple dwelling units
NTE	Network Terminal Equipment
O2E	Optical To Electrical
OFB	Operating Frequency Band
PSD	Power Spectral Density
QOS.SCHED.DS_US_RATE	Parameter to define the time usage (in %) between downstream/upstream slots
SISO	Single Input, Single Output
SFU	Single family unit
SUT	System Under Test
UDP	User Datagram Protocol
VECTORBOOST.GENERAL.ENABLE	Parameter to enable or disable VectorBoost feature.
VLAN	Virtual LAN

3 Technical Report Impact

3.1 Energy Efficiency

TR-476 has no impact on energy efficiency.

3.2 Security

TR-476 has no impact on security.

3.3 Privacy

TR-476 has no impact on privacy.

4 System Under Test

4.1 System Under Test Information

A system is a combination of a GAM and one GNT and is referred to as a ‘System Under Test’ or ‘SUT’ in the remainder of the test plan.

Table 4-1 and Table 4-2 are intended to provide test engineers and readers of the test report with sufficient information about the SUT in order to ensure repeatability of results and to allow for comparisons of reported test results.

The information defined in the tables SHALL be provided to the test engineer prior to the start of the testing and SHALL be included as part of the test report. All fields SHALL be populated; if an item is not applicable to the GAM or GNT, the item MAY be marked as “Not Applicable.”

Table 4-1 – GAM Information

Manufacturer/Vendor	This is the name of the manufacturer and vendor.
FirmwareVersion	FirmwareVersion of the node.
HardwareVersion	HardwareVersion of the node.
DomainName	This is the domain name (Broadband Forum in TR-476) to which the node is registered.
DomainID	Domain Identifier of the domain to which the node is registered.
MACAddress	MAC Address of the node.
DeviceID	The Device Identifier assigned by the Domain Master, denoted as DEVICE_ID in G.9961.
StandardVersions	ITU-T G.996x versions that the node supports.
Medium Type	The type of medium that the node interface operates on (refer to Table 7-5/G.996.2). Enumeration of: • Phoneline Baseband • Coax Baseband
MaxBandplan	The largest bandplan capability (operational frequency band (OFB)) that the node can support (see 8.8.5.5/G.9961), e.g., 100MHz or 200MHz.
MaxTransmitRate	The maximum PHY data rate, expressed in Mbps, that the node is capable of transmitting.
TxPhyRate	The PHY transmit data rate (expressed in Mbps) to the remote node.
RxPhyRate	The PHY receive data rate (expressed in Mbps) from the remote node.
BlocksErrorReceived	The total number of received LPDUs that contained errors.
BlocksReceived	The total number of LPDUs that were received by the node through a physical medium, with or without errors.
Ethernet interface (type, speed)	e.g., 1000BASE-TX, 1Gbps.
Operating type	SISO/MIMO.
PHYThroughputDiagnosticsEnable (optional)	List of DeviceIDs of nodes with their PHY throughput diagnostics mode enabled and participating in the G.hn network PHY throughput diagnostics process.
PerformanceMonitoringDiagnosticsEnable (optional)	List of DeviceIDs of nodes with their Performance Monitoring (PM) diagnostics mode enabled and participating in the G.hn network PM throughput diagnostics process.

Table 4-2 – GNT Information

Manufacturer/Vendor	This is the name of the manufacturer and vendor.
FirmwareVersion	FirmwareVersion of the node.
HardwareVersion	HardwareVersion of the node.
DomainName	This is the domain name (Broadband Forum in TR-476) to which the node is registered.
DomainID	Domain Identifier of the domain to which the node is registered.
MACAddress	MAC Address of the node.
DeviceID	The Device Identifier assigned by the Domain Master, denoted as DEVICE_ID in G.9961.
StandardVersions	ITU-T G.996x versions that the node supports.
Medium Type	The type of medium that the node interface operates on (refer to Table 7-5/G.9962). Enumeration of: • Phoneline Baseband • Coax Baseband
MinSupportedBandplan	The minimal bandplan capability (OFB) for a node that is allowed to register to the domain, e.g., 100MHz or 200MHz.
MaxSupportedBandplan	The maximum bandplan capability (OFB) for a node that is allowed to register to the domain, e.g., 100MHz or 200MHz.
TxPhyRate	The PHY transmit data rate (expressed in Mbps) to the remote node.
RxPhyRate	The PHY receive data rate (expressed in Mbps) from the remote node.
BlocksErrorReceived	The total number of received LPDUs that contained errors.
BlocksReceived	The total number of LPDUs that were received by the node through a physical medium, with or without errors.
Ethernet interface (type, speed)	e.g., 1000BASE-TX, 1Gbs.
Operating type	SISO/MIMO.
PHYThroughputDiagnosticsEnable (optional)	List of DeviceIDs of nodes with their PHY throughput diagnostics mode enabled and participating in the G.hn network PHY throughput diagnostics process.
PerformanceMonitoringDiagnosticsEnable (optional)	List of DeviceIDs of nodes with their Performance Monitoring (PM) diagnostics mode enabled and participating in the G.hn network PM throughput diagnostics process.

4.2 Management of the GAM and GNT

From a conceptual perspective, any ITU-T G.996x-based system is a plug-and-play system that works automatically without requiring any manual configuration by a technician or user. The GAM and GNT pair of devices SHALL be provided to the test engineer with a G.hn interface (physical node) pre-configured by vendors. The negotiation how to best perform under the operating conditions in each test case is done automatically, following the standard rules and using the parameters pre-configured in the GAM.

Nevertheless, for testing purposes vendors may decide to implement a protocol for remote management and provisioning of the devices, allowing an external entity to interact with the node management entity (NME) in order to read/write parameters internal to the node. Examples of such protocols are Broadband Forum's CPE WAN Management Protocol (TR-069) [8] and User Services Platform [19], with its corresponding device data model (TR-181) [9], and HomeGrid Forum's HGF-LCMP [6], the Layer 2 Configuration and Management protocol, with its corresponding data model (HGF-DM) [7].

5 Test Setup

This section contains all the specifications and information required for building the basic testing environment (e.g., test configurations, test setup characteristics, configuration settings of the System Under Test, and setup of the simulated network environment) for the GHNA test cases defined in this Technical Report. Test case specific configuration settings are defined in their related section.

5.1 Test Setup Requirements

5.1.1 Ethernet/ Traffic Equipment

The GNT and GAM SHALL support means to pass Ethernet/IP traffic through the "G.hn in Access Scenarios" link.

The GAM and GNT each SHOULD support the following requirements to enable these tests. Figure 5-1 shows the basic setup for passing Ethernet/IP traffic through the GAM and GNT device in a single line test.

The GAM SHOULD support:

1. Forwarding of Ethernet traffic between the "G.hn in Access Scenarios" interface(s) and the northbound Ethernet interface, based on MAC learning or VLAN markings.

The GNT SHOULD support at least one of the following configurations:

1. IPv4 Bridging between the WAN and LAN ports, as defined in TR-124 Issue 3, WAN.BRIDGE.1.
2. Ipv4 Port Forwarding between the WAN and LAN ports, as defined in TR-124 Issue 3, LAN.PFWD.1. The GNT SHALL be configured for forward Ipv4 traffic for UDP Port 1024 between the WAN and LAN.

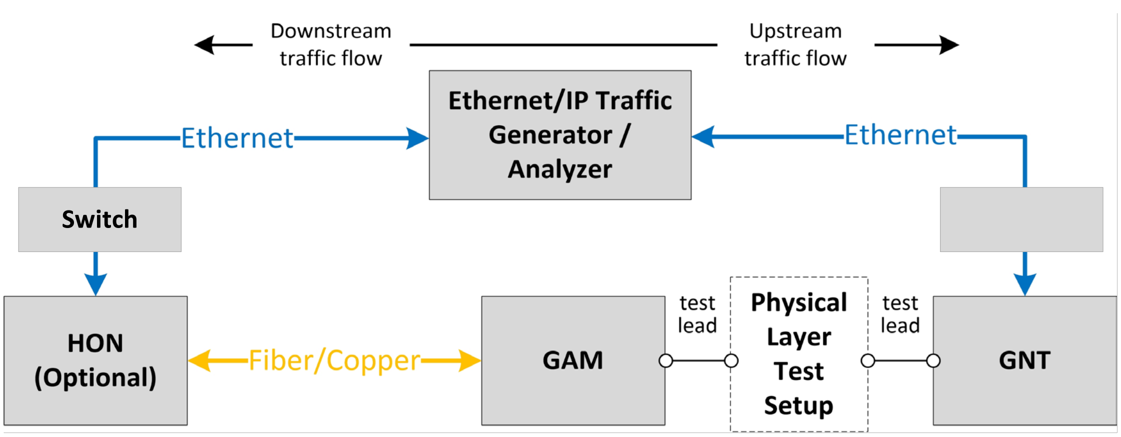

Figure 5-1 – Test setup for Ethernet/IP traffic with single line test

The test leads, shown in Figure 5-1, used to connect the Physical Layer Test Setup to the GAM and GNT(s) SHALL be of 1 meter ± 2.5 cm length and SHALL be of type CAT6 or better.

The Ethernet/IP Traffic Generator/Analyzer shown in Figure 5-1 is not able to distinguish whether Ethernet frames are dropped in the GAM, the GNT, the HON, or the Ethernet switch. Hence, when verifying that no Ethernet frames are dropped in the SUT, a background frame loss ratio (FLR) of 4e-7 is allowed as to not fail the SUT for frames dropped outside its control.

> **Note:** An FLR of 4e-7 corresponds with about 10 dropped downstream frames and 3 dropped upstream frames when running Ethernet traffic at a 1 Gbit/s aggregate net data rate at the default 4:1 downstream:upstream split ratio for 5 minutes, with a frame size distribution as defined in section 5.1.2. This FLR of 4e-7 accommodates the cascading of up to 4 Ethernet interfaces (as shown in Figure 5-1), each at an FLR of 1e-7. A minimum of 5 dropped frames is allowed for the test to be statistically relevant given the measurement time.

For the test setup for Ethernet/IP traffic with single line test shown in Figure 5-1.

1. The purpose of the Ethernet Switch is to allow a single port to be used on the Ethernet traffic generator/analyzer for the GNT side testing. If multiple ports are used on the Ethernet traffic generator/analyzer, this switch may be eliminated.
2. If used, the Ethernet switch SHALL support a backplane switching speed so as not to limit the performance of the “G.hn in Access Scenarios” system, i.e., greater than the summation over all lines of the upstream and downstream “G.hn in Access Scenarios” net data rates.
3. The Ethernet connection between the switch and Ethernet traffic generator/analyzer link speed SHALL be 10 Gigabit Ethernet or better.

Test traffic SHALL be defined as Ethernet frames containing the headers shown in Table 5-1.

Table 5-1 – Ethernet/IP test frame definition

Ethernet Frame Header	VLAN Tag	Ipv4 Header	UDP Header	Data Payload
MAC Destination/Source Addresses, etc.	Optional, downstream flow only	Ipv4 Source/Destination Addresses, etc.	UDP Port, etc.	Pseudo-random bit pattern

The information listed in Table 5-2 SHALL be used to construct the Ethernet/IP frames used for testing. Fields not defined SHALL be calculated according to the appropriate standard (e.g., RFC791 [16] on Ipv4) or SHOULD use well known and/or industry-default values. Frames received by the GNT LAN interface, for transmission in the upstream direction, SHALL NOT include a VLAN tag. Frames transmitted in the downstream direction MAY include a VLAN tag, if required by the HON and/or GAM.

Table 5-2 – Ethernet/IP frame parameter values

	Downstream Flow	Upstream Flow	Description
Ethernet Frame Header			
MAC Destination Address (Note 1)	MAC1	MAC2	Unicast MAC address, static for the duration of testing.
MAC Source Address	MAC2	MAC1	
VLAN Tag (Optional)			
TPID	0x8100	N/A	
VID	Based on equipment configuration.	N/A	
PCP	7	N/A	
DEI	0	N/A	
Ipv4 Header			
IP Source	IP1	IP3 (Note 2)	Unicast Ipv4 address. IP1 & IP2 SHOULD be globally routable, public IP addresses. IP3 MAY be a private IP address if the GNT is implementing port forwarding.
IP Destination	IP2 (Note 2)	IP1	
UDP Header			
UDP Source Port	1024	1024	
UDP Destination Port	1024	1024	
Payload			
Datagram Payload	PRBS	PRBS	Pseudo-random bit pattern filling remainder of frame bytes.
Note 1: The destination MAC address might be dependent on the configuration of the GNT. **Note 2:** For GNT devices supporting Bridge Mode, IP2 SHALL equal IP3.			

5.1.2 Ethernet Traffic Frame Sizes

The following describes the Ethernet traffic and frames sizes which SHALL be used within each test case described in this document, unless specified otherwise within the specific test case (e.g., where a single, fixed frame size is required).

A mix of Ethernet frame sizes SHALL be used during testing, with the mix of frames being evenly distributed according to the probabilities listed in Table 5-3.

Table 5-3 – Frame Size Distribution within Ethernet Traffic

Frame Size (bytes)	Probability
1566	0.050
1500	0.673
1024	0.088
256	0.014
70	0.175
NOTE – All Ethernet frame sizes being on the first byte of the Destination MAC Address and end on the last byte of the Frame Check Sequence (FCS).	

To calculate the total number of frames per second to transmit through a connection of a given bit-rate, the following calculations SHALL be used.

$$\text{Average\_Frame\_Size\_of\_Mix}\left(\frac{bytes}{frame}\right) = \left[\sum_{i=1}^{M} \text{frame\_probability}(i) \times \text{frame\_size}(i)\right]$$

For the Frame Size Distribution in Table 5-3, the Average_Frame_Size_of_Mix is 1193 bytes.

$$\text{Required\_Frame\_Rate}\left(\frac{frames}{\text{sec}}\right) = \left\lfloor \frac{\text{Required\_Throughput} \times \frac{1}{8}}{\text{Average\_Frame\_Size\_of\_Mix}} \right\rfloor$$

where Required Throughput is in units of bits per second and specified in each specific test case for a specific direction, upstream or downstream.

5.1.3 Physical Layer Test Setup

This section contains the specifications and information required for building the basic physical layer testing environment for “G.hn in Access Scenarios” test cases defined in this Technical Report. Different configurations and settings needed for specific test cases are defined in the related sections.

The dotted box shown in Figure 5-2 is referred to as the 'Physical Layer Test Setup' for test loop topologies, with noise injected, defined in section 5.3.2. The elements within the Physical Layer Test Setup' are vendor/lab discretionary.

The combination of the 'Noise source' and the 'Noise injector' can also be referred to as the 'Noise generator'.

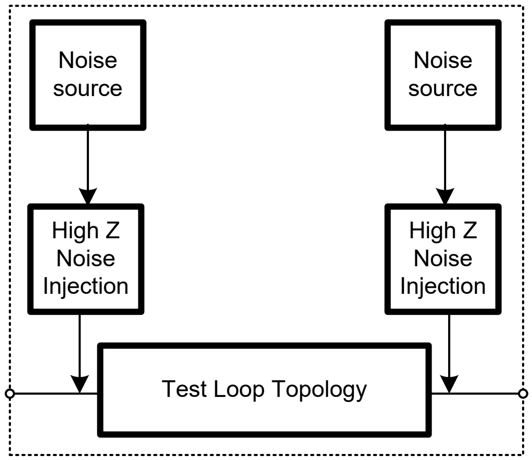

Figure 5-2 – Physical Layer Test Setup

The requirements for the Test Loop Topology used to realize the test loop topology are specified in section 5.3.2.

Noise can be injected at the GAM and GNT side (at both end of the loop).

The performance tests require one noise injection active per direction where the noise characteristic can be the same or different for GAM and for GNT. Details about noise injection are specified for each test case as part of its test procedure.

5.2 Test Setup Characteristics

Test results obtained as a result of testing performed in accordance with TR-476 SHALL contain the information described in sections 5.2.1 and 5.2.2.

5.2.1 Temperature and Humidity

The ranges of temperature and humidity of the test facility, over the entire time tests are conducted, SHALL be recorded in a manner similar to that shown in Table 5-4 and SHALL be included as part of the test report. The range of temperature SHOULD be between 15 °C (59 °F) and 35 °C (95 °F). The range of humidity SHOULD be between 5% and 85%.

Table 5-4 – Temperature and Humidity Range of Test Facility

Parameter	High	Low
Temperature		
Humidity		

5.2.2 Test Equipment Calibration

The measurement systems documented in this section SHALL be calibrated with traceable and verifiable steps dependent on the specific measurement setup and test equipment.

The test equipment calibration documentation SHALL be included as part of a written test report.

5.2.3 Loop Environment Characteristics

The test loops, including information about the cable (type, gauge, and length) and the loop emulator SHALL be recorded in a manner similar to that shown in Table 5-5 and SHALL be included as part of the test report.

Table 5-5 – Loops used for Testing

Test Loop	Cable type (coaxial or twisted pair), gauge and length Loop emulator (manufacturer, serial number and model number)

5.3 Profiles, Loop Topologies and Noise Models

5.3.1 Testing Profiles

Testing profiles for G.hn Access performance tests, referred to as GHNA profiles, are defined in Table 5-6.

Each testing profile is defined by three parameters:

1. Medium type: twisted pair or coax
2. Operating frequency band (OFB): 100MHz or 200MHz
3. Operating type: SISO or MIMO

Table 5-6 – G.hn Access (GHNA) Profiles

GHNA Profile	Medium Type	Operating Frequency Band (OFB) / Profile 1 OFB	Operating Type
GHNA.P100	Twisted pair	2 – 100 MHz / 100 MHz-TB	SISO
GHNA.P100-MIMO (Note 1)	Twisted pair	2 – 100 MHz / 100 MHz-TB	MIMO

GHNA.P200	Twisted pair	2 – 200 MHz / 200 MHz-TB	SISO
GHNA.C100	Coax	2 – 100 MHz / 100 MHz-CB	SISO
GHNA.C200	Coax	2 – 200 MHz / 200 MHz-CB	SISO
Note 1: As defined in [4], an [ITU-T G.9963] MIMO transceiver SHALL be fully compliant with [ITU-T G.9960] and [ITU-T G.9961] transceiver. In deployments where only a single pair of wires is used, a modem equipped with a MIMO transceiver will behave as an [ITU-T G.9960] transceiver.			

5.3.2 Test Loop Topologies

Single line (point-to-point) tests are performed on two loop types:

- TP-100 twisted single pair defined in Annex E of TR-285 Issue 2 [10]
- RG-6 coax defined in Annex D of TR-285 Issue 2 [10]

5.3.2.1 Single- Twisted Pair Cable Test Loop Topology

The twisted single-pair SHALL be of type TP-100.

The twisted single-pair lengths (not including the test leads) SHALL be as defined in Table 5-7.

Table 5-7 – Twisted single pair TP-100 loop length (m)

FTTdp Use Case	MDU Use Case	SFU Use Case	FE Use Case
100	50	50	50
200	100	100	
300	200		
400	300		
500			

The accuracy of the loop SHALL be represented by the Mean Absolute Error (MAE) and Mean Error (ME).

MAE and ME for loop X are given by Equation 5-1 and Equation 5-2:

Equation 5-1: MAE

$$MAE_{LoopX} = \frac{1}{N_i} \sum_{i \in \{A_{Ti} \leq A_{max}\}} |A_{Ri} - A_{Ti}|$$

Equation 5-2: ME

$$ME_{LoopX} = \frac{1}{N_i} \sum_{i \in \{A_{Ti} \leq A_{max}\}} (A_{Ri} - A_{Ti})$$

where

A_{Ri} = Attenuation sample, in dB, of the measured loop X,

A_{Ti} = Attenuation sample, in dB, of the theoretical loop X, and

A_{MAX} SHALL be equal to 70 dB.

The A_{Ti} values SHALL be calculated according to the TP-100 model defined in TR-285 Annex E [10].

The index "i" belongs to a set defined by the points necessary to measure the attenuation in steps of 50kHz or less from 2 MHz to 200 MHz and take into account only those measurement points for which $A_T \leq A_{MAX}$ dB.

N_i is the number of elements in the above set.

The loop SHALL be compensated by adjusting the loop length such that the absolute value of ME is minimized while maintaining an MAE less than or equal to 1 dB. The compensation procedure for all loop lengths SHALL be performed with the noise injector connected as shown in Figure 5-2.

This accuracy requirement SHALL apply for all test loops.

5.3.2.2 Single Coaxial Cable Test Loop Topology

The single coaxialcable test loop topology is shown in Figure 5-3.

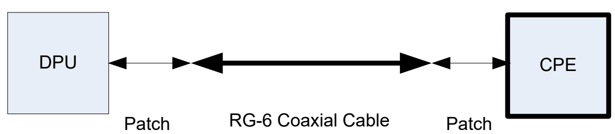

Figure 5-3 – Use of Single Coaxial Cable Test Loop Topology

The patch coaxial cable connected from the GAM to the Coaxial Cable and from the coaxial cable to the GNT SHALL be of 1m length.

Any balun that is needed to test a device with twisted pair output operating over coax SHALL be considered as part of the GAM.

The coaxial cable and patch sections SHALL be of type RG-6 with characteristics described in Annex D of TR-285[10].

The coaxial cable lengths (not including the patch sections) SHALL be as defined in Table 5-8:

Table 5-8 – Coaxial RG-6 cable length (m)

FTTdp Use Case	MDU Use Case	SFU Use Case	FE Use Case
100	100	100	100
200	200		
300	300		
400			
500			

5.3.2.2.1 Coax Cable Accuracy

The RG6 coaxial cable used for testing SHALL meet the following accuracy requirements.

The typical Insertion Loss (IL) is defined in TR-285 Annex D for the RG-6 Cable. The required range of accuracy is +/- 0.5dB for 1 and 10 MHz, linearly interpolated to a bound of +/- 1 dB from the typical IL for frequency range 50MHz and 100MHz, linearly interpolated to a bound of +/- 2dB from the typical IL for frequency at 200MHz.

The f-type connectors are taken into account as an added tolerance with the following values: MIN=0.1dB, TYP=0.15dB, MAX=0.3dB.

The measured IL (dB) of the RG6 cable used SHALL fall within the MIN IL (dB) and MAX IL (dB) range for each of the key frequency points listed in Table 5-9 through Table 5-14.

> **Note:** The IL of a coax cable is not only determined by its electrical parameters as defined in TR-285 but is also influenced by its mechanical and material construction.

In order to meet the required accuracy, it may be needed to use a coaxial cable with 90% or higher braid coverage.

Table 5-9 – Accuracy Requirements for 50m RG-6

50m RG-6	MIN IL (dB)	TYP IL (dB)	MAX IL (dB)
1 MHz	0.1	0.45	1.10
10 MHz	0.59	1.14	1.79
50 MHz	1.40	2.45	3.60
100 MHz	2.41	3.46	4.61
200 MHz	2.87	4.92	7.07

Table 5-10 – Accuracy Requirements for 100m RG-6

100m RG-6	MIN IL (dB)	TYP IL (dB)	MAX IL (dB)
1 MHz	0.19	0.74	1.39
10 MHz	1.33	2.13	3.03

50 MHz	3.45	4.75	6.15
100 MHz	5.22	6.77	8.42
200 MHz	7.13	9.68	12.33

Table 5-11 – Accuracy Requirements for 200m RG-6

200m RG-6	MIN IL (dB)	TYP IL (dB)	MAX IL (dB)
1 MHz	0.53	1.33	2.23
10 MHz	3.06	4.11	5.26
50 MHz	7.81	9.36	11.01
100 MHz	11.35	13.40	15.55
200 MHz	16.16	19.21	22.36

Table 5-12 – Accuracy Requirements for 300m RG-6

200m RG-6	MIN IL (dB)	TYP IL (dB)	MAX IL (dB)
1 MHz	1.02	1.92	2.92
10 MHz	4.78	6.08	7.48
50 MHz	12.16	13.96	15.86
100 MHz	17.47	20.02	22.67
200 MHz	25.20	28.75	32.40

Table 5-13 – Accuracy Requirements for 400m RG-6

400m RG-6	MIN IL (dB)	TYP IL (dB)	MAX IL (dB)
1 MHz	1.46	2.51	3.66
10 MHz	6.51	8.06	9.71
50 MHz	16.51	18.56	20.71
100 MHz	23.60	26.65	29.80
200 MHz	34.23	38.28	42.43

Table 5-14 – Accuracy Requirements for 500m RG-6

500m RG-6	MIN IL (dB)	TYP IL (dB)	MAX IL (dB)
1 MHz	-2.55	3.10	-3.75
10 MHz	-9.49	10.04	-10.69

50 MHz	-22.12	23.17	-24.32
100 MHz	-32.22	33.27	-34.42
200 MHz	-45.76	47.81	-49.96

The loop SHALL be compensated such that the measured IL(dB) of the RG6 cable used falls within the MIN IL (dB) and MAX IL (dB) range for each of the key frequency points listed in Table 5-9 through Table 5-14. The compensation procedure SHALL be performed with the noise injector connected. In cases where a switch matrix for automatted cable length selection is used the switch matrix SHALL be present during the compensation procedure. This accuracy requirement SHALL apply for all test loops.

5.3.3 Noise Models

5.3.3.1 Test Noise for Single Twisted Pair Testing

The test noise is defined as an Additive Gaussian Noise (AGN) that extends from 2 MHz to 240 MHz with a PSD as defined in this section.

> **Note:** The AGN extends to 240 MHz so that it is not discontinuous at the 200 MHz boundary of the G.9964 [5] signal spectrum.

The test noise PSD for single twisted pair testing, referred to as PSD_{TTP}, is defined as follows :

PSD_{TTP} = -140 dBm/Hz for 2 MHz ≤ f ≤ 30 MHz (low frequency region);

-140 dBm/Hz to -150 dBm/Hz for 30 MHz ≤ f ≤ 40.656 MHz (interpolated dB/f region);

-150 dBm/Hz for 40.656 MHz < f ≤ 240 MHz (high frequency region).

> **Note:** This noise PSD definition recognizes that at the higher frequencies above 30 MHz, the test noise, while having a flat spectrum, is lower than at the lower frequencies below 30 MHz.

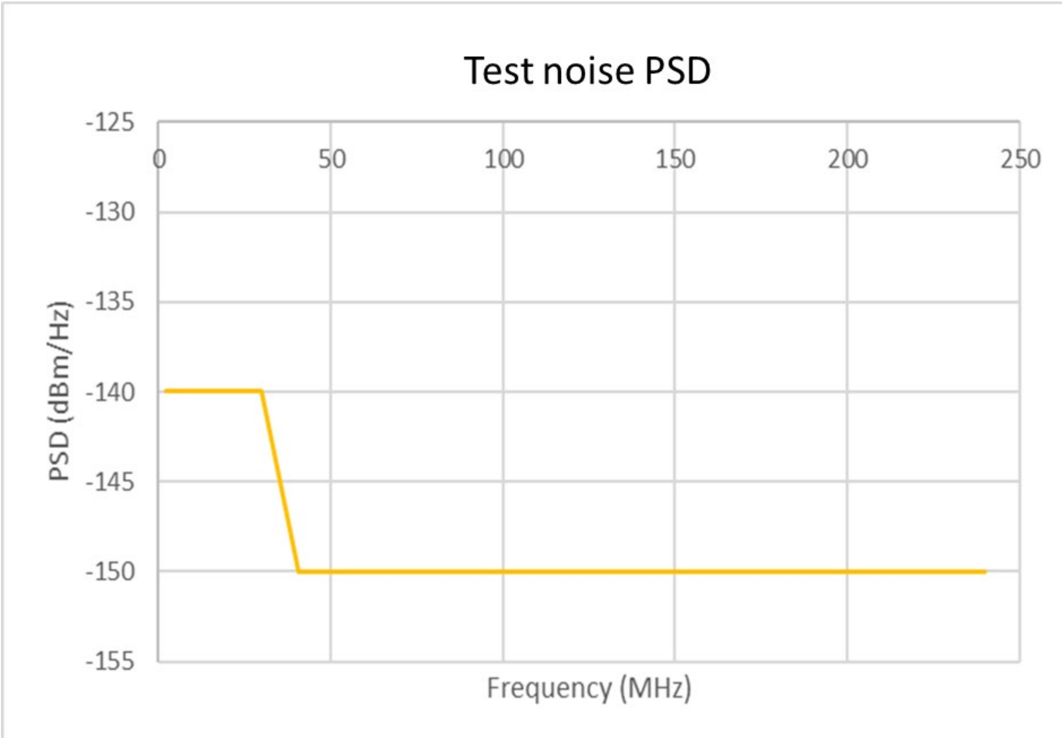

Figure 5-4 – PSD of the Test Noise PSD_{TTP}

5.3.3.2 Test Noise for Coax Testing

The test noise for coax testing, referred to as PSD_{TC}, is defined as an Additive Gaussian Noise (AGN) that extends from 2 MHz to 240 MHz with a PSD of -150 dBm/Hz.

5.3.4 Noise Injection

5.3.4.1 Accuracy of Noise Sources

The determination of ME/MAE accuracy of the noise seen by the DUT SHALL be performed with the internal cabling, switches, loop, noise sources, and noise injectors present. All active equipment SHALL be powered on.

Each noise SHALL be measured independently at the terminating points of the 'Physical Layer Test Setup'. This SHALL be done for one noise generator at a time, with the noise generator at the near end (spectrum analyser side) actively generating noise. If present, the noise generator at the far end SHALL be powered on and SHALL NOT generate noise.

The reference load impedance Rv SHALL be plugged directly into the far-end terminating point of the 'Physical Layer Test Setup'.

The analyzer probe lead SHALL be connected to the near-end terminating point of the 'Physical Layer Test Setup'. This probe lead SHOULD be as short as possible (a few cm).

An example setup is shown in Figure 5-5:

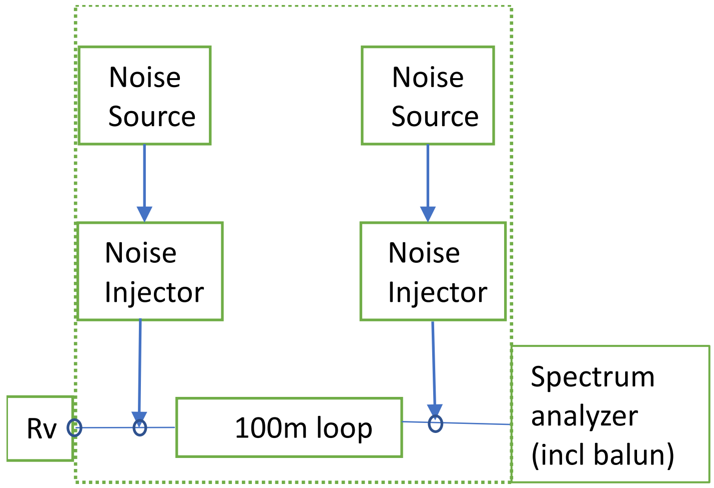

Figure 5-5 – Example Noise calibration setup

With a single-pair Physical Layer Test Setup, R_v = 100 Ohms.

With a coaxial cable Physical Layer Test Setup, R_v = 75 Ohms.

At least one measurement SHALL be made per 100 kHz interval with a 100 kHz resolution bandwidth. The Mean Error and Mean Absolute Error of the measured simulated noise level values (in dBm/Hz), relative to the theoretical noise level values (in dBm/Hz), SHALL be calculated over the calibration frequency range.

The MAE for noise X is defined as:

Equation 5-3 – Noise MAE calculation

$$MAEnoise\ X = \frac{1}{M} \sum_{i \in \{P_{Ti} \geq -150\ dBm/Hz\}} |P_{Ri} - P_{Ti}|$$

The ME for noise X is defined as:

Equation 5-4 – Noise ME calculation

$$MEnoise\ X = \frac{1}{M} \sum_{i \in \{P_{Ti} \geq -150\ dBm/Hz\}} (P_{Ri} - P_{Ti})$$

Note: Positive error indicates excessive noise power.

Where:

P_{Ri} = power sample, in dBm/Hz, of the generated noise X,

P_{Ti} = power sample, in dBm/Hz, of the theoretical noise X, and

M is the number of power samples.

The index “i” belongs to a set defined by the points necessary to measure the noise power in steps of 100kHz or less and taking into account only those points for which Pti ≥ -150 dBm/Hz.

The noise generator SHALL be compensated such that the absolute value of ME is minimized while maintaining a MAE accuracy of 0.5 dB from 2MHz to 120 MHz and 1 dB from 120 MHz to 240 MHz.

The noise compensation SHALL be done for the 100m loop and applied to all other loop lengths. However, in case the noise ME/MAE requirements cannot be met for the loops other than 100m, a loop specific compensation SHALL be used.

> **Note:** For noise calibration, there is measurement uncertainty that can not be compensated, consisting of the following contributions:
>
> 1. absolute amplitude accuracy
> 2. vertical linearity
> 3. frequency response of the measurement equipment used
> 4. tolerance of the calibration impedance.

5.3.4.2 Test Setup Background Noise Measurement

A measurement of the test setup and lab background noise MAY be made.

The measured noise power levels SHOULD be such that it does not cause a failure of the MAE requirement defined in section 5.3.4.1. This implies the measured noise power level is below the level of the noises generated and injected into the test setup during testing.

The measurement of the laboratory test setup background noise floor MAY exclude narrow band noise "spikes", where a narrow band noise "spike" has a bandwidth of less than 1 MHz and a PSD of less than -100dBm/Hz. The presence of such spikes SHOULD be minimized.

The measurement SHALL be made with a 1MHz resolution bandwidth.

For statistical relevance the measurement SHALL use an averaging of at least 16 sweeps.

All equipment in the test setup including loop simulator (if applicable), noise generator, and noise injector SHALL be connected and powered on without generating noise.

Figure 5-5 shows the measurement setup.

The measurement MAY be performed for any test loop in Table 5-7 and Table 5-8.

5.3.5 Minimum interface speed of the SUT

In the SUT, the GAM SHALL support an uplink interface speed of 1 Gbit/s or better. The link partner GNT is expected to have a LAN port interface speed of at least 1 Gbit/s.

6 Performance Tests

The criteria for passing the GHNA.P200 Throughput Test cases and GHNA.C200 Throughput Test cases requires the aggregate data rate and the number of dropped Ethernet frames fulfill the requirements defined under the Expected Results for each of the tests.

In the method of procedure, the estimated application-layer throughput in GAM and GNT should be recorded as downstream data rate PHY_DOWN and upstream data rate PHY_UP by reading an internal MIB parameter FLOWMONITOR.INFO.XPUT_INDICATOR defined as:

$$FLOWMONITOR.INFO.XPUT\_INDICATOR = 0.8 \times RxPhyRate \times (1 - BLER)$$

Parameter *BLER* is defined as:

$$BLER = \frac{BlocksErrorsReceived}{BlocksReceived}$$

The normative definition of the PHY receive rate (parameter *RxPhyRate*), the total number of received LPDUs that contained errors (parameter *BlocksErrorsReceived*) and the total number of LPDUs received, with or without errors (parameter *BlocksReceived*) and the Block Error Rate (parameter *BLER*) are [8] published in the associated version of the USP data models as defined by TR-181 Issue 2 Amendment 15 [9] and described under the Device.Ghn.Diagnostics. Refer to the latest version of the Device:2 data model for USP for more information.

6.1 GHNA.P200 Throughput Test

6.1.1 Purpose

The purpose of this test is to verify that the SUT running the GHNA.P200 test profile can establish a stable link of sufficient reported performance and stability to pass data traffic at the required data rates relative to the reported physical layer rates.

Test requirement: Conditional mandatory.

6.1.2 Test Setup

1. The SUT SHALL be connected to the test setup shown in Figure 5-1.
2. The twisted single pair loop lengths listed in Table 5-7, SHALL be used for the testing.
3. The Ethernet/IP Traffic Generator/Analyzer SHALL be configured to transmit a continuous upstream and downstream flow of Ethernet frames.
4. Inject the test noise PSD_{TTP} as defined in section 5.3.3.1 at both ends of the loop.

6.1.3 Method of Procedure

1. Disable VectorBoost functionality in GAM and GNT and set DS/US split ratio to 50/50 and reboot nodes.
2. Allow the SUT to establish a connection through the first loop listed in Table 5-7.
3. Configure and start the traffic generator transmitting frames at the maximum supported interface speed of the traffic generator in both upstream and downstream.
4. Run the traffic for 30 seconds to allow the SUT to perform any adjustments to the link.

5. Record the downstream and upstream data rates reading the estimated application-layer throughput in GAM and GNT (reported in MIB parameter FLOWMONITOR.INFO.XPUT_INDICATOR) and record these values as PHY_DOWN and PHY_UP.
6. Reconfigure and start the traffic generator in both the upstream and downstream directions with a required throughput equal to 47.5% of the aggregate data rate according to the following:

$$47.5\% * (PHY\_DOWN + PHY\_UP)$$

7. After 10 seconds reset the throughput counter from step 5, without stopping the traffic.
8. Let the traffic run for 5 minutes.
9. Record the total number of Ethernet frames transmitted and received in the upstream and downstream directions.
10. Repeat steps 1 through 9 for each of the other loops listed in Table 5-7.

6.1.4 Report

The following items/measurements SHALL be included in the report:

1. PHY_DOWN and PHY_UP recorded in step 5 for each loop length.
2. The required frame rate (derived from the required throughput used in step 6, as defined in section 6.1.3) for each direction and for each loop length.
3. The total number of Ethernet frames transmitted and received in the upstream and downstream directions recorded in step 9 and the derived frame loss ratio in each direction (FLRds and FLRus).

6.1.5 Expected Results

For each loop length:

1. The aggregate data rate (PHY_DOWN + PHY_UP) SHALL be equal to or higher than the required aggregate data rate indicated in Table 6-1 for the specific loop length.
2. The number of dropped downstream (i.e., transmitted minus received) Ethernet frames SHALL not exceed 5, or the FLRds SHALL not exceed the background FLR defined in section 5.1.1.
3. The number of dropped upstream (i.e., transmitted minus received) Ethernet frames SHALL not exceed 5, or the FLRus SHALL not exceed the background FLR defined in section 5.1.1.

Table 6-1 – GHNA.P200 minimum performance requirements

Loop length (m)	Minimum required Aggregate data rate (kbit/s)	Use Case			
		FTTdp	MDU	SFU	FE
50	988400	-	√	√	√
100	862800	√	√	√	-
200	502000	√	√	-	-
300	236400	√	√	-	-
400	117900	√	-	-	-
500	54000	√	-	-	-

6.2 GHNA.C200 Throughput Test

6.2.1 Purpose

The purpose of this test is to verify that the SUT running the GHNA.C200 test profile can establish a stable link of sufficient reported performance and stability to pass data traffic at the required data rates relative to the reported physical layer rates.

Test requirement: Conditional mandatory.

6.2.2 Test Setup

1. The SUT SHALL be connected to the test setup shown in Figure 5-1.
2. The coaxial cable lengths listed in Table 5-8, SHALL be used for the testing.
3. The Ethernet/IP Traffic Generator/Analyzer SHALL be configured to transmit a continuous upstream and downstream flow of Ethernet frames.
4. Inject the test noise PSD_{TC} as defined in section 5.3.3.2 at both ends of the loop.

6.2.3 Method of Procedure

1. Allow the SUT to establish a connection through the first loop listed in Table 5-8.
2. Configure and start the traffic generator transmitting frames at the maximum supported interface speed of the traffic generator in both upstream and downstream.
3. Run the traffic for 30 seconds to allow the SUT to perform any adjustments to the link.
4. Record the downstream and upstream data rates reading the estimated application-layer throughput in GAM and GNT (reported in MIB parameter FLOWMONITOR.INFO.XPUT_INDICATOR) and record these values as PHY_DOWN and PHY_UP.
5. Reconfigure and start the traffic generator in both the upstream and downstream directions with a required throughput equal to 47.5% of the aggregate data rate according to the following:

   47.5% * (PHY_DOWN + PHY_UP)

6. After 10 seconds reset the throughput counter from step 5, without stopping the traffic.
7. Let the traffic run for 5 minutes.
8. Record the total number of Ethernet frames transmitted and received in the upstream and downstream directions.
9. Repeat steps 1 through 8 for each of the other loops listed in Table 5-8.

6.2.4 Report

The following items/measurements SHALL be included in the report:

1. PHY_DOWN + PHY_UP recorded in step 4 for each loop length.
2. The required frame rate (derived from the required throughput used in step 5, as defined in section 6.2.3) for each direction and for each loop length.
3. The total number of Ethernet frames transmitted and received in the upstream and downstream directions recorded in step 8 and the derived frame loss ratio in each direction (FLRds and FLRus).

6.2.5 Expected Results

For each loop length:

1. The aggregate data rate (PHY_DOWN + PHY_UP) SHALL be equal to or higher than the required aggregate data rate indicated in Table 6-2 for the specific loop length.
2. The number of dropped downstream (i.e., transmitted minus received) Ethernet frames SHALL not exceed 5, or the FLRds SHALL not exceed the background FLR defined in section 5.1.1.
3. The number of dropped upstream (i.e., transmitted minus received) Ethernet frames SHALL not exceed 5, or the FLRus SHALL not exceed the background FLR defined in section 5.1.1.

Table 6-2 – GHNA.C200 minimum performance requirements

Loop length (m)	Minimum required Aggregate data rate (kbit/s)	Use Case			
		FTTdp	MDU	SFU	FE
100	1264600	√	√	√	√
200	1216800	√	√	-	-
300	1166300	√	√	-	-
400	1107200	√	-	-	-
500	989300	√	-	-	-

End of Broadband Technical Report TR-476