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Evaluation of the Tellabs 1150 GPON Multiservice Access Platform Volume II

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ABSTRACT

For over two years, Sandia National Laboratories has been using a Gigabit Passive Optical Network (GPON) access layer for selected networks. The GPON equipment includes the Tellabs 1150 Multiservice Access Platform (MSAP) Optical Line Terminal (OLT), the Tellabs ONT709 and ONT709GP Optical Network Terminals (ONTs), and the Panorama PON Network Manager.

In late 2013, the Tellabs equipment was updated to Software Release FP27.1_015130. Because a new software release has the potential to affect performance and functionality, it needed to be thoroughly tested. This report documents that testing. It also provides a comparison between the current release and the previous Software Release FP25.5.1_013274 that was being used.

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GLOSSARY

ACL	Access Control List
ARP	Address Resolution Protocol
bps	Bits per Second
CLI	Command Line Interface
CoS	Class of Service
DHCP	Dynamic Host Configuration Protocol
DSCP	Differentiated Services Code Point
FEC	Forward Error Correction
fps	Frames per Second
Gbps	Gigabits per Second
GEM	GPON Encapsulation Method
GPON	Gigabit Passive Optical Network
GUI	Graphical User Interface
IP	Internet Protocol
IPTM	Internet Protocol Telephone Manager
INM	Integrated Network Manager
ITU-T	International Telecommunication Union Telecom Standardization Sector
LAN	Local Area Network
MAC	Media Access Control
Mbps	Megabits per Second
μs	Microseconds
MOS	Mean Opinion Score
MPEG	Motion Picture Experts Group
MSAP	Multiservice Access Platform
NA	Not Applicable
NASA	National Aeronautics and Space Administration
OLT	Optical Line Terminal
ONT	Optical Network Terminal
PCoIP	PC over IP
PoE	Power over Ethernet
PON	Passive Optical Network
QoS	Quality of Service
RDP	Remote Desktop Protocol
RDT	Remote Distribution Terminal
RFC	Request for Comments
s	Seconds
SNL	Sandia National Laboratories
VDI	Virtual Desktop Infrastructure
VLAN	Virtual Local Area Network
VoIP	Voice over Internet Protocol

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1. INTRODUCTION

For over two years, Sandia National Laboratories has been using a Gigabit Passive Optical Network (GPON) access layer for selected networks. The GPON equipment includes the Tellabs 1150 Multiservice Access Platform (MSAP) Optical Line Terminal (OLT), the Tellabs ONT709 and ONT709GP Optical Network Terminals (ONTs), and the Panorama PON Network Manager.

In late 2013, the Tellabs equipment was updated to Software Release FP27.1_015130. Because a new software release has the potential to affect performance and functionality, it needed to be thoroughly tested. This report documents that testing. It also provides a comparison between the current release and the previous Software Release FP25.5.1_013274 that was being used. For an in-depth coverage of Software Release FP25.5.1_013274, please see SAND2012-9525[1].

This report begins with results of throughput tests using the Spirent TestCenter network performance tester. Because Sandia National Laboratories is deploying Voice over IP (VoIP) using this equipment, VoIP testing was also performed and the results are documented in the next section. The Tellabs 1150 MSAP is also used for streaming video. Therefore, streaming video was tested, and the results of those tests are presented. Zero Clients were also tested and the results are documented in the next section. Security is also very important. For that reason, security tests were performed and the results are presented in the next section. Because GPON is designed to be an access layer network technology, the end user field testing results of various applications are then documented. Next, the management of the Tellabs 1150 MSAP and the Tellabs ONTs using the Panorama PON Network Manager is discussed. Because energy consumption is important, the energy used by the Tellabs 1150 MSAP and the ONTs was also tested and results presented. Finally, the report ends with a summary about using this release at Sandia National Laboratories (SNL). The appendices contain detailed testing results. Appendix L presents a performance comparison of Software Release FP25.5.1_013274 and Software Release FP27.1_015130.

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2. TESTED EQUIPMENT

2.1 Tellabs GPON Equipment

Tellabs offers a full line of GPON equipment depending upon the capacity required. The equipment that was tested includes the following:

Tellabs 1150 MSAP - This is the OLT. It consists of the 1150 chassis and various modules which are inserted into the chassis. The 1150 MSAP supports up to 16 GPON QOIU7 modules. Each module has 4 GPON ports. Therefore, the 1150 MSAP can support 64 GPON ports. Each GPON port can support up to 32 ONTs. This allows the 1150 MSAP to support up to 2048 ONTs. The 1150 MSAP can support up to a 400 Gbps switching fabric capacity. It can also support up to 4-10 Gbps and/or 8-1 Gbps uplinks depending upon the configuration.

Tellabs ONT709 - This ONT has four Ethernet ports providing 10/100/1000 Base-T connectivity. The ONT709 is compliant to ITU-T G.984 recommendations.

Tellabs ONT709GP - This ONT has four Power over Ethernet (PoE) ports providing 10/100/1000 Base-T connectivity and ITU-T G.984 compliance.

Tellabs Panorama PON Network Manager - This is the software that is used to manage the Tellabs OLTs and ONTs. It is supported on both Windows and Solaris platforms. It operates in a client/server fashion which allows concurrent access to the Panorama server from multiple Panorama clients.

The Tellabs 1150 MSAP hardware and software used is presented in Table 1.

Table 1. Tellabs 1150 MSAP Hardware and Software

Hardware and Software	Model or Version
Chassis	1150 MSAP
Modules	
Controller and Uplink	ESU2A
GPON Module	2x QOIU7B
ONTs	
Standard ONT	8x ONT709
PoE ONT	1x ONT709GP
Software	
Software Release	FP27.1_015130
Network Manager	Panorama PON 19.1.0 (Build G)

2.2 Other Equipment

There are several other networking components that are needed for the Tellabs 1150 MSAP to function. These components can be categorized as PON equipment and other network equipment.

2.2.1 PON Equipment

This equipment is not specific to GPON and can be used with other Passive Optical Network (PON) technologies such as EPON or XG-PON.

Splitter - Each GPON port connects to a single strand of single-mode fiber. This fiber connects to an optical splitter. Optical splitters come in various sizes or number of splits. Typical sizes are 1x2, 1x4, 1x16, and 1x32. All testing performed in this report was completed with 1x16 splitters. Actual production deployments at SNL are implemented with 1x32 splitters. Each splitter output connects to an individual ONT.

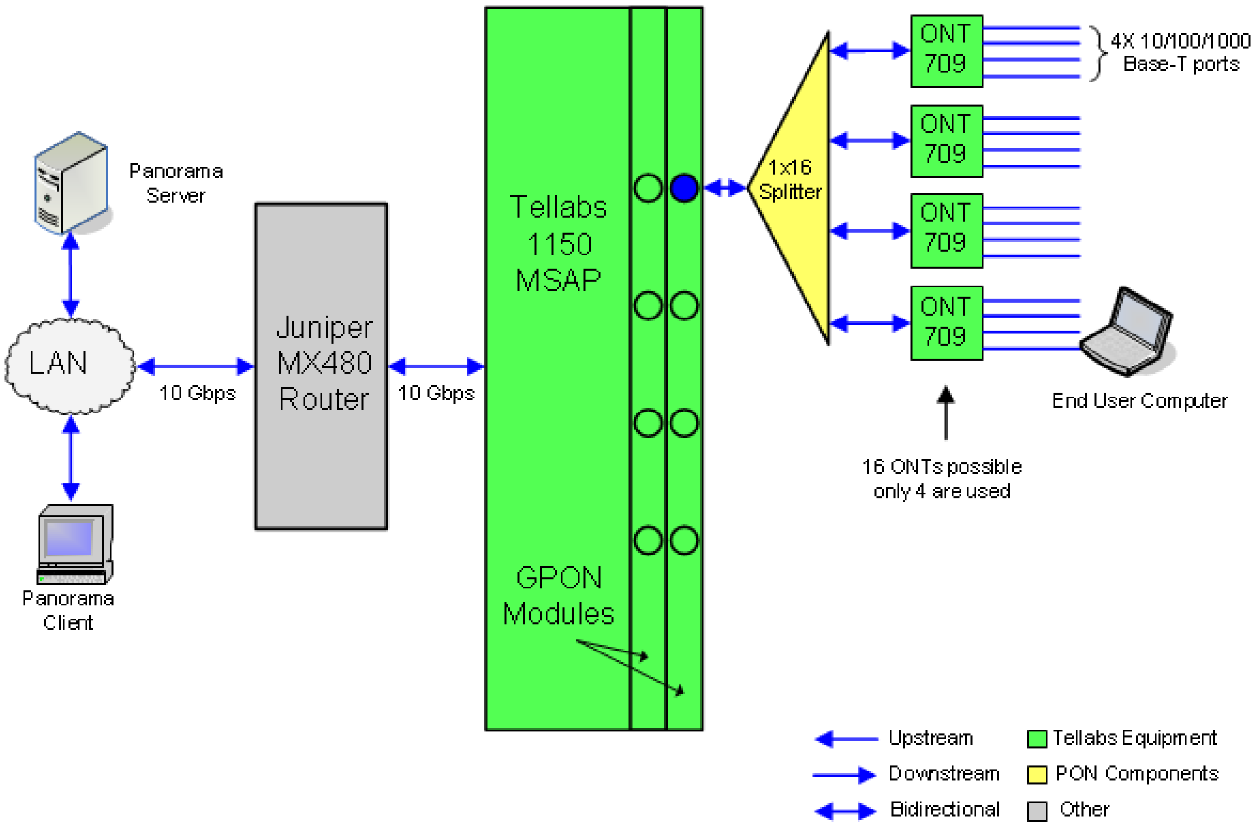
2.2.2 Other Network Equipment

Router - The uplink(s) from the Tellabs 1150 MSAP need to connect to a router. The router performs several important functions. It allows the GPON users to connect to the rest of the network. It provides routing functions for GPON users who are on different Virtual Local Area Networks (VLANs) on the same Tellabs 1150 MSAP to communicate. Users on the same VLAN who are on the same Tellabs 1150 MSAP will not need a router to communicate if they are using the “Full Bridging” mode of operation on the Tellabs 1150 MSAP. The router used for this testing is the Juniper Networks MX480.

Other LAN Equipment - This is other network gear such as switches and other routers which are not directly connected to the Tellabs 1150 MSAP. They provide connectivity to the Panorama server and other servers used for testing.

Figure 1 illustrates a typical Tellabs 1150 MSAP GPON test configuration. The router is used to connect the GPON network to the rest of the network. The Tellabs 1150 MSAP is used to distribute an optical signal to the user network devices which are ONT709s and ONT709GPs. The Panorama PON Network Manager server is used to manage the Tellabs 1150 MSAP and the ONTs.

Figure 1. Tellabs 1150 MSAP GPON Test Configuration



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3. SPIRENT TESTCENTER PERFORMANCE TESTING

3.1 Spirent TestCenter Test Configuration

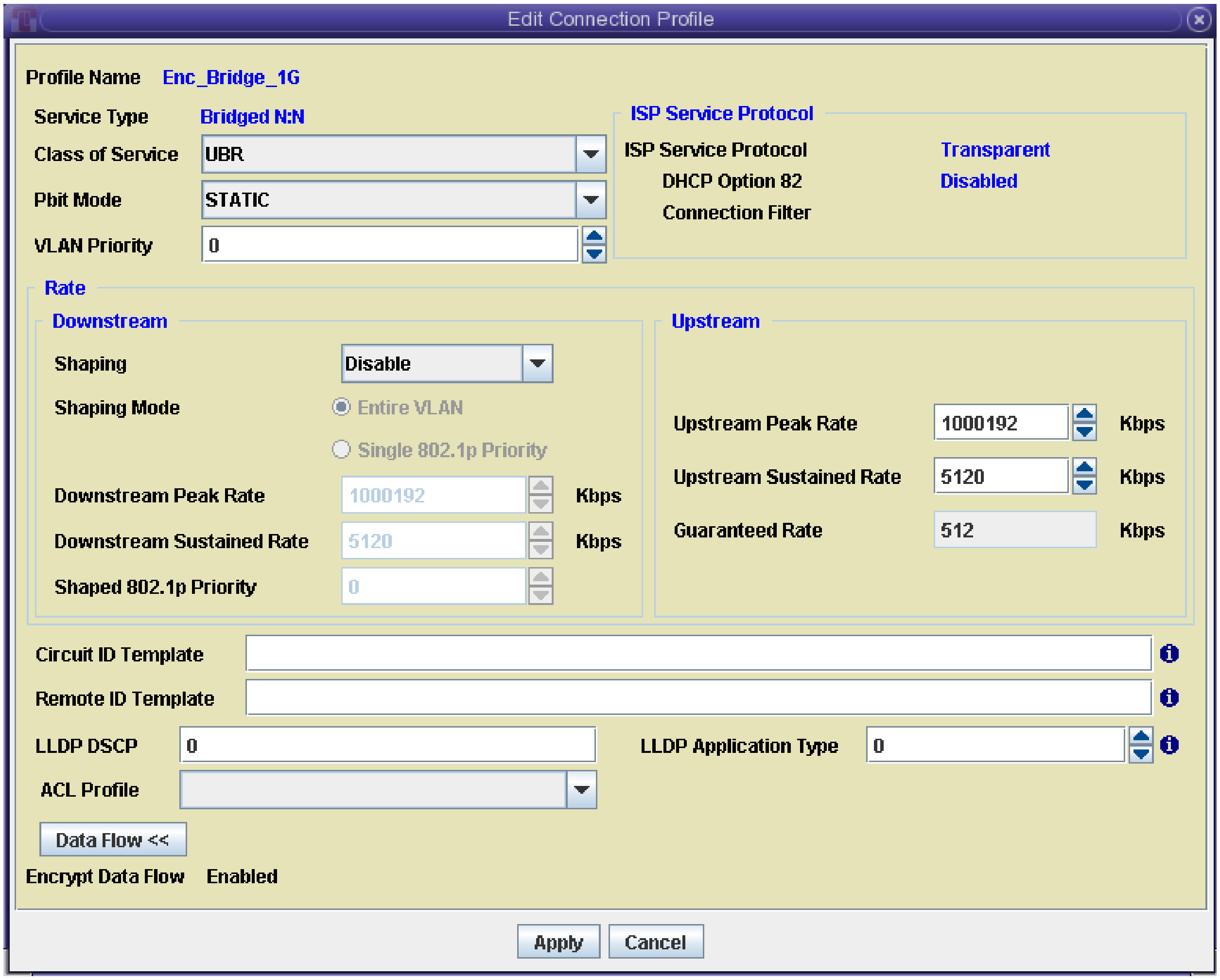
The first set of tests performed used the Spirent TestCenter, a testing platform from Spirent Communications. The Spirent TestCenter consists of a chassis and various test modules such as multi-port 1 Gigabit Ethernet (used) and 10 Gigabit Ethernet modules (not used) and testing software. The Spirent TestCenter hardware and software used in these tests are listed in Table 2. Note that in SAND2012-9525[1] the test duration was 60 seconds. Laboratory experimentation verified that 10 second tests yield the same results as 60 second tests.

Table 2. Spirent TestCenter Hardware and Software

Hardware and Software	Model or Version
Chassis	SPT-3U
Modules	2x HyperMetrics CM-1G-D4 (4 Port Gigabit Ethernet)
Software	
Firmware Version	TestCenter 4.10
Test Suite	RFC 2544
Test Duration	10 seconds
Test Protocol Packets	IP Experimental (Protocol = 253)

For all testing performed, unless otherwise noted, the following traffic profile shown in Figure 2 was set on each ONT port that was connected to each Spirent TestCenter port. Note that Encrypt Data Flow (downstream encryption) and Forward Error Correction (FEC) options were enabled on all GPON ports being tested.

Figure 2. ONT Traffic Profile with Encryption Enabled

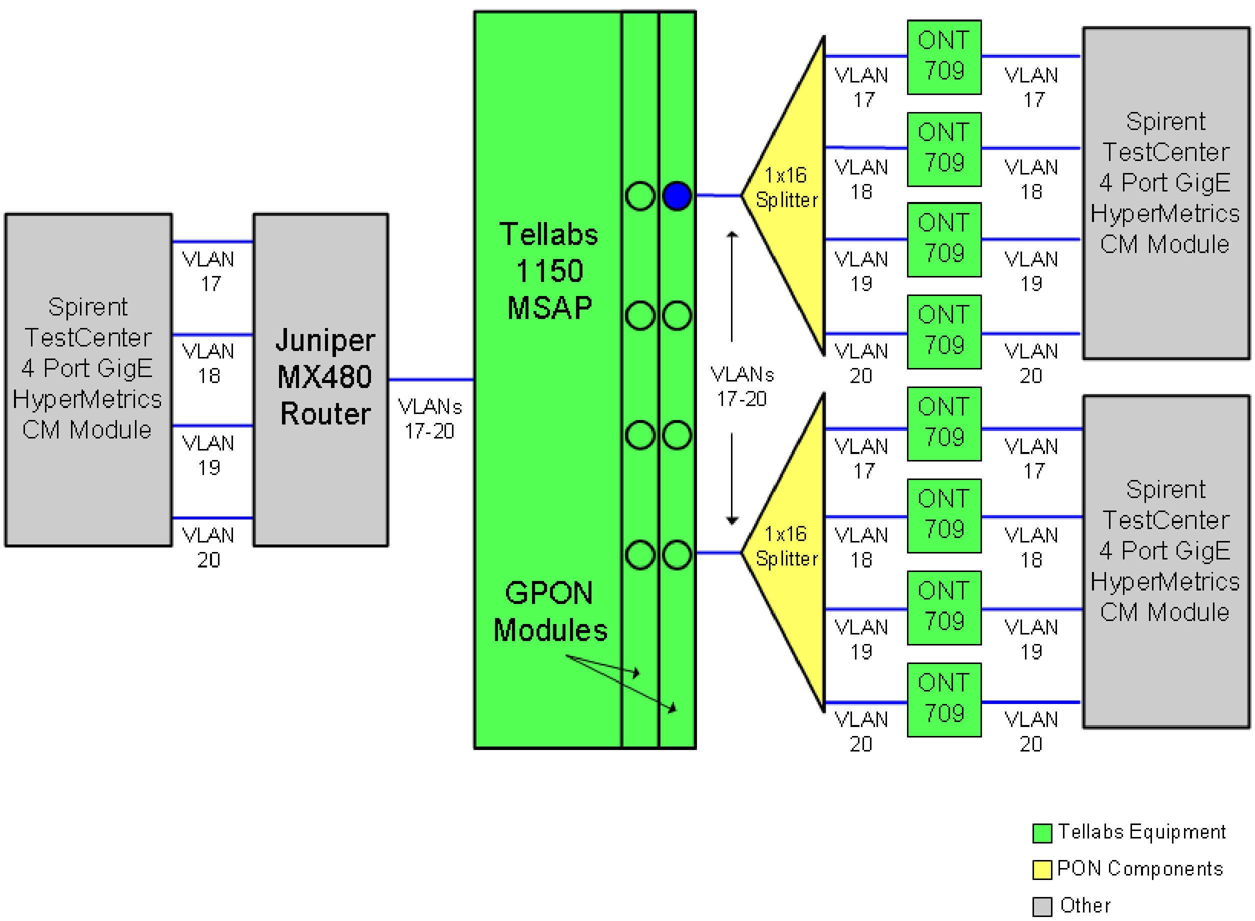


3.2 Spirent TestCenter Test Strategy

As illustrated in Figure 3, the four 10/100/1000 Base-T ports on one Spirent TestCenter CM-1G-D4 module were connected to a port on each of four ONT709s. The four ports from the other CM-1G-D4 module were connected to ports on the Juniper MX480. Each port on the Spirent TestCenter CM-1G-D4 modules was in a separate VLAN. The ONT709 port that was connected to the Spirent TestCenter CM-1G-D4 module was also in the same VLAN as the port on the CM-1G-D4 module. The 10 Gbps uplink from the Tellabs 1150 MSAP carried all 4 test VLANs into the Juniper MX480. There was no routing performed by the Juniper MX480. Note that only 4 ports on the 16 port splitters are being used. Also note that there are only two CM-1G-D4 modules being used for testing, but depending upon the test, the modules can be used in three different configurations.

Once properly connected, the RFC 2544 test suite was run on the Spirent TestCenter for 1, 2, 3, and 4 Stream Blocks. For the purpose of these tests, a Stream Block can be defined as a separate data flow from a Spirent TestCenter CM-1G-D4 port through the ONT709 and Tellabs 1150 MSAP through the Juniper router to a port in the same VLAN on the other Spirent CM-1G-D4. Unless otherwise noted, there is only 1 Stream Block per ONT709. For each Stream Block, the Ethernet frame size was varied to include 64, 128, 256, 512, 1024, 1500, and 1518 byte Ethernet frames. Each Ethernet frame size iteration ran for 10 seconds or until a frame drop occurred. If there was a frame drop, the load was decreased; if there was no drop, the load was increased. Each test was run 5 times and the mean computed from those values. The following graphs present a summary of the results. Detailed results for these tests are presented in Appendices A through K.

Figure 3. VLAN Configuration for all Spirent TestCenter Testing



3.3 Upstream, Downstream, and Bidirectional Testing

Tests were performed for upstream, downstream, and bidirectional traffic. The purpose of these tests is to determine the forwarding rate supported by the Tellabs 1150 MSAP on a single GPON port.

Upstream performance testing was performed first. The configuration for upstream testing is illustrated in Figure 4. Data flows from right to left as denoted by the arrows.

Figure 4. Configuration for Upstream Performance Testing

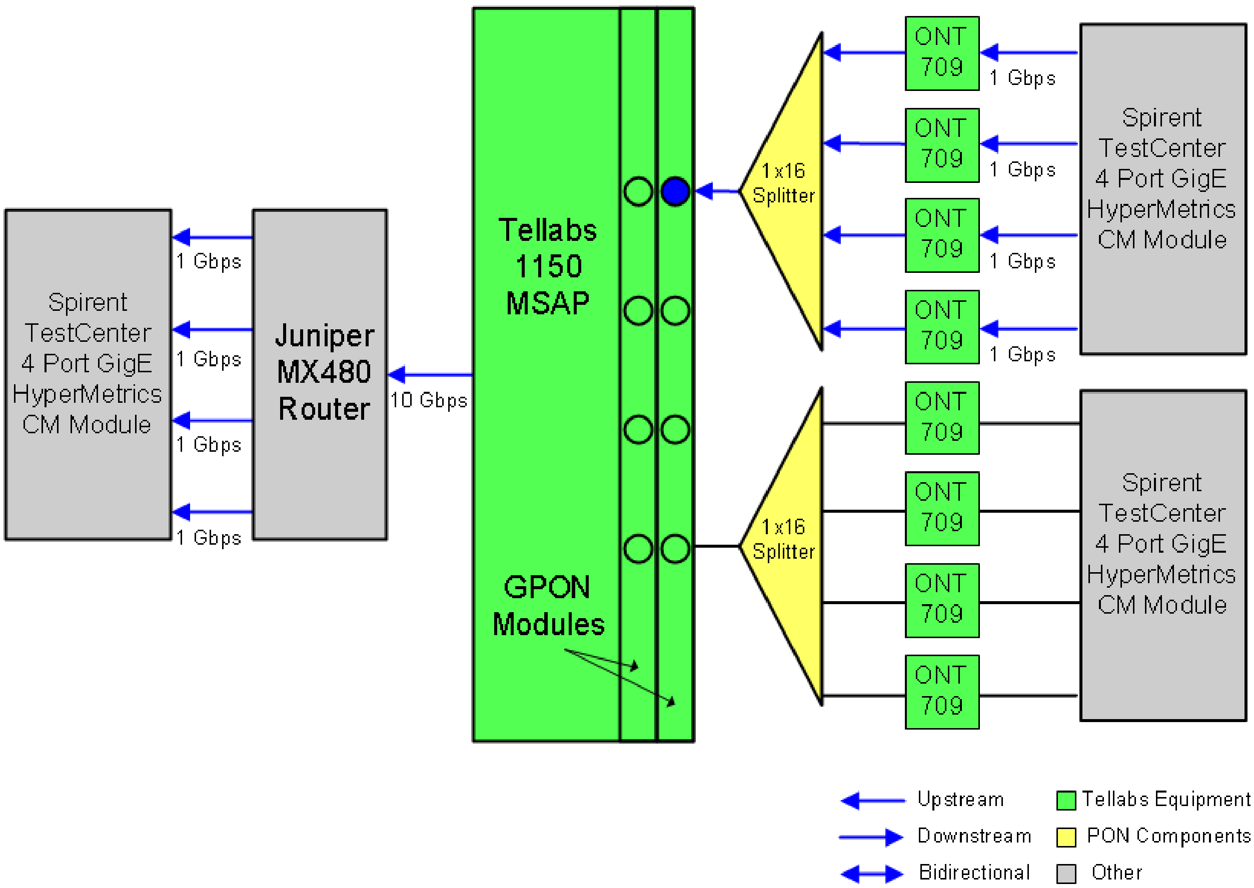
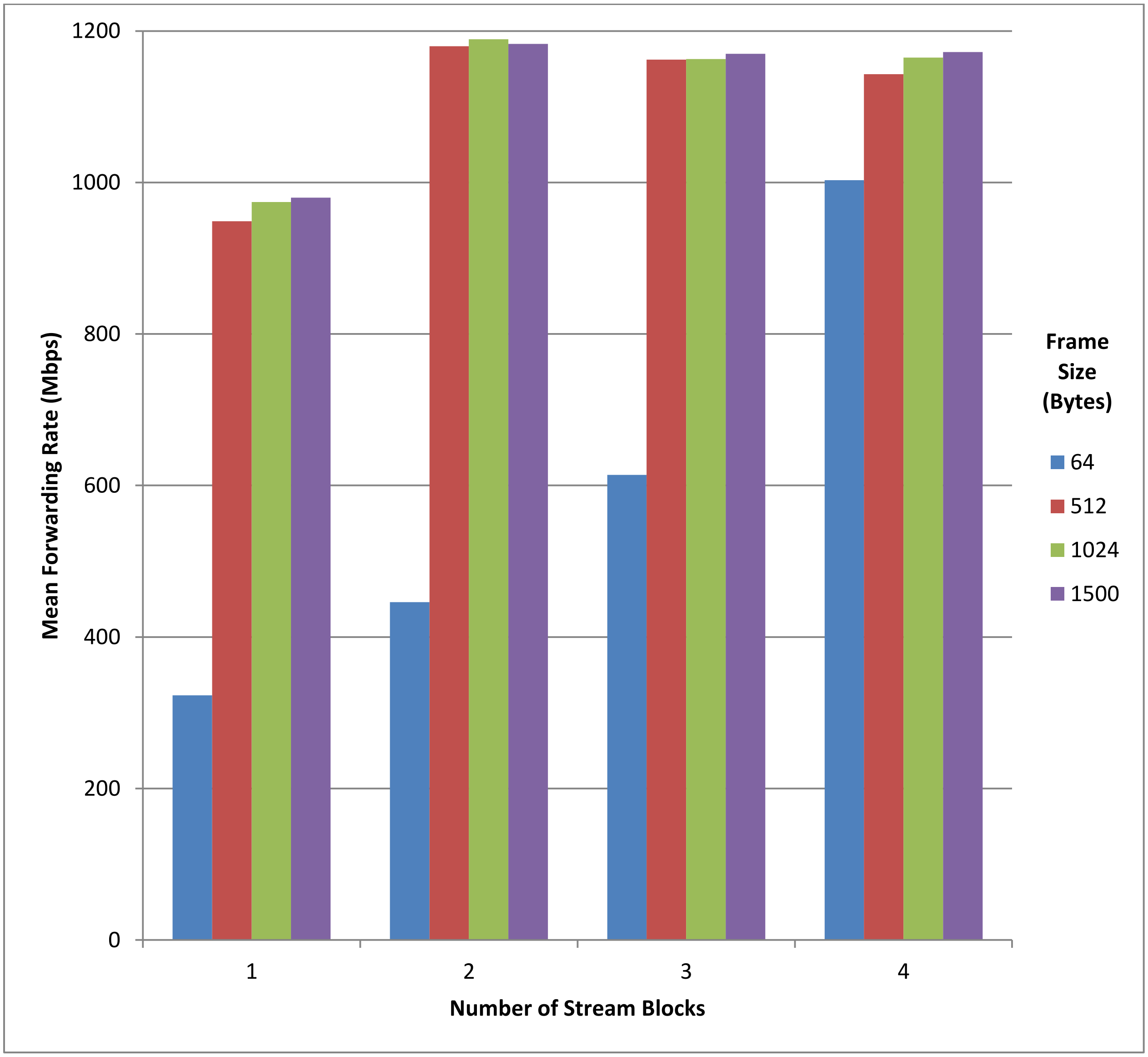


Figure 5 presents the mean upstream forwarding rate performance results for 5 trials with 1, 2, 3, and 4 Stream Blocks. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, a GPON port on the Tellabs 1150 MSAP can support upstream forwarding rates of over 1100 Mbps when more than one ONT709 is used. Detailed results are presented in Appendix A.

Figure 5. Mean Upstream Forwarding Rate Performance Results



Downstream performance testing was performed next. The configuration for downstream performance testing is illustrated in Figure 6. Data flows from left to right as denoted by the arrows.

Figure 6. Configuration for Downstream Performance Testing

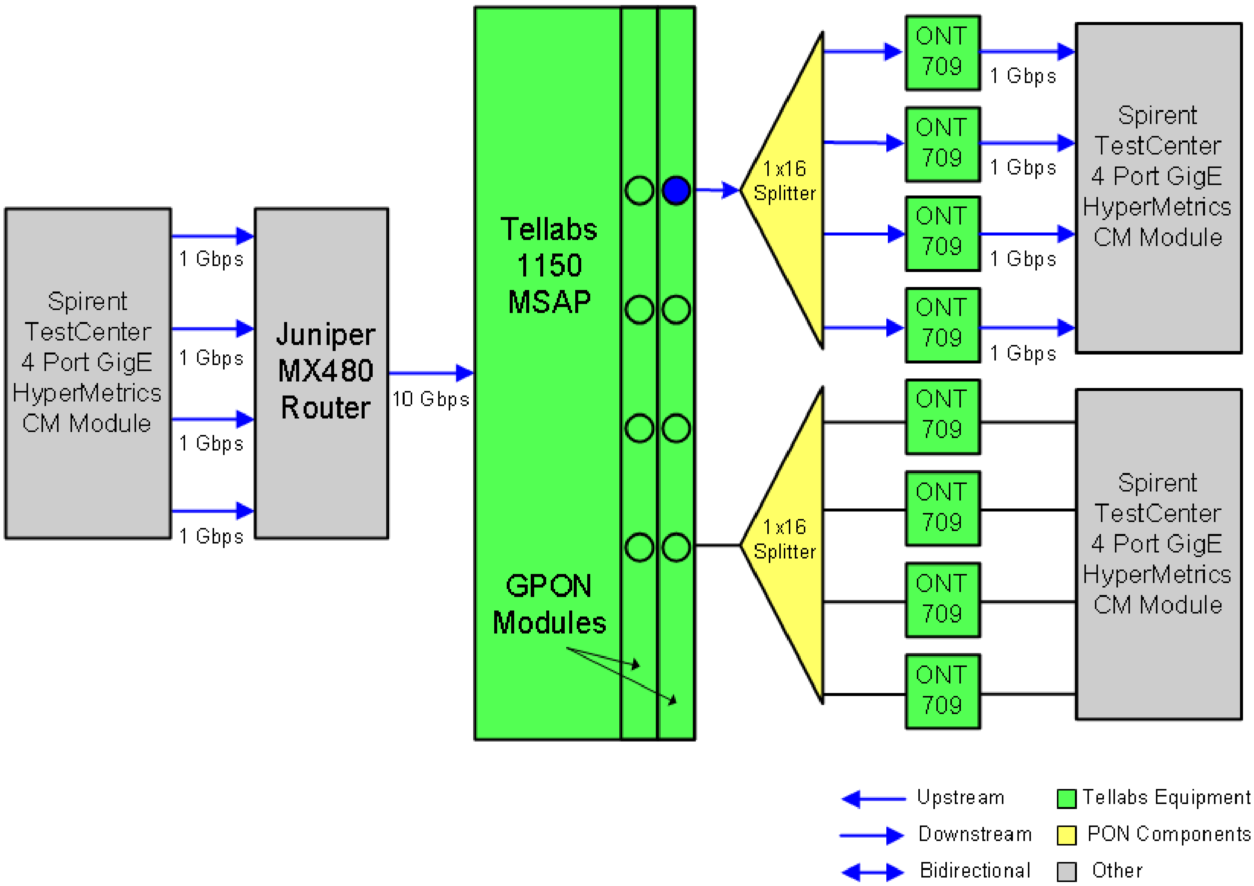
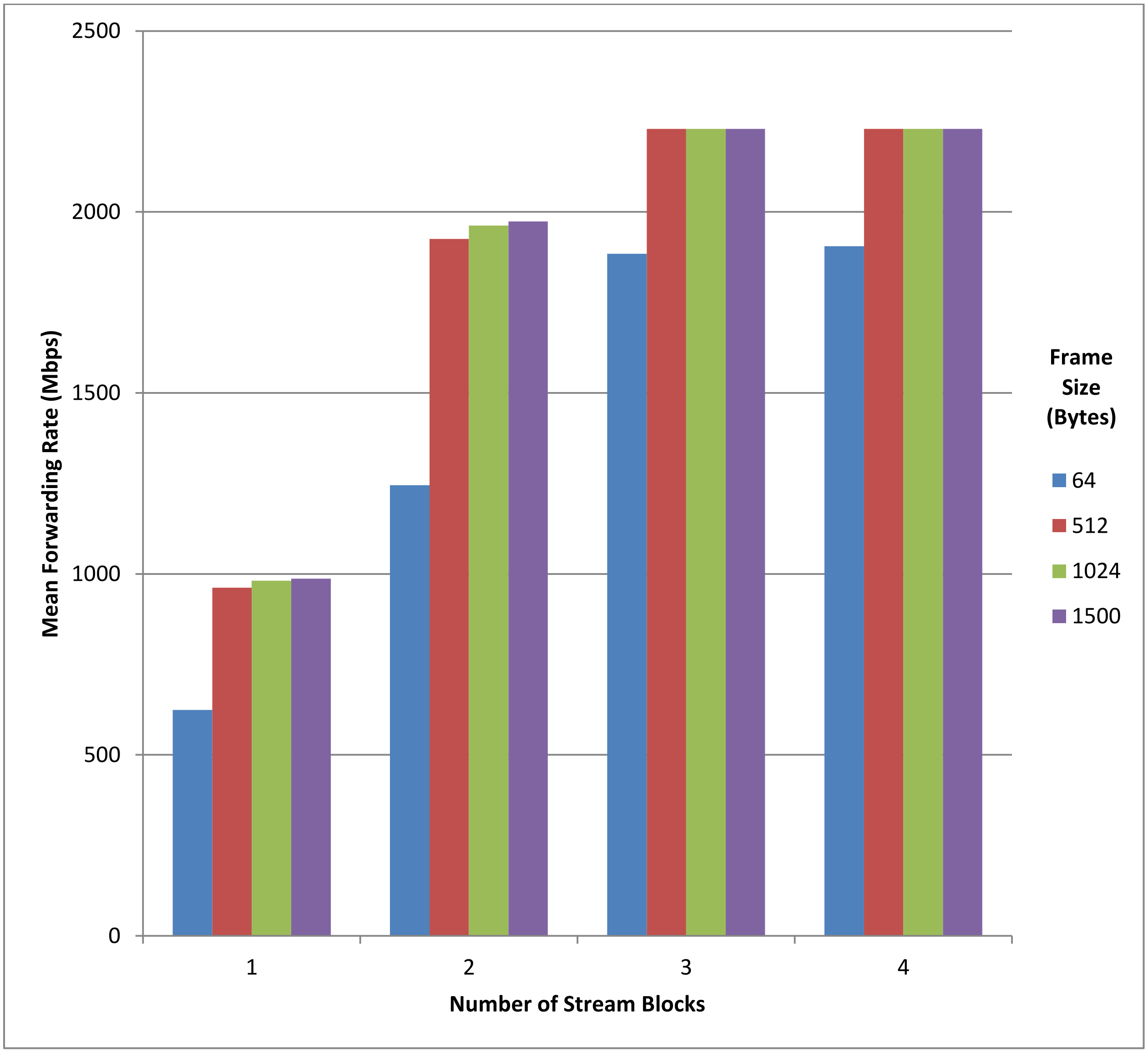


Figure 7 presents the mean downstream forwarding rate performance results for 5 trials with 1, 2, 3, and 4 Stream Blocks. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, a GPON port on the Tellabs 1150 MSAP can support downstream forwarding rates of over 2200 Mbps when more than two ONT709s are used. Detailed results are presented in Appendix B.

Figure 7. Mean Downstream Forwarding Rate Performance Results



Bidirectional performance testing was performed next. The configuration for bidirectional performance testing is illustrated in Figure 8. Data flows upstream and downstream simultaneously as denoted by the arrows.

Figure 8. Configuration for Bidirectional Performance Testing

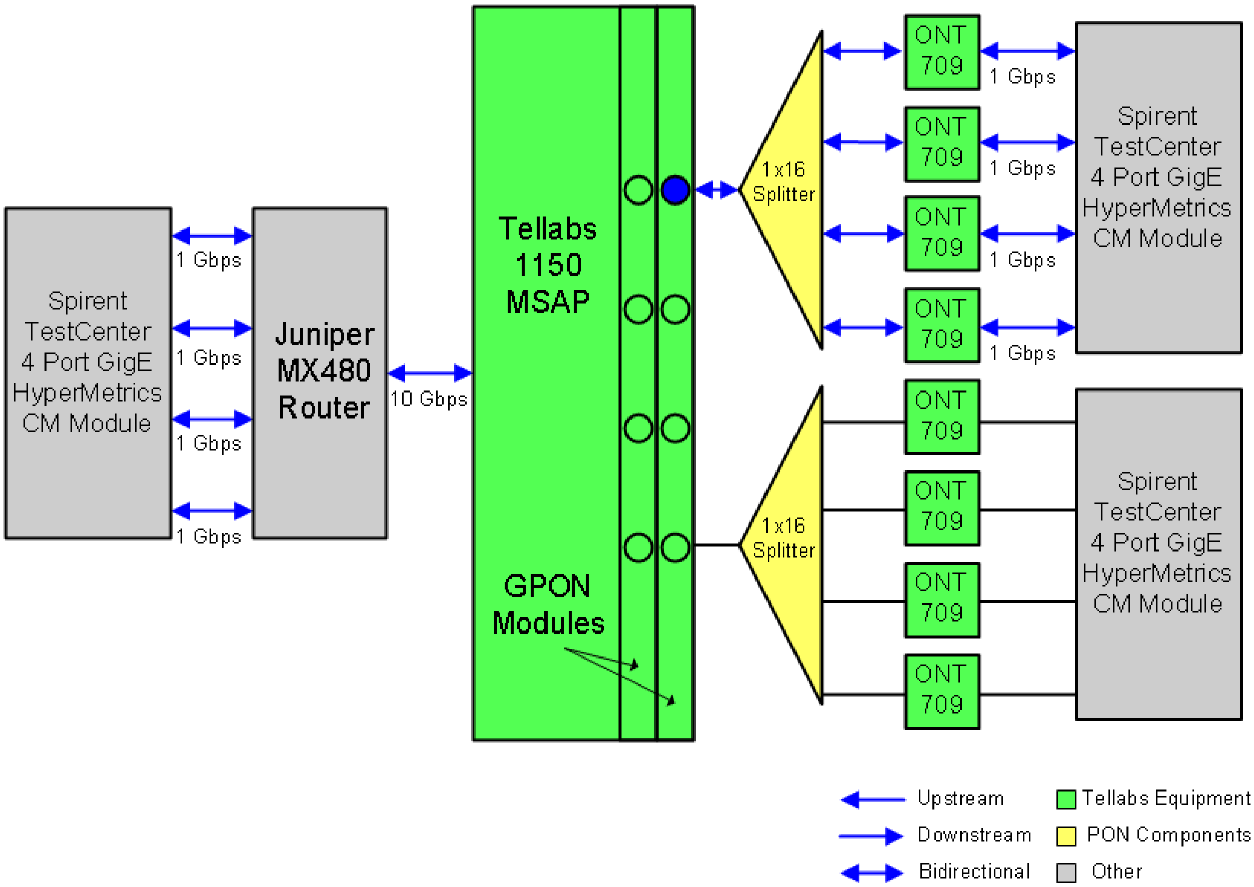
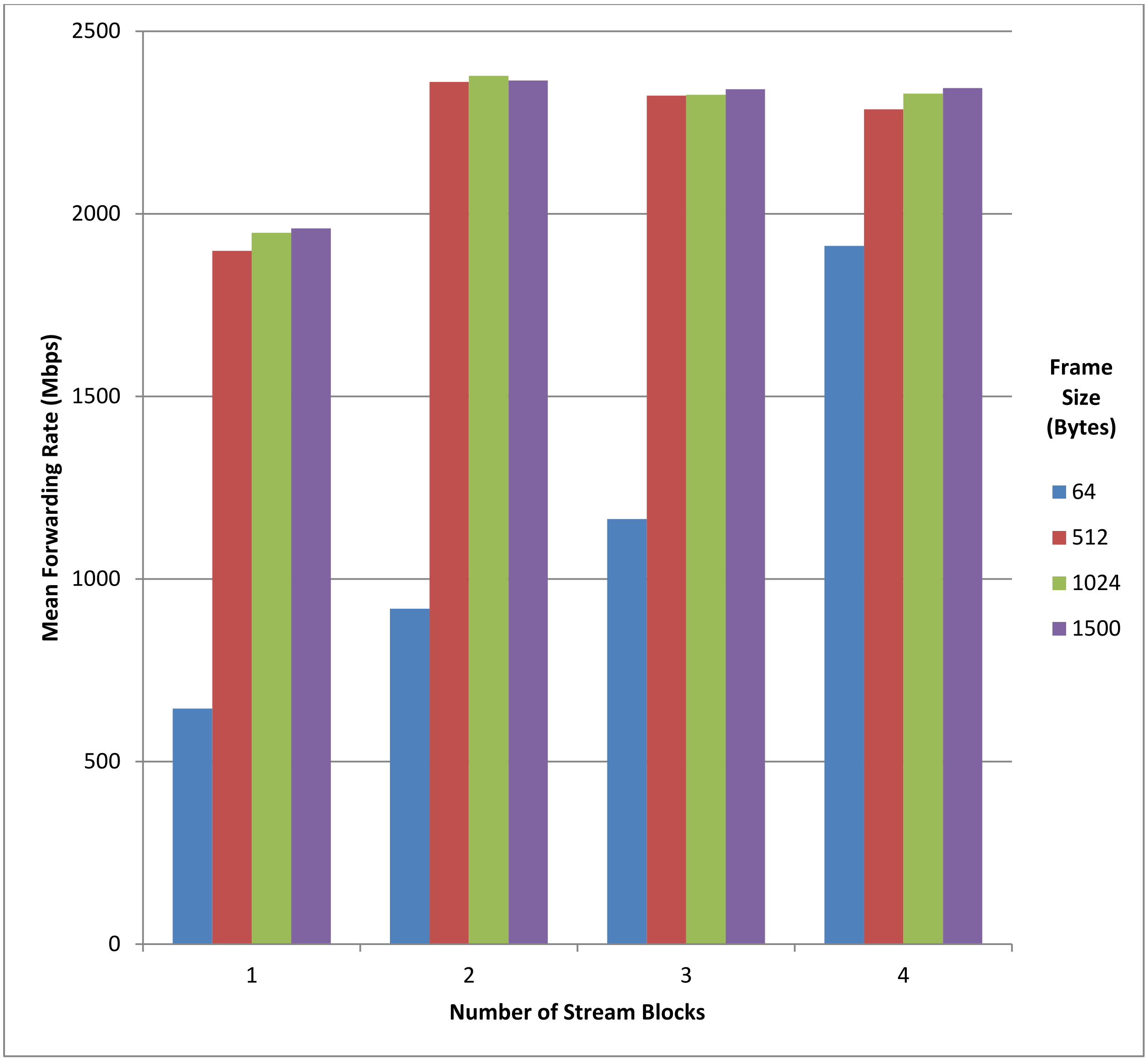


Figure 9 presents the mean aggregate bidirectional forwarding rate performance results for 5 trials with 1, 2, 3, and 4 Stream Blocks. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, a GPON port on the Tellabs 1150 MSAP can support bidirectional forwarding rates of over 2200 Mbps when more than one ONT709 is used. Note that the forwarding rate aggregate is the sum of the forwarding rates in each direction, as it would not be possible for a GPON port to support upstream forwarding rates at 2000 Mbps. Also, these are the results of RFC 2544 Benchmarking Test Package which do not fully test the asymmetric GPON forwarding rates of 1.244 Gbps upstream and 2.488 Gbps downstream independently in each direction. Manual testing has shown that a GPON port on the Tellabs 1150 MSAP can support aggregate bidirectional forwarding rates of over 3000 Mbps. Detailed results are presented in Appendix C.

Figure 9. Mean Aggregate Bidirectional Forwarding Rate Performance Results



3.4 GPON Port to GPON Port Testing Using Different GPON Modules

The purpose of these tests is to determine the forwarding rate supported by the Tellabs 1150 MSAP between GPON ports on different GPON modules. These tests were performed for unidirectional and bidirectional traffic. For unidirectional tests, traffic was flowing upstream on the source GPON port and downstream on the destination GPON port. The configuration for this test is shown in Figure 10.

Figure 10. Configuration for Unidirectional Performance Testing Using Different GPON Modules

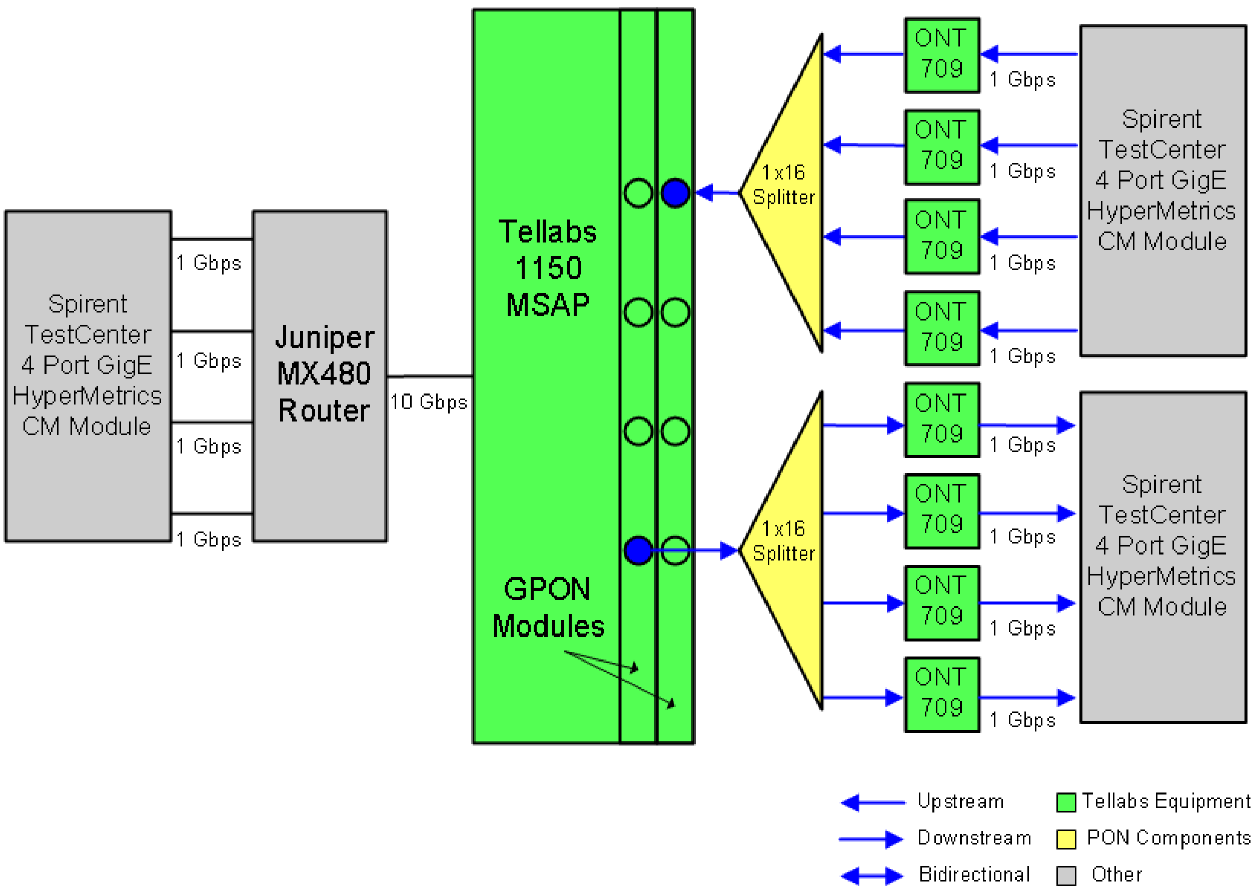
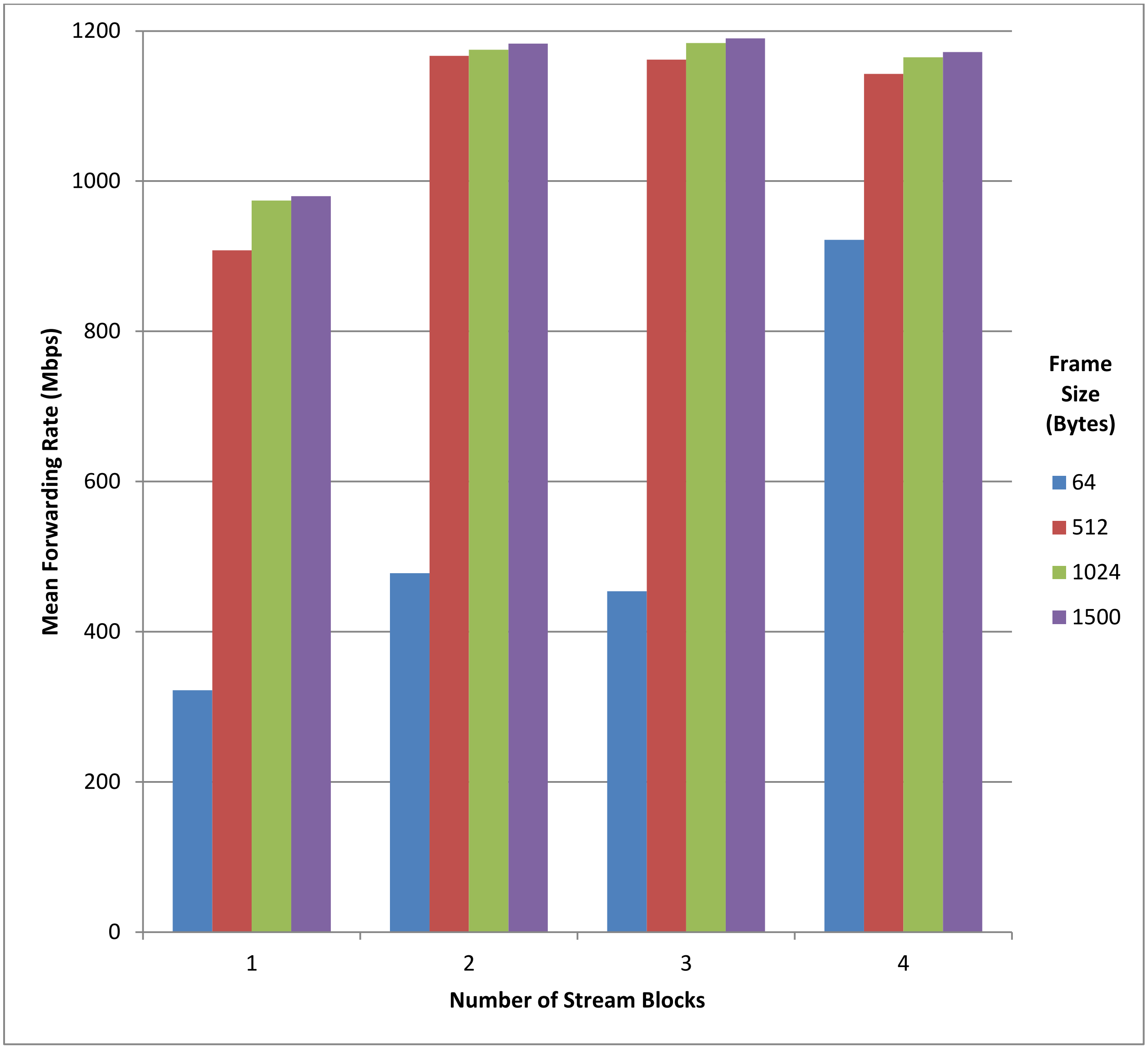


Figure 11 presents the mean unidirectional forwarding rate performance results using different GPON modules for 5 trials with 1, 2, 3, and 4 Stream Blocks. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, a GPON port on the Tellabs 1150 MSAP can support forwarding rates of over 1100 Mbps when more than two ONT709s are used and the destination ONT709s are located on a GPON port on a different GPON module. Detailed results are presented in Appendix D.

Figure 11. Mean Unidirectional Forwarding Rate Performance Results Using Different GPON Modules



Bidirectional performance testing between ONT709s located on ports on different GPON modules was also performed. For these tests, data was flowing upstream and downstream simultaneously on each GPON port as illustrated in Figure 12.

Figure 12. Configuration for Bidirectional Performance Testing Using Different GPON Modules

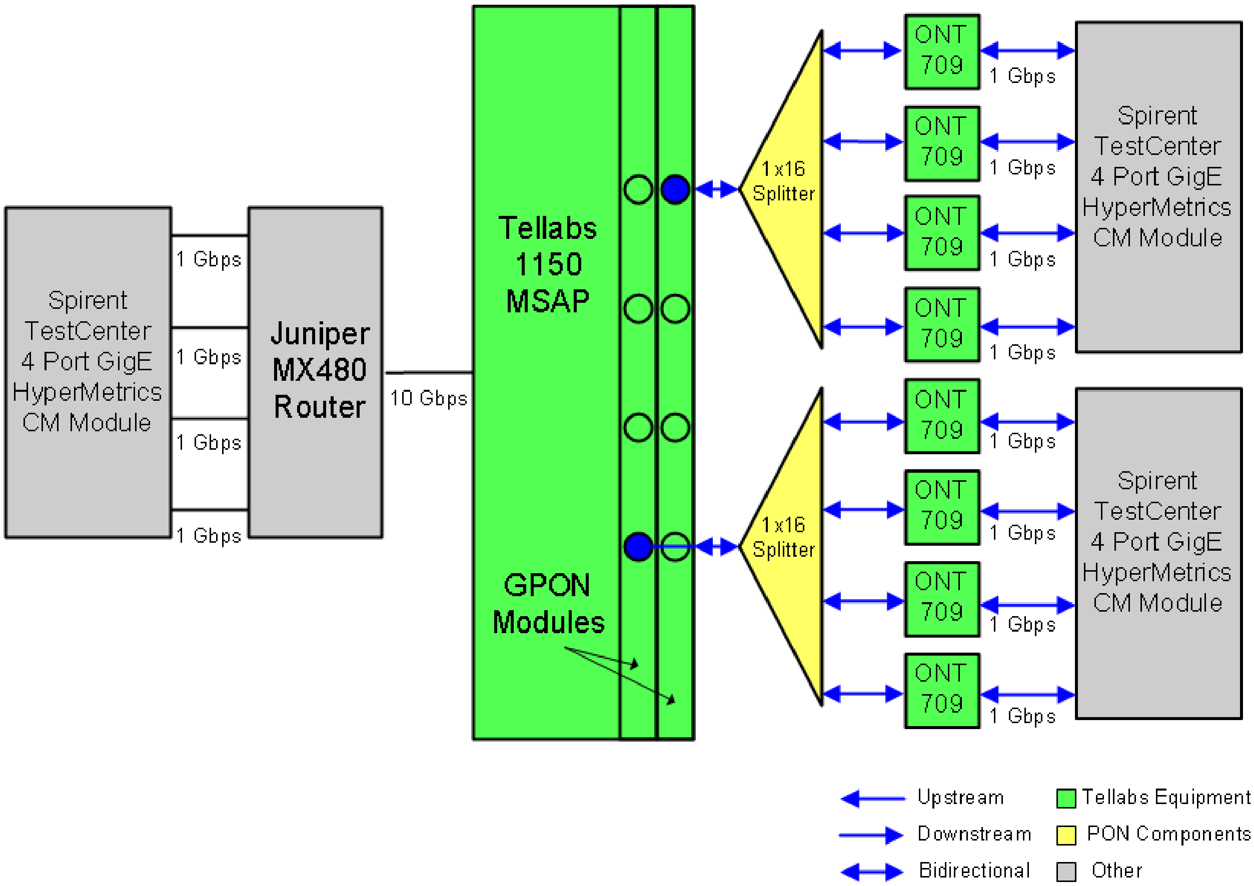
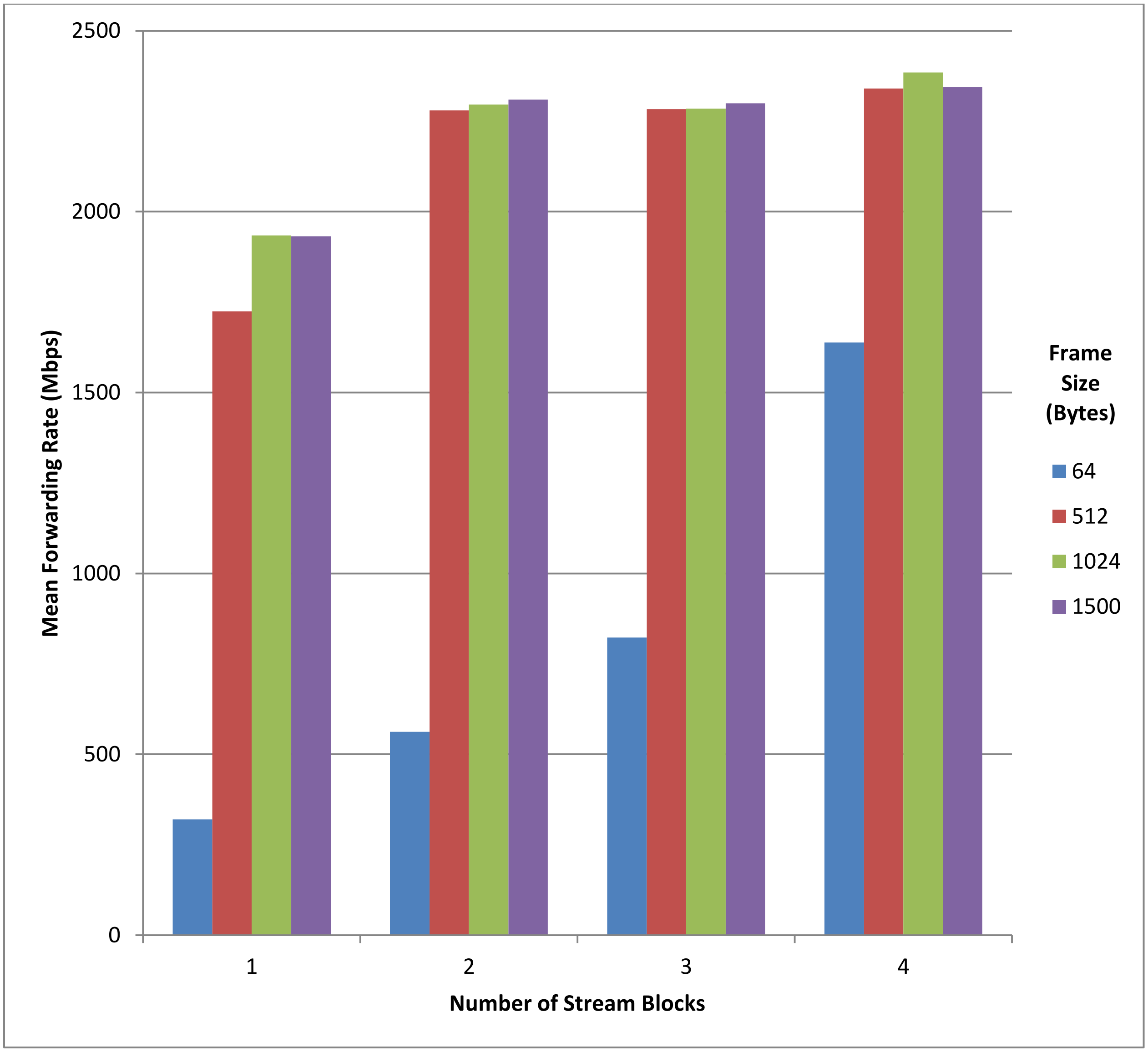


Figure 13 presents the mean aggregate bidirectional forwarding rate performance results using different GPON modules for 5 trials with 1, 2, 3, and 4 Stream Blocks. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, a GPON port on the Tellabs 1150 MSAP can support forwarding rates of over 2000 Mbps when more than two ONT709s are used and the destination ONT709s are located on a GPON port on a different GPON module. Detailed results are presented in Appendix D.

Figure 13. Mean Aggregate Bidirectional Forwarding Rate Performance Results Using Different GPON Modules



3.5 GPON Port to GPON Port Testing Using the Same GPON Module

The purpose of these tests is to determine the forwarding rate supported by the Tellabs 1150 MSAP between ONT709s when the GPON ports are located on the same GPON module. These tests were performed for unidirectional and bidirectional traffic. For unidirectional tests, traffic was flowing upstream on the source GPON port and downstream on the destination GPON port. The configuration for this test is shown in Figure 14.

Figure 14. Configuration for Unidirectional Performance Testing Using the Same GPON Module

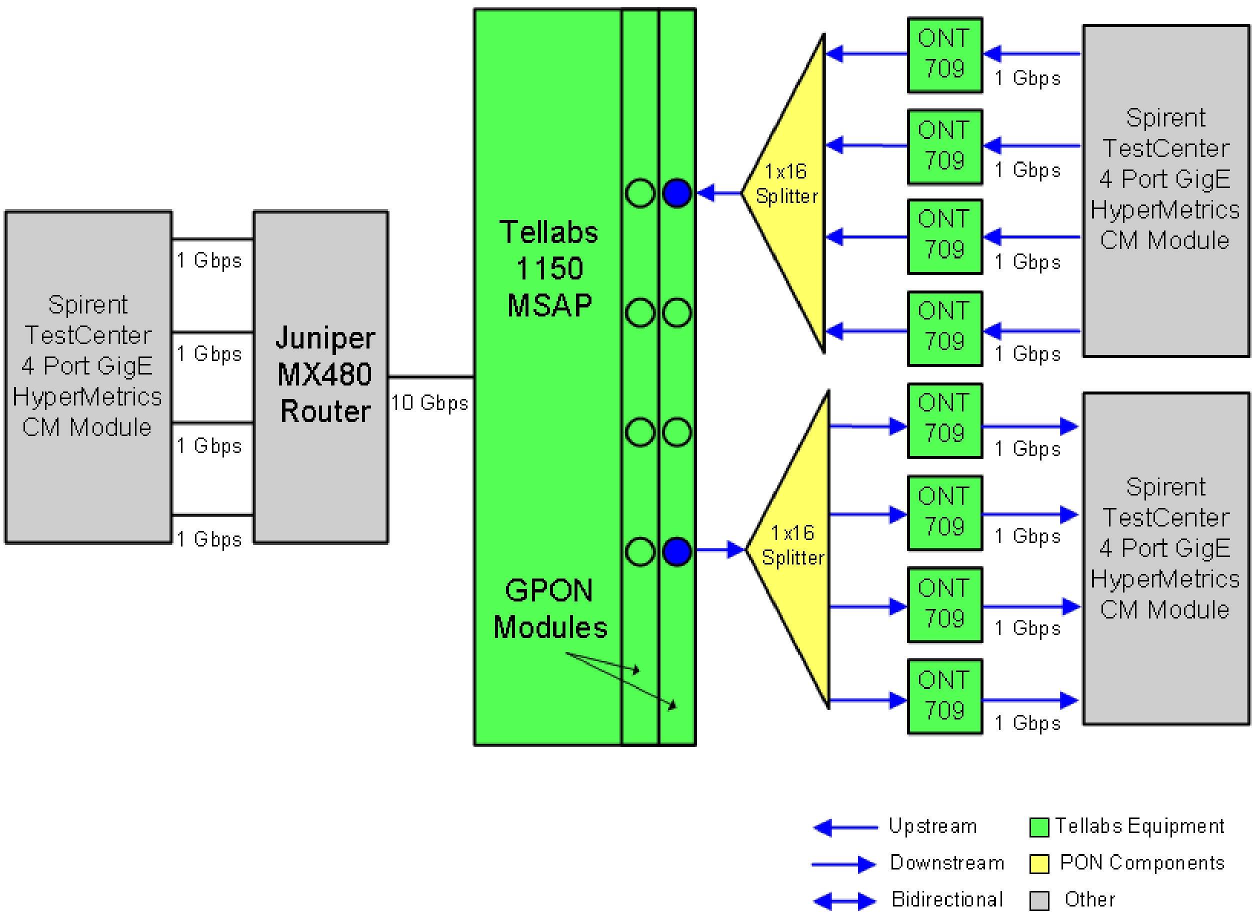
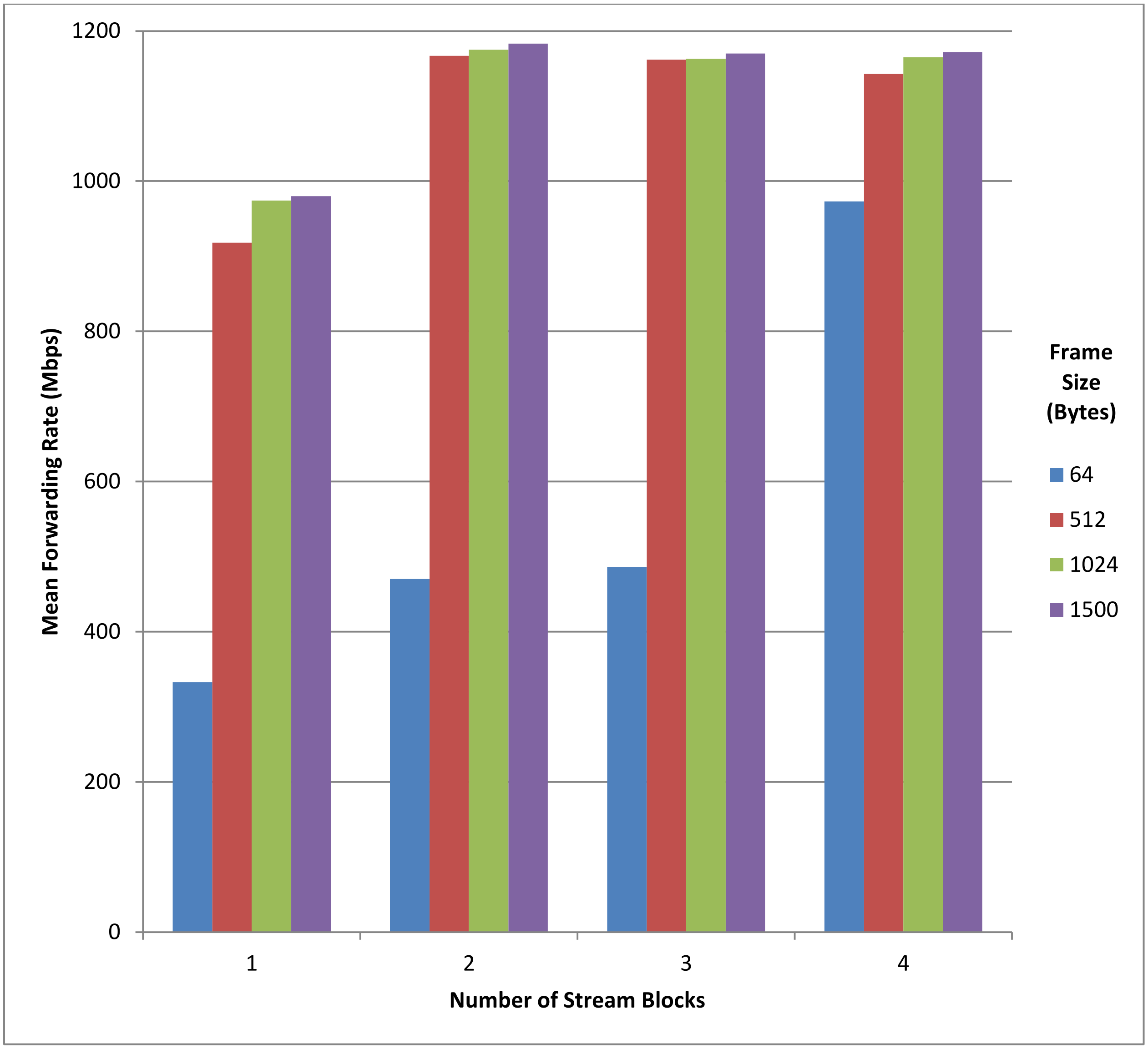


Figure 15 presents the mean unidirectional forwarding rate performance results using the same GPON module for 5 trials with 1, 2, 3, and 4 Stream Blocks. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, a GPON port on the Tellabs 1150 MSAP can support forwarding rates of over 1100 Mbps when two or more ONT709s are used and the destination ONT709s are located on a different GPON port on the same GPON module. Detailed results are presented in Appendix E.

Figure 15. Mean Unidirectional Forwarding Rate Performance Results Using the Same GPON Module



Bidirectional performance testing between ONT709s located on ports on the same GPON module was performed next. For these tests, data was flowing upstream and downstream simultaneously on each GPON port as illustrated in Figure 16.

Figure 16. Configuration for Bidirectional Performance Testing Using the Same GPON Module

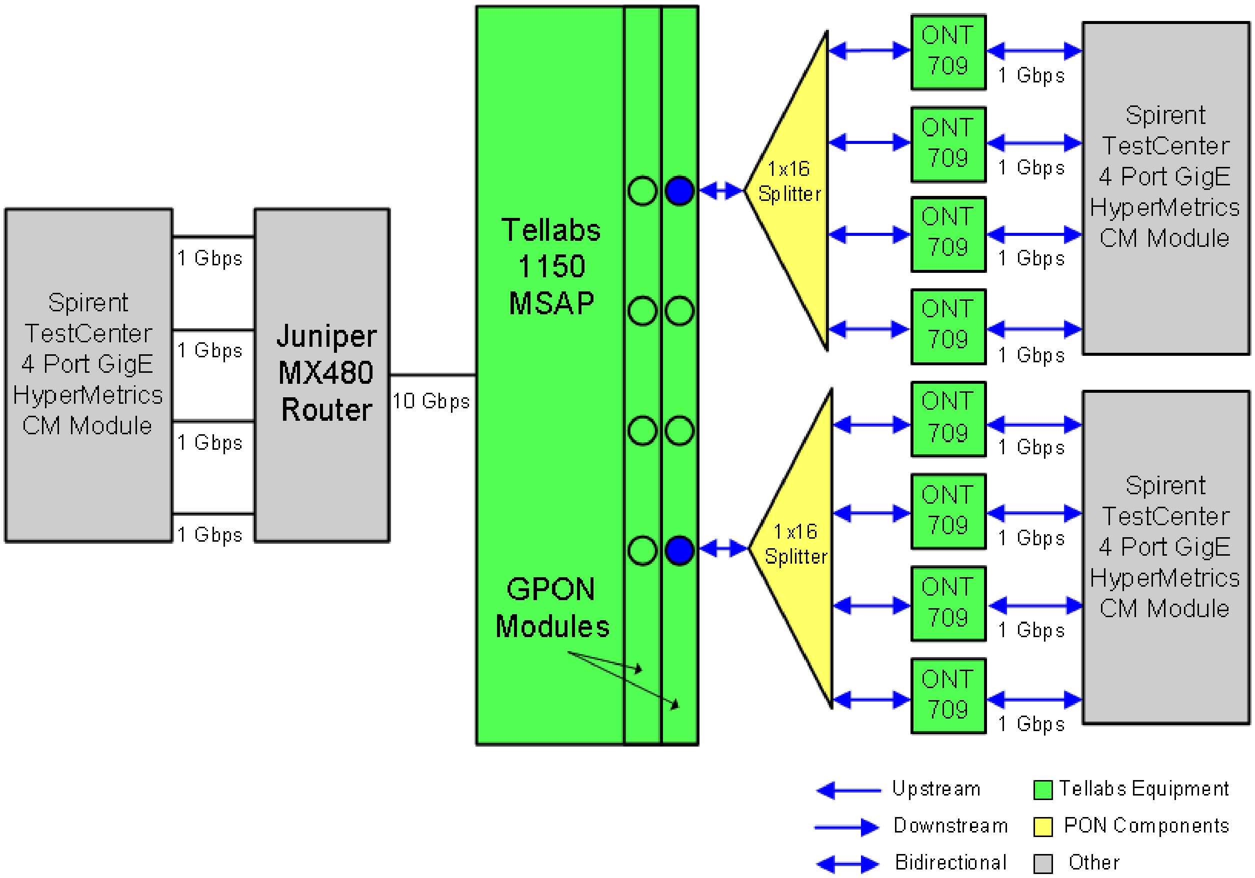
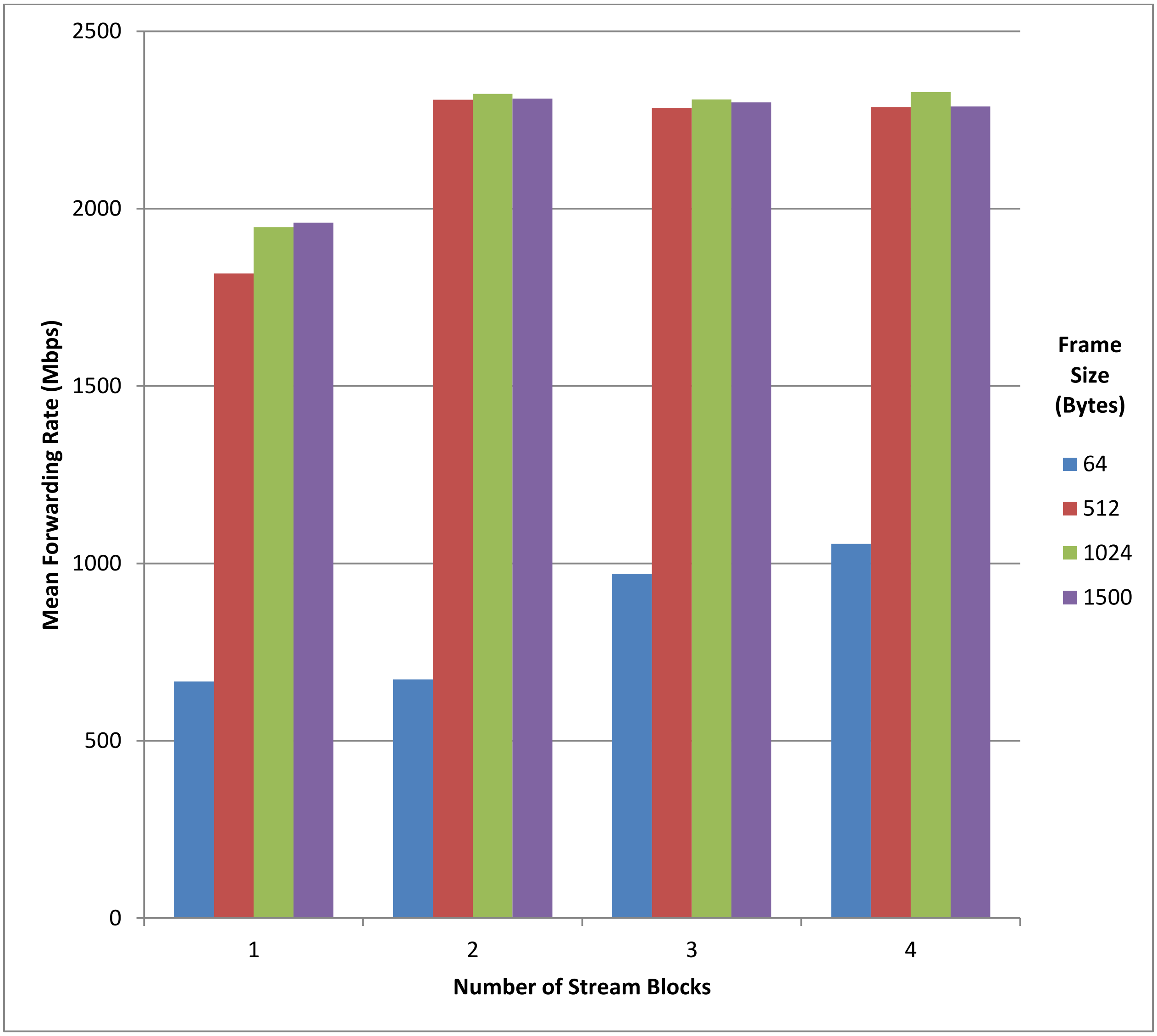


Figure 17 presents the mean aggregate bidirectional performance results using the same GPON module for 5 trials with 1, 2, 3, and 4 Stream Blocks. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, a GPON port on the Tellabs 1150 MSAP can support forwarding rates of over 2200 Mbps when two or more ONT709s are used and the destination ONTs are located on a GPON port on the same GPON module. Detailed results are presented in Appendix E.

Figure 17. Mean Aggregate Bidirectional Performance Results Using the Same GPON Module



3.6 Single ONT709 Testing

The purpose of these tests is to determine the forwarding rate supported by a single Tellabs ONT709. These tests were performed for upstream, downstream, and bidirectional traffic. The tests were conducted for 1, 2, 3, and 4 ports through a single ONT709. Upstream performance testing was completed first. The configuration for this test is shown in Figure 18.

Figure 18. Configuration for Upstream Performance Testing Using a Single ONT709

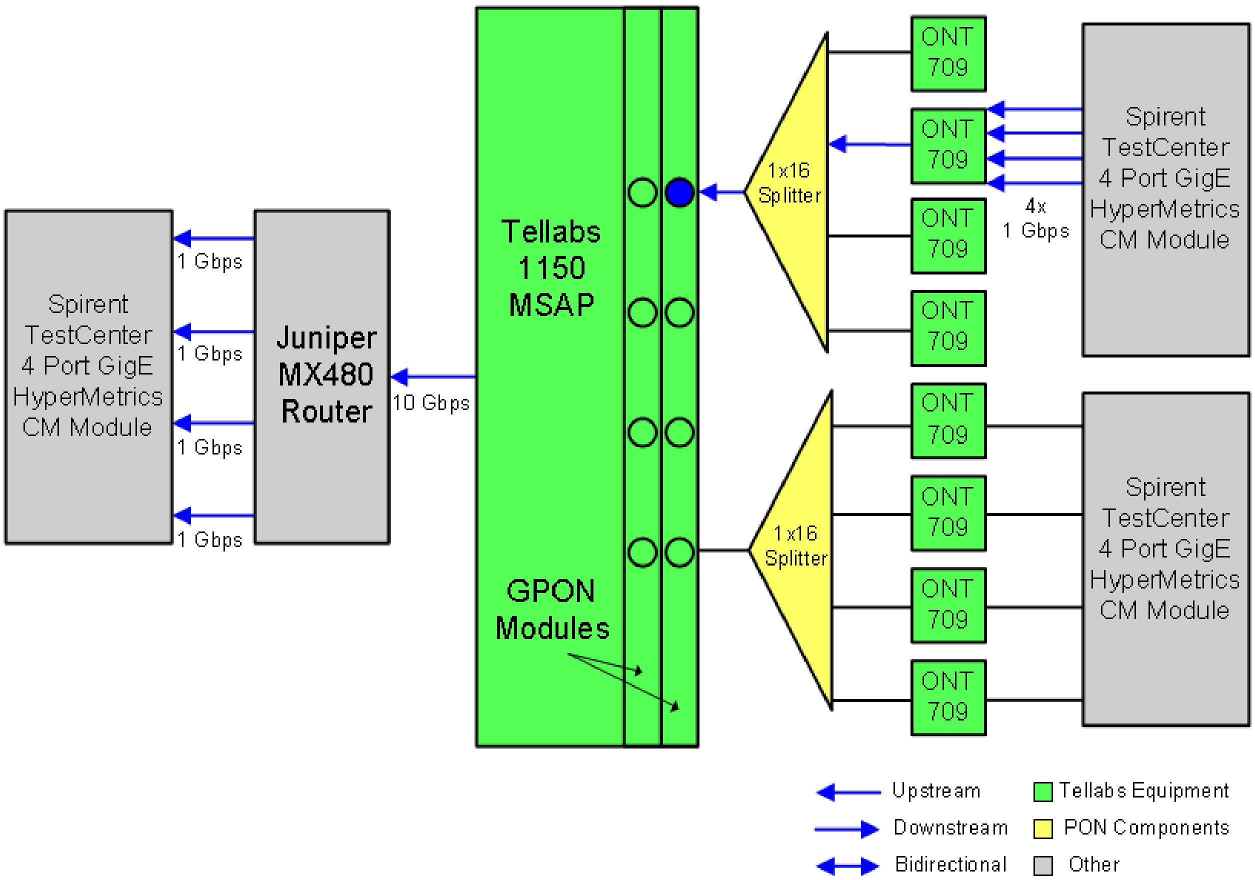
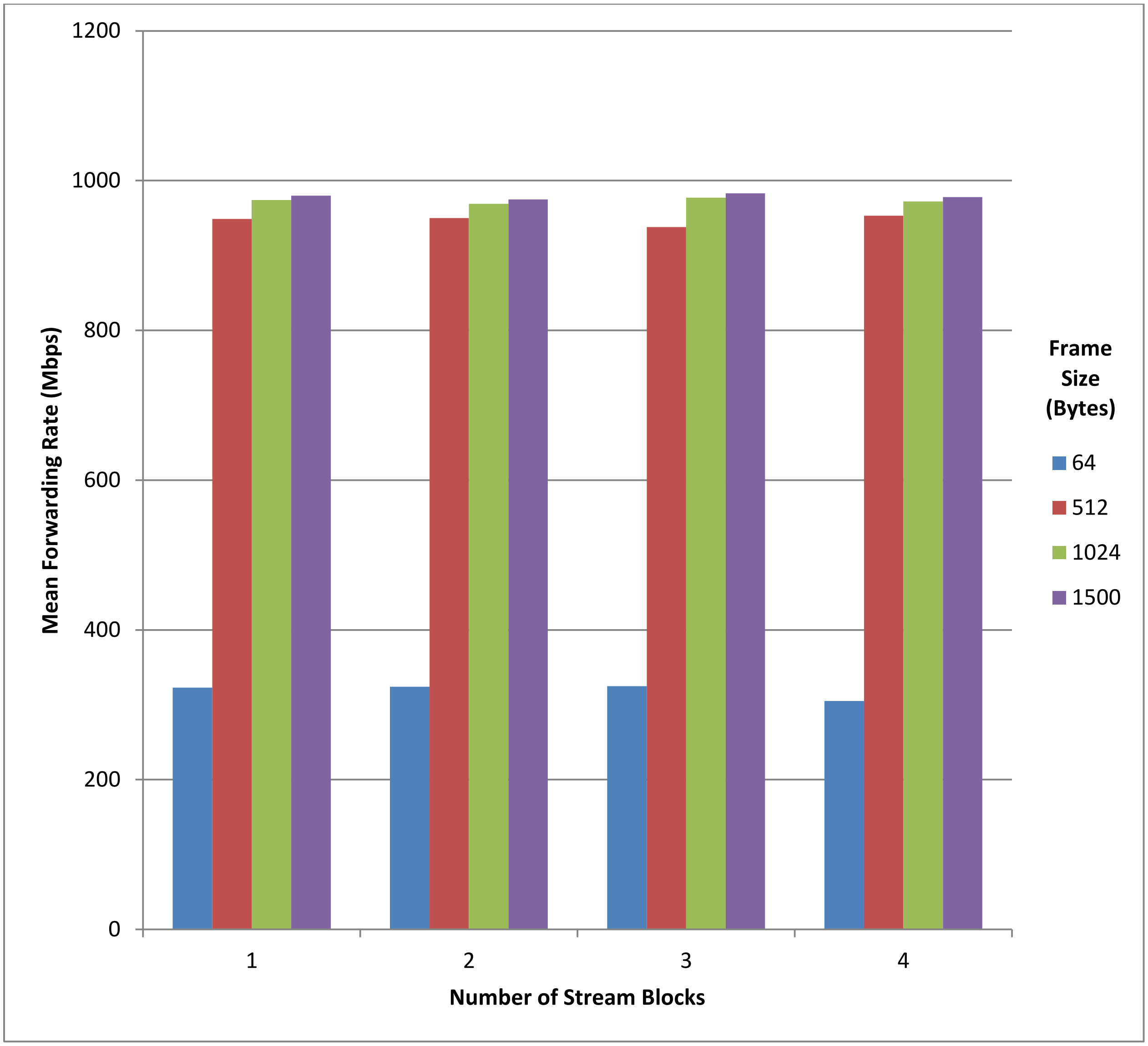


Figure 19 presents the mean upstream forwarding rate performance results using a single ONT709 for 5 trials with 1, 2, 3, and 4 Stream Blocks. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, a single Tellabs ONT709 can support upstream forwarding rates of nearly 1000 Mbps for 1, 2, 3, and 4 Stream Blocks. Detailed results for 1, 2, 3, and 4 Stream Blocks are presented in Appendix F.

Figure 19. Mean Upstream Forwarding Rate Performance Results Using a Single ONT709



Downstream performance testing using a single ONT709 was also performed. The configuration for downstream performance testing is illustrated in Figure 20.

Figure 20. Configuration for Downstream Performance Testing Using a Single ONT709

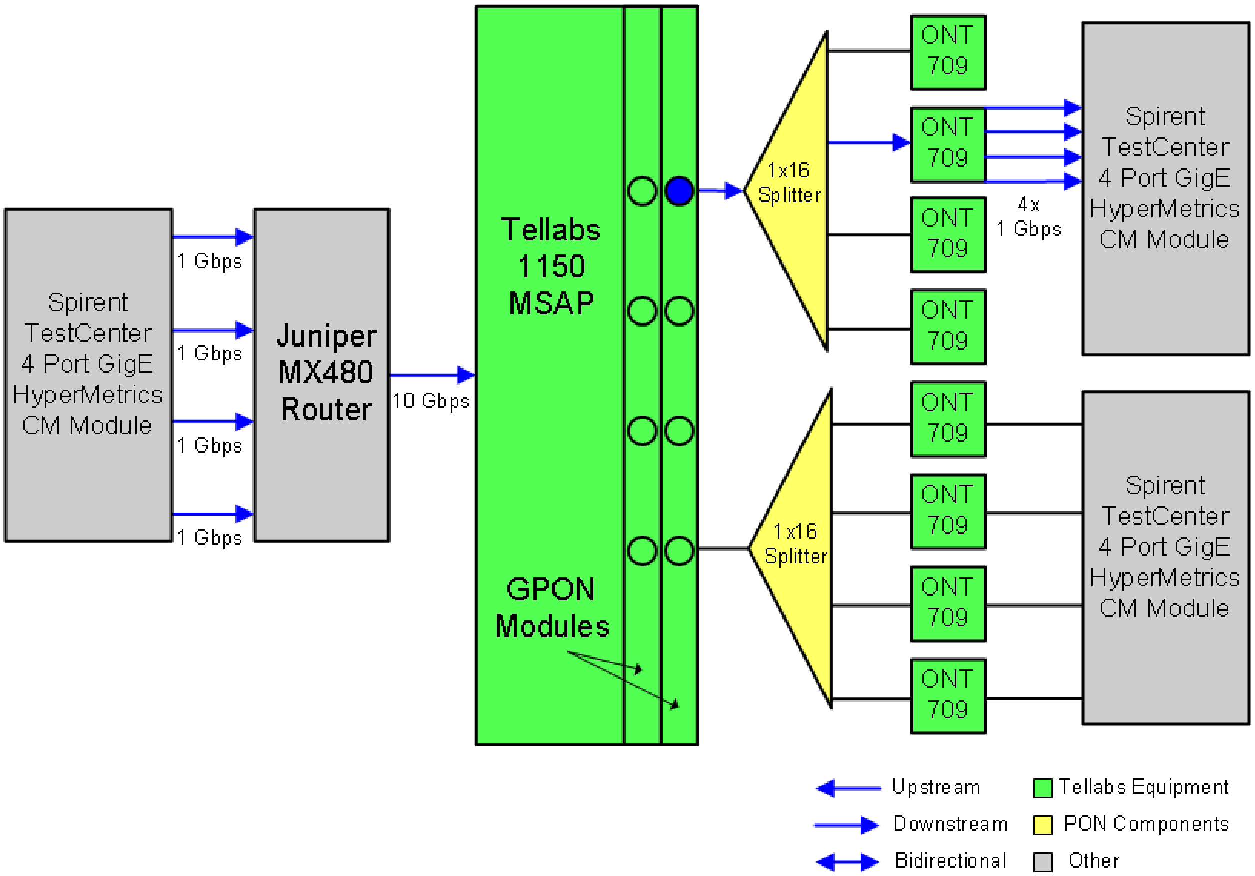
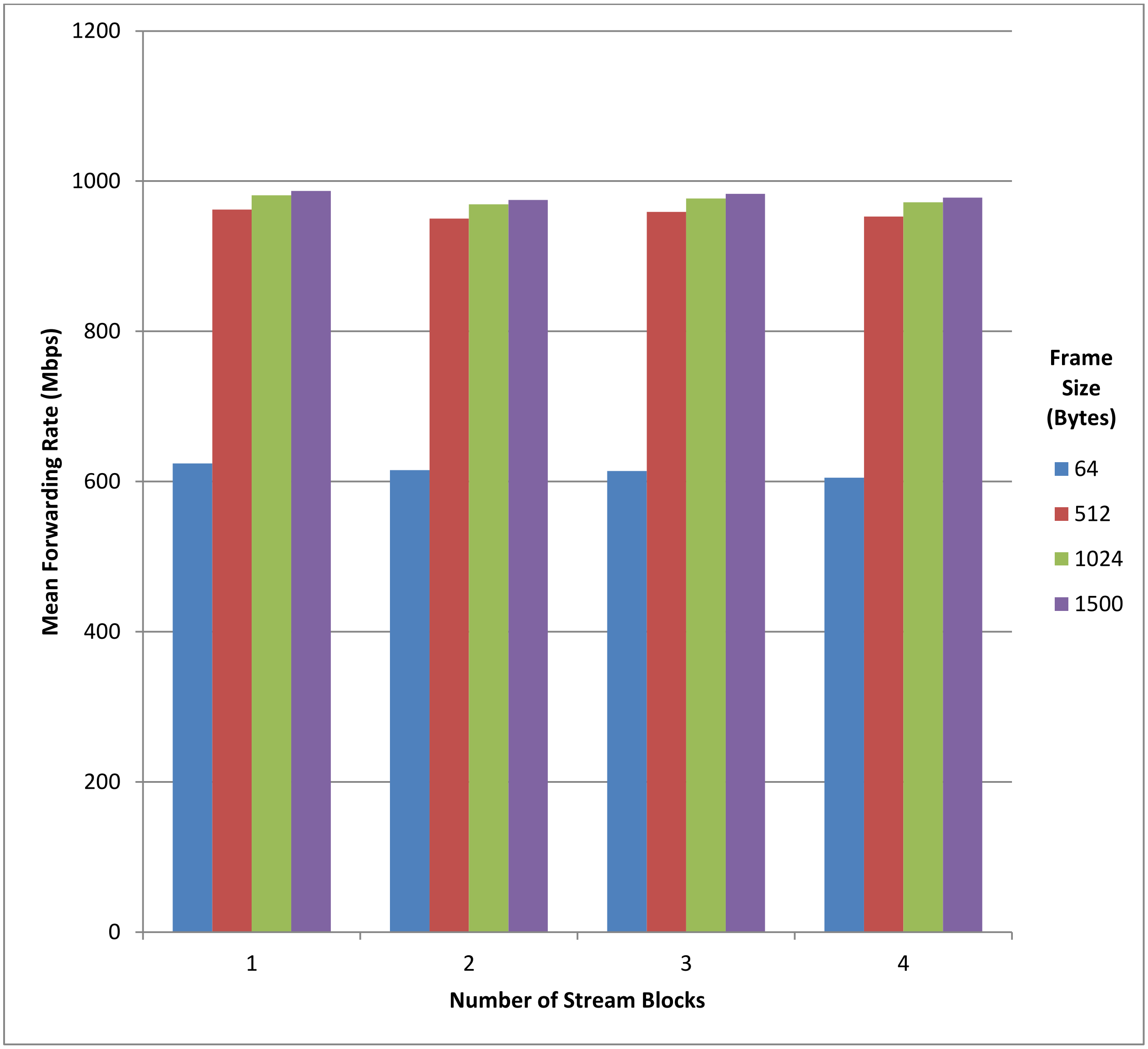


Figure 21 presents the mean downstream forwarding rate performance results using a single ONT709 for 5 trials with 1, 2, 3, and 4 Stream Blocks. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, a single Tellabs ONT709 can support downstream forwarding rates of nearly 1000 Mbps for 1, 2, 3, and 4 Stream Blocks. Detailed results for 1, 2, 3, and 4 Stream Blocks are presented in Appendix G.

Figure 21. Mean Downstream Forwarding Rate Performance Results Using a Single ONT709



Bidirectional performance testing for a single ONT709 was also performed. For these tests, data was flowing upstream and downstream simultaneously on each ONT709 port as illustrated in Figure 22.

Figure 22. Configuration for Bidirectional Performance Testing Using a Single ONT709

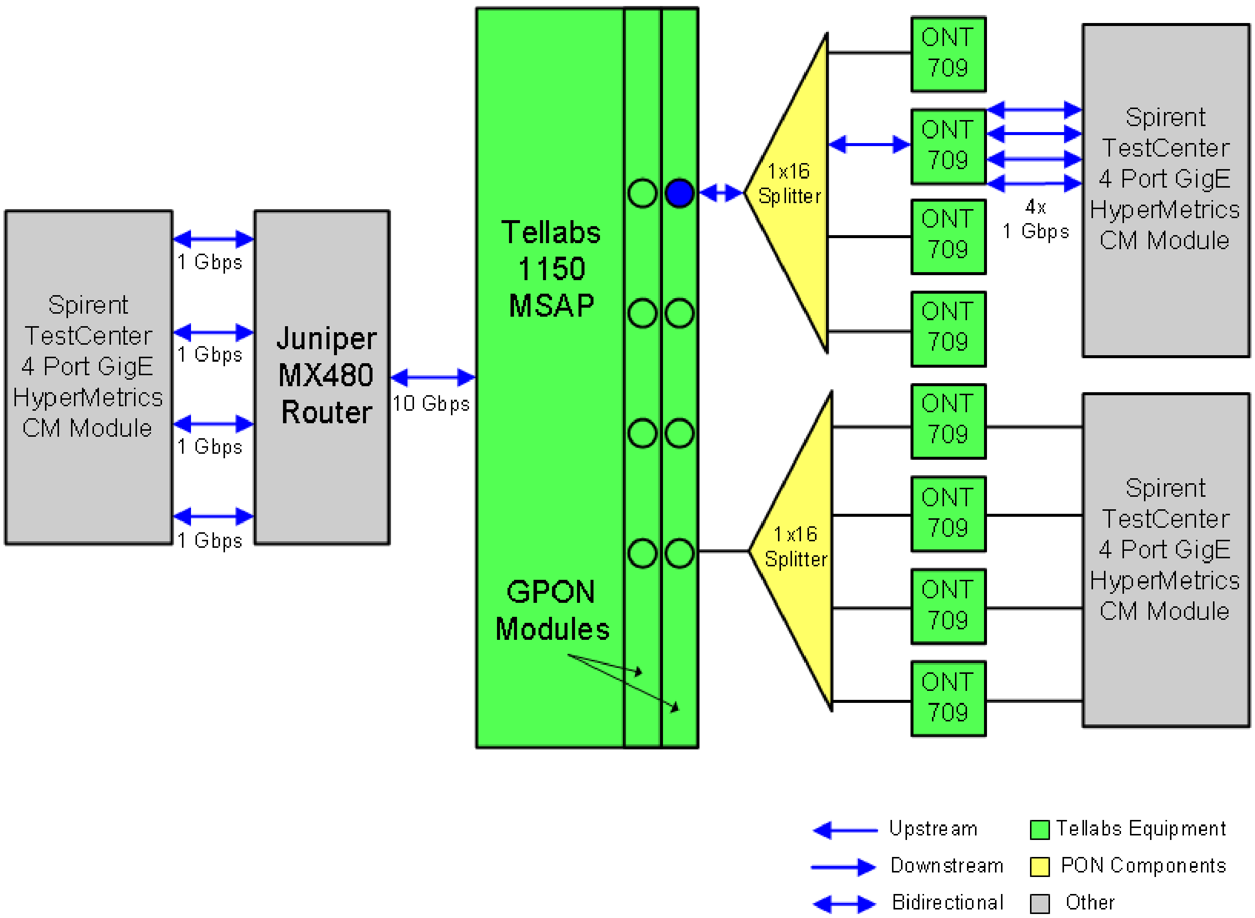
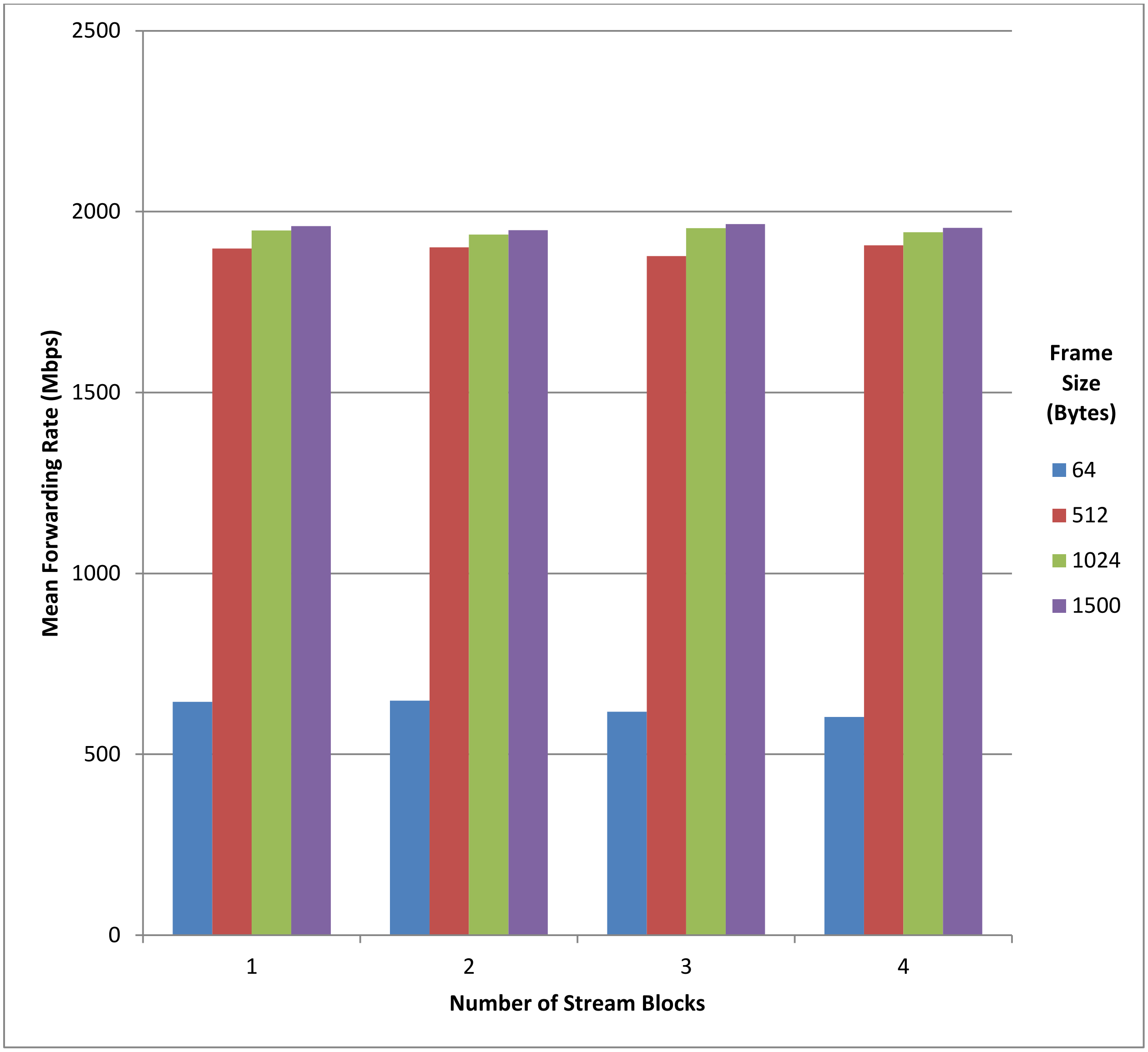


Figure 23 presents the mean aggregate bidirectional forwarding rate results using a single ONT709 for 5 trials with 1, 2, 3, and 4 Stream Blocks. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, a single Tellabs ONT709 can support aggregate bidirectional forwarding rates of almost 2000 Mbps for 1, 2, 3, and 4 Stream Blocks. Detailed results for 1, 2, 3, and 4 Stream Blocks are presented in Appendix H.

Figure 23. Mean Aggregate Bidirectional Forwarding Rate Performance Results Using a Single ONT709



3.7 Single ONT709GP Testing

The purpose of these tests is to determine the forwarding rate supported by a single Tellabs ONT709GP. These tests were performed for upstream, downstream, and bidirectional traffic. The tests were conducted for 1, 2, 3, and 4 ports through a single ONT709GP. Upstream performance testing was performed first. The configuration for this test is shown in Figure 24.

Figure 24. Configuration for Upstream Performance Testing Using a Single ONT709GP

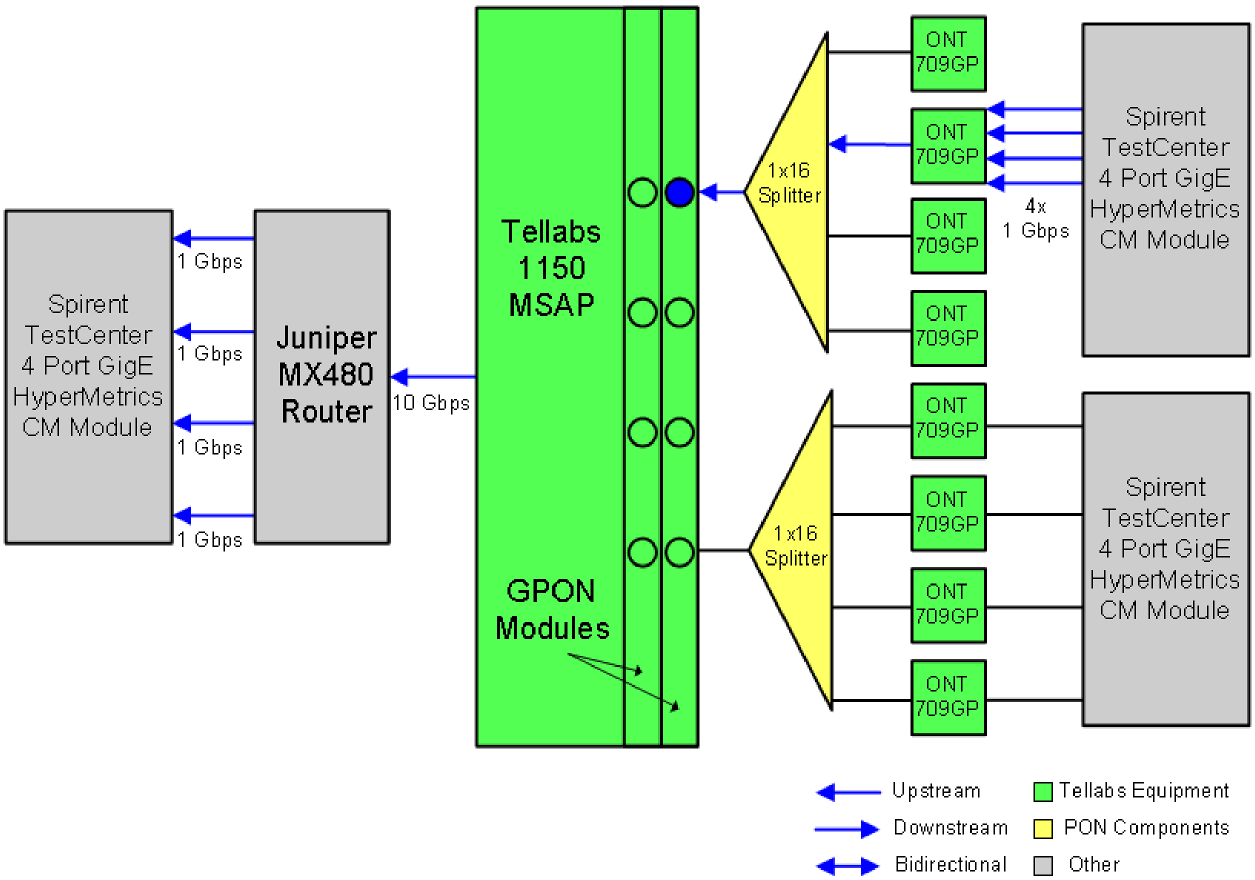
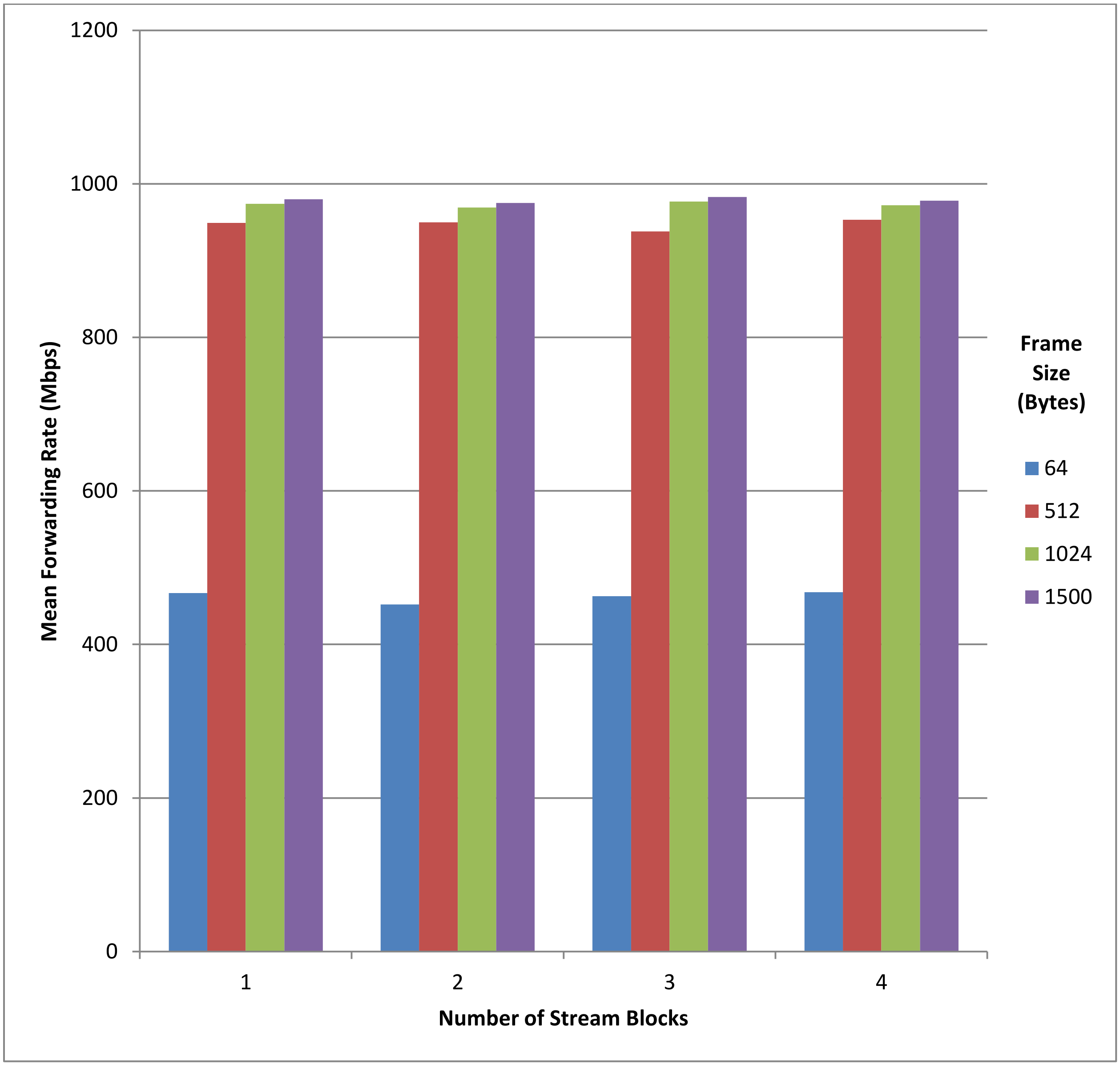


Figure 25 presents the mean upstream forwarding rate performance results using a single ONT709GP for 5 trials with 1, 2, 3, and 4 Stream Blocks. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, a single Tellabs ONT709GP can support upstream forwarding rates of nearly 1000 Mbps for 1, 2, 3, and 4 Stream Blocks. Detailed results for 1, 2, 3, and 4 Stream Blocks are presented in Appendix I.

Figure 25. Mean Upstream Forwarding Rate Performance Results Using a Single ONT709GP



Downstream performance testing using a single ONT709GP was also performed. The configuration for downstream performance testing is illustrated in Figure 26.

Figure 26. Configuration for Downstream Performance Testing Using a Single ONT709GP

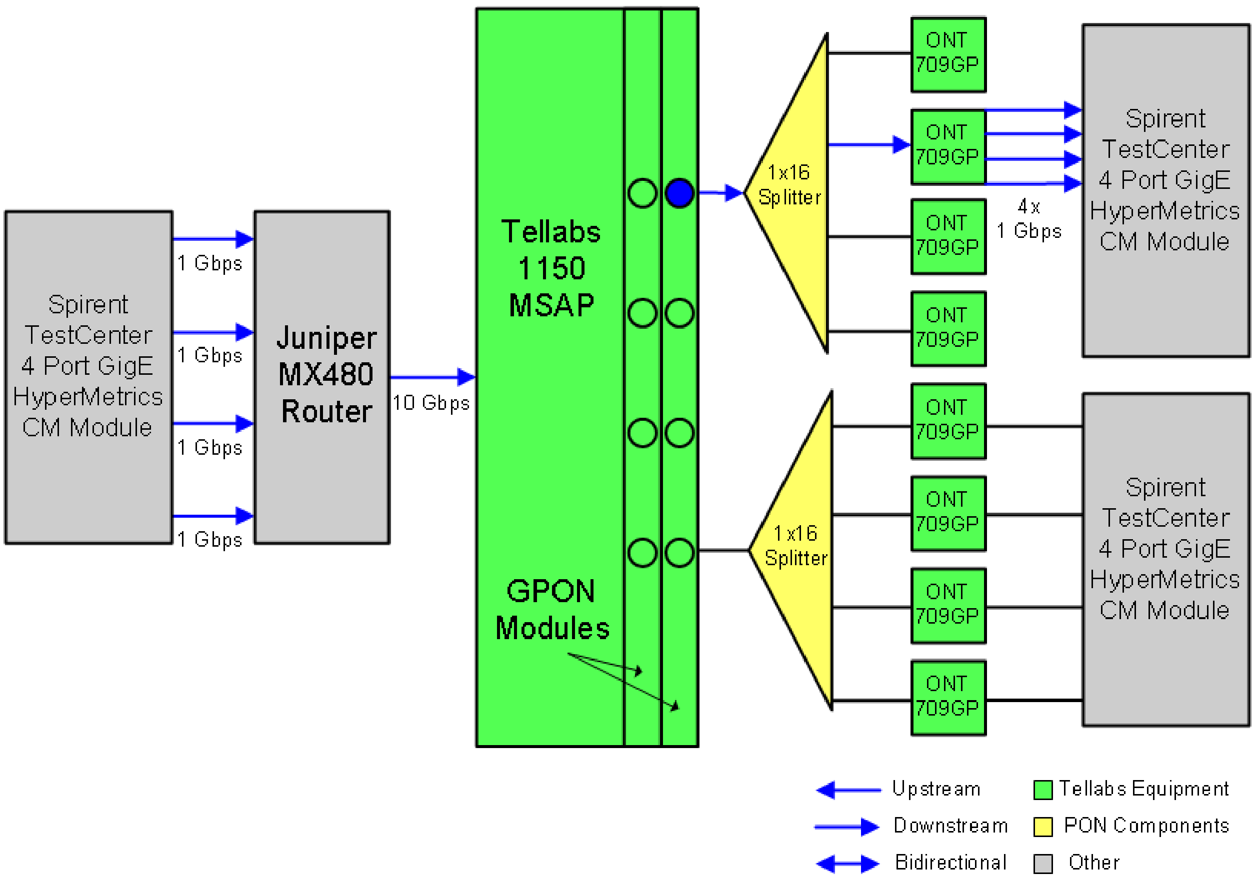
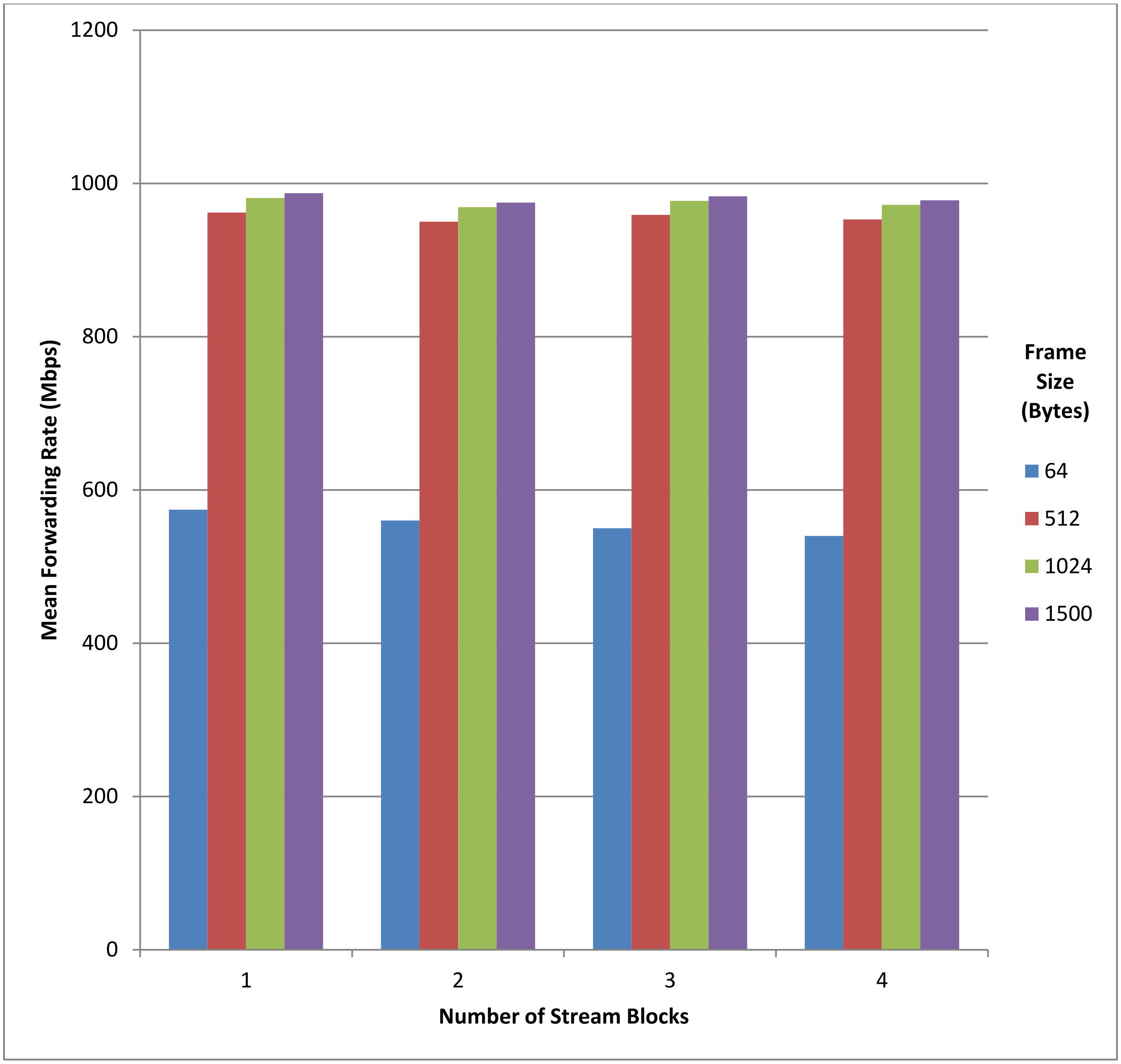


Figure 27 presents the mean downstream forwarding rate performance results using a single ONT709GP for 5 trials with 1, 2, 3, and 4 Stream Blocks. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, a single Tellabs ONT709GP can support downstream forwarding rates of nearly 1000 Mbps for 1, 2, 3, and 4 Stream Blocks. Detailed results for 1, 2, 3, and 4 Stream Blocks are presented in Appendix J.

Figure 27. Mean Downstream Forwarding Rate Performance Results Using a Single ONT709GP



Bidirectional performance testing for a single ONT709GP was also performed. For these tests, data was flowing upstream and downstream simultaneously on each ONT709GP port as illustrated in Figure 28.

Figure 28. Configuration for Bidirectional Performance Testing Using a Single ONT709GP

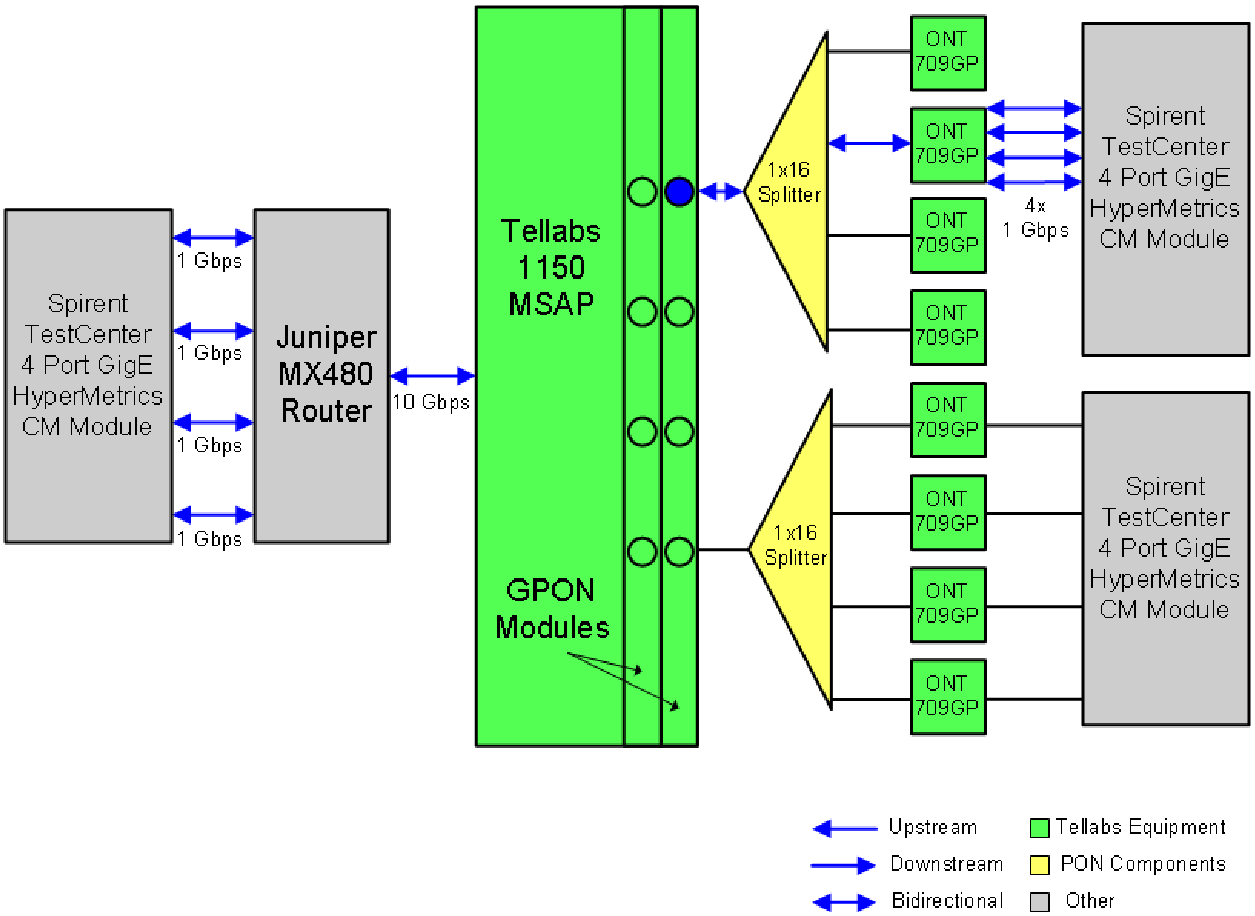
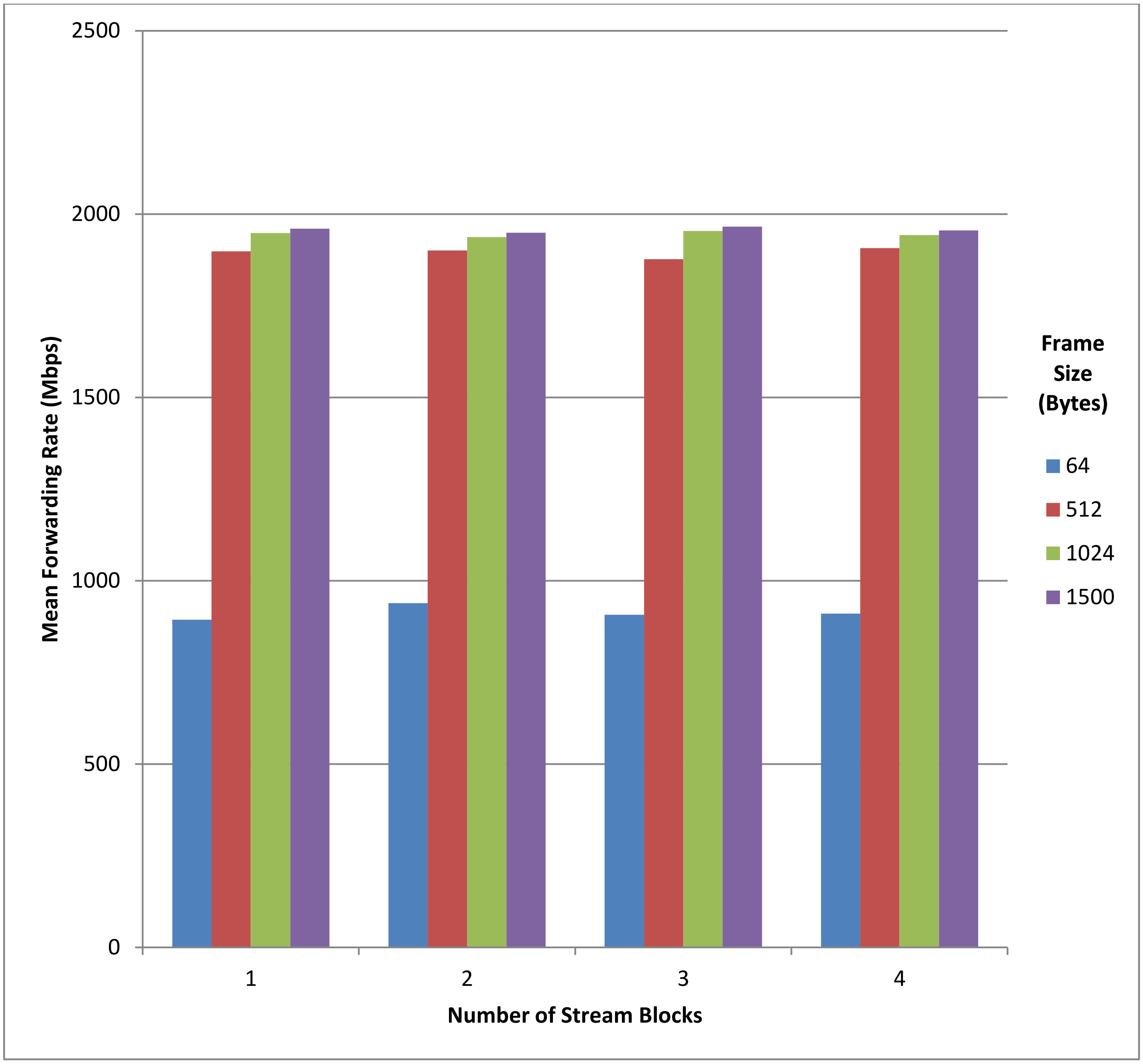


Figure 29 presents the mean aggregate bidirectional forwarding rate results using a single ONT709GP for 5 trials with 1, 2, 3, and 4 Stream Blocks. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, a single Tellabs ONT709GP can support aggregate bidirectional forwarding rates of almost 2000 Mbps for 1, 2, 3, and 4 Stream Blocks. Detailed results for 1, 2, 3, and 4 Stream Blocks are presented in Appendix K.

Figure 29. Mean Aggregate Bidirectional Forwarding Rate Performance Results Using a Single ONT709GP



3.8 Performance Comparisons between the ONT709 and ONT709GP

Because both the ONT709 and ONT709GP are widely deployed at Sandia National Laboratories, a performance comparison between these ONTs may provide useful information.

Figure 30 presents the mean upstream forwarding rate performance results for 5 trials with 1, 2, 3, and 4 Stream Blocks for both the ONT709 and ONT709GP. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As can be seen, performance is similar but the ONT709GP has better performance for 64 byte Ethernet frames.

Figure 30. Mean Upstream Forwarding Rate Performance Comparison between the ONT709 and ONT709GP

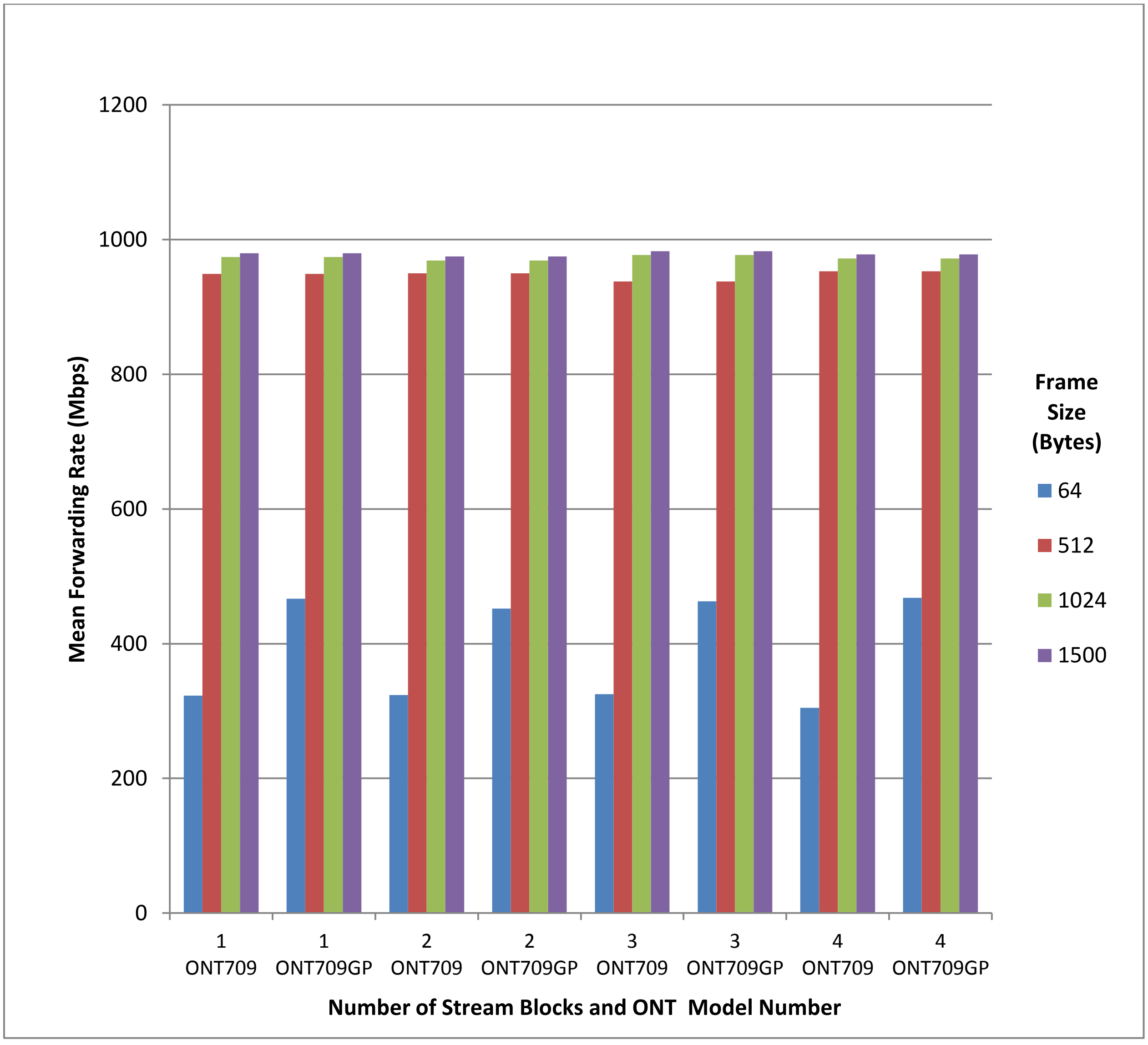


Figure 31 presents the mean downstream forwarding rate performance results for 5 trials with 1, 2, 3, and 4 Stream Blocks for both the ONT709 and ONT709GP. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes.

As can be seen, performance is similar but the ONT709 has slightly better performance for 64 byte Ethernet frames.

Figure 31. Mean Downstream Forwarding Rate Performance Comparison between the ONT709 and ONT709GP

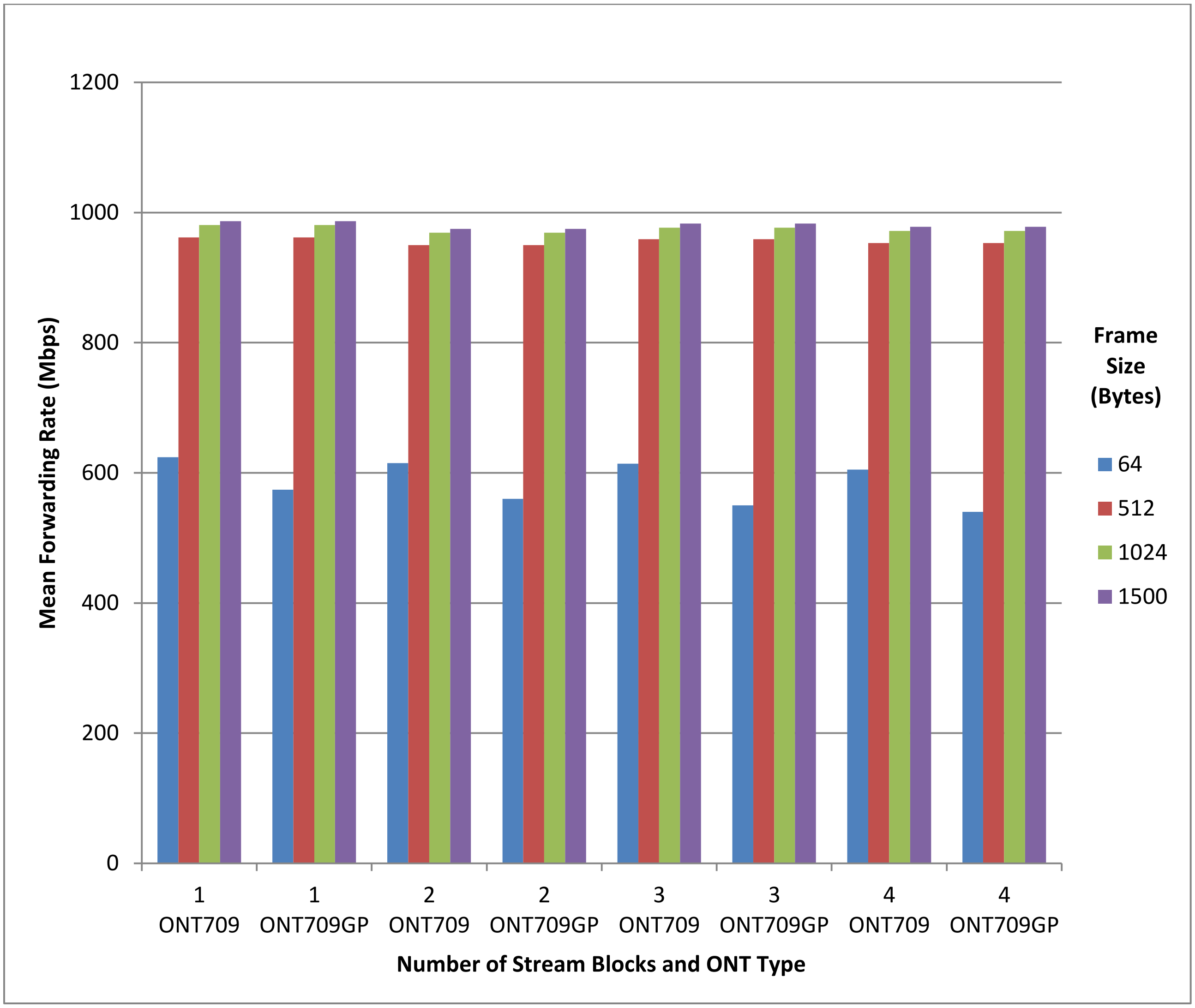
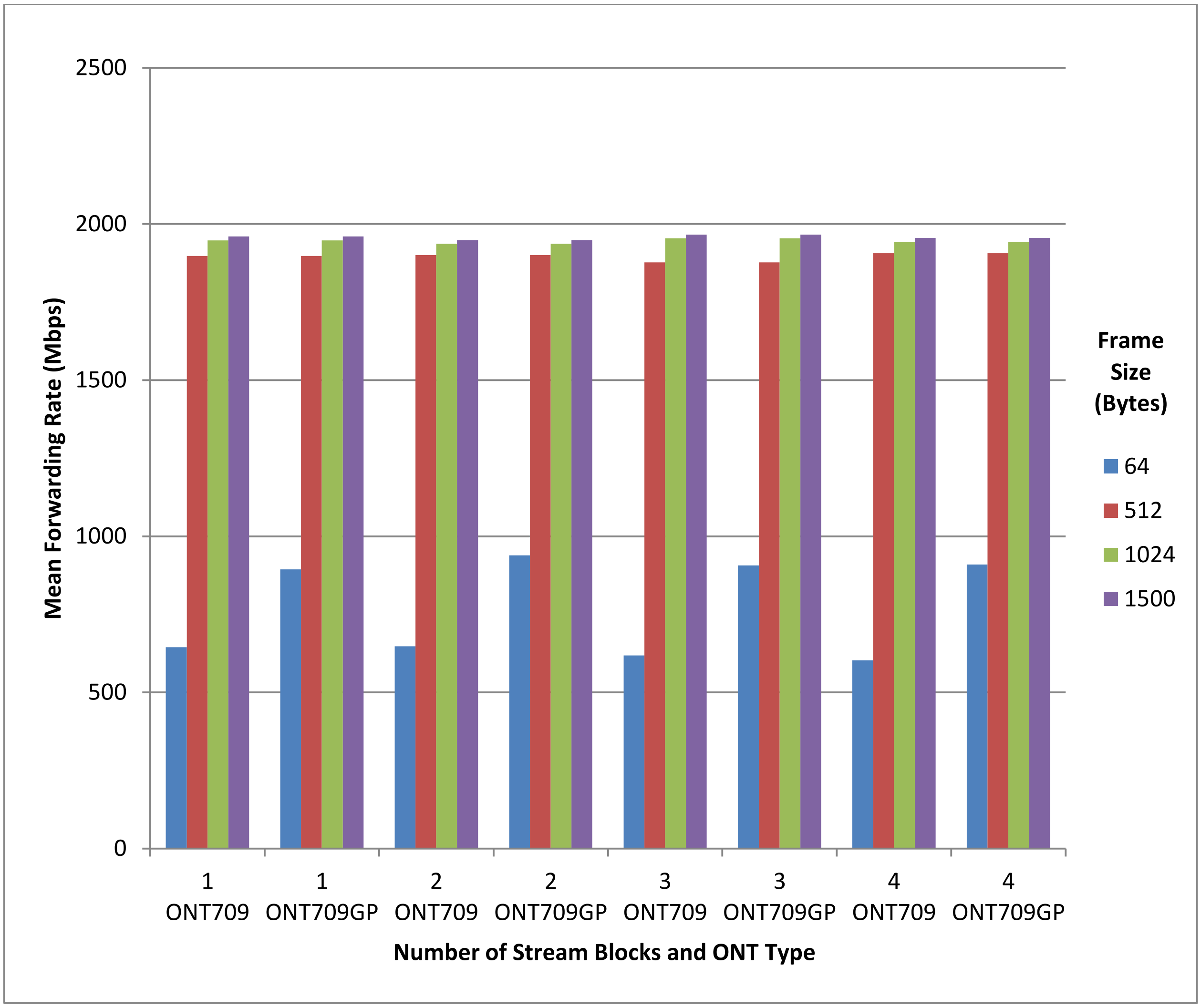


Figure 32 presents the mean bidirectional forwarding rate performance results for 5 trials with 1, 2, 3, and 4 Stream Blocks for both the ONT709 and ONT709GP. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes.

As can be seen, performance is similar but the ONT709GP has better performance for 64 byte Ethernet frames.

Figure 32. Mean Bidirectional Forwarding Rate Performance Comparison between the ONT709 and ONT709GP

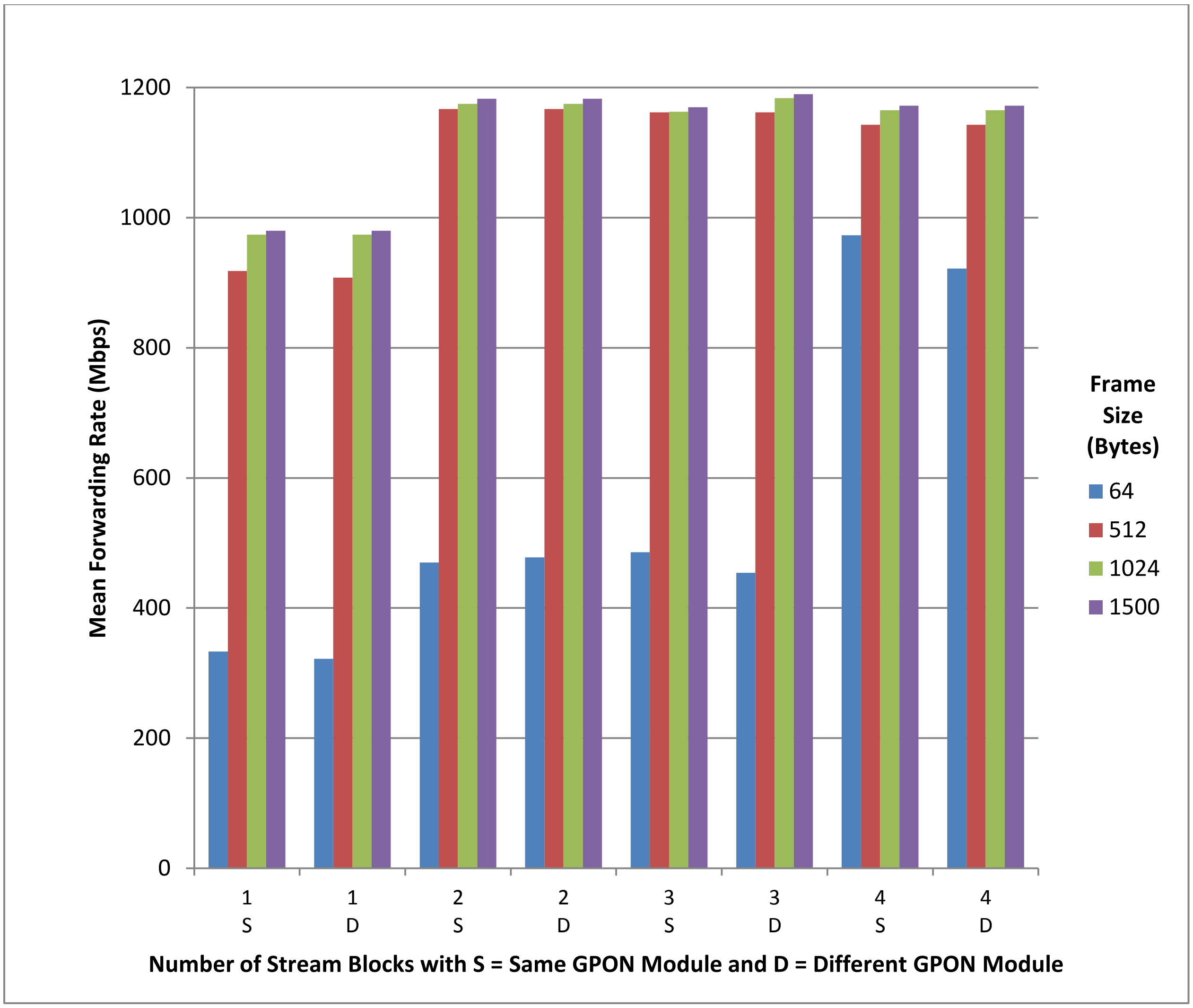


3.9 GPON Port to GPON Port Comparison Testing

From the tests performed in Sections 3.4 and 3.5, it was possible to combine the results and determine if the unidirectional forwarding rates for ONT709s on a GPON port were affected if the destination ONT709s were on a GPON port located on the same GPON module or a different GPON module. The configurations tested are illustrated in Figures 10 and 14.

Figure 33 presents the mean unidirectional GPON port to GPON port forwarding rate performance results for 1, 2, 3, and 4 Stream Blocks from ONT709s on a GPON port located on the same GPON module and also for ONT709s on a GPON port located on a different GPON module. These tests were conducted for 5 trials. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, there is a slight performance advantage when the destination ONT709s are on a GPON port located on the same GPON module.

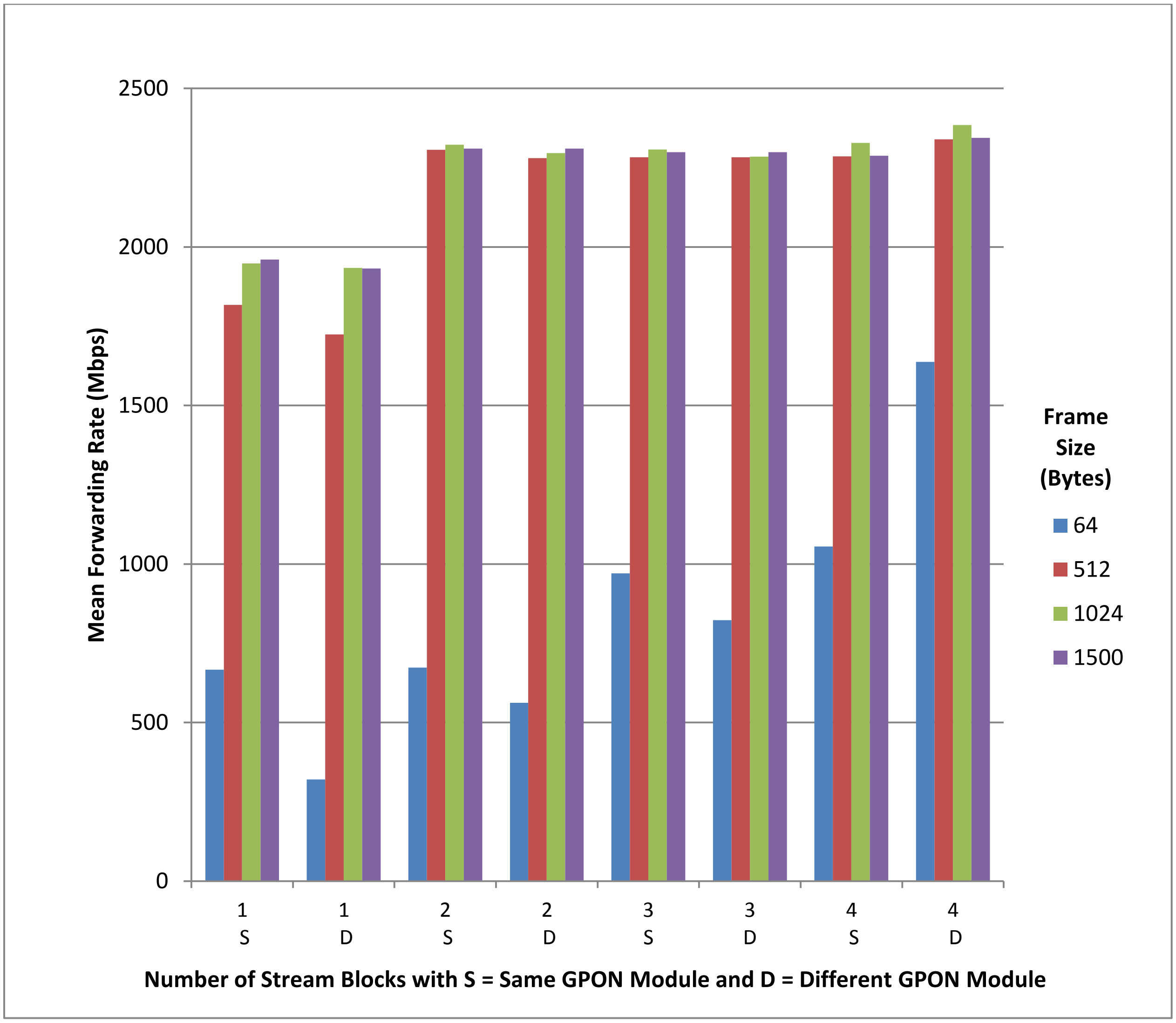
Figure 33. Mean Unidirectional GPON Port to GPON Port Forwarding Rate Performance Results



From the tests performed in Sections 3.4 and 3.5, it was also possible to combine the results and determine if the bidirectional forwarding rates for ONT709s on a GPON port were affected if the destination ONT709s were on a GPON port located on the same GPON module or a different GPON module. The configurations tested are illustrated in Figures 12 and 16.

Figure 34 presents the mean aggregate bidirectional GPON port to GPON port forwarding rate performance results for 1, 2, 3, and 4 Stream Blocks from ONT709s on a GPON port located on the same GPON module and also for ONT709s on a GPON port located on a different GPON module. These tests were conducted for 5 trials. Ethernet frame sizes are 64, 512, 1024, and 1500 bytes. As illustrated, except for 4 Stream Blocks, there is a slight performance advantage when the destination ONT709s are on a GPON port located on the same GPON module.

Figure 34. Mean Aggregate Bidirectional GPON Port to GPON Port Forwarding Rate Performance Results



3.10 Spirent TestCenter Performance Testing Summary

Based on the results presented in this section, the following conclusions can be reached:

- A Tellabs 1150 MSAP GPON port can support:
    - upstream forwarding rates of over 1100 Mbps
    - downstream forwarding rates of over 2200 Mbps
    - aggregate bidirectional forwarding rates of over 2200 Mbps using RFC 2544 testing
    - aggregate bidirectional forwarding rates of over 3000 Mbps using manual Spirent TestCenter testing
- A single Tellabs ONT709 can support:
    - upstream forwarding rates of nearly 1000 Mbps
    - downstream forwarding rates of nearly 1000 Mbps
    - aggregate bidirectional forwarding rates of nearly 2000 Mbps
- Performance of an ONT709 and ONT709GP are similar.

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4. VOIP TESTING

4.1 VoIP at Sandia National Laboratories

Sandia National Laboratories is in the process of piloting VoIP using GPON with the Tellabs 1150 MSAP. For that reason, VoIP running on the Tellabs 1150 needed to be thoroughly tested.

4.2 VoIP Test Configuration

The test configuration for testing VoIP on the Tellabs 1150 MSAP is shown in Figures 35-37. The VoIP telephones are connected to ONT709s. When the telephone boots up, the DHCP server sends the VoIP telephone its IP address information. When the user picks up the handset and dials, the VoIP telephone signals the Communication Manager to establish a call. At that point, voice packets are sent from VoIP telephone to VoIP telephone. The signal channel connections from the Communication Manager to the VoIP telephones are maintained throughout the call to exchange feature and signal requests during the call. The actual hardware and software used for testing purposes are listed in Table 3.

4.3 Quality of Service for VoIP

QoS features were used to prioritize VoIP traffic. The Tellabs 1150 MSAP performs packet marking and prioritization for upstream frames at the ONT709. This is enabled in the Connection Profile as illustrated in Figure 2. Should the Type of Service byte in the IP header of the IP packet arriving at an ONT709 port be set with Differentiated Service Code Point (DSCP) bits, the Tellabs 1150 MSAP has the ability to map these DSCP bits into 802.1P CoS bits. For downstream traffic, the Tellabs 1150 MSAP can be configured to honor and give priority to 802.1P CoS bits. Higher 802.1P CoS bit values receive a higher priority compared to other Ethernet frame types.

4.4 VoIP Test Strategy

The test strategy used for VoIP is different than the Spirent performance tests performed in Section 3. For network data rate throughput tests, the Spirent TestCenter forwarding rates of each stream was measured and collected for a variety of tests. For VoIP testing, the Spirent TestCenter is used to generate competing network traffic while calls are made between VoIP telephones. The voice quality of each call is measured with a Mean Opinion Score (MOS) value by the Prognosis IP Telephone Manager (IPTM) server. The traffic generated by the Spirent TestCenter is varied for upstream, downstream, and bidirectional flows. Then new calls are made and tested for that level of Spirent TestCenter traffic.

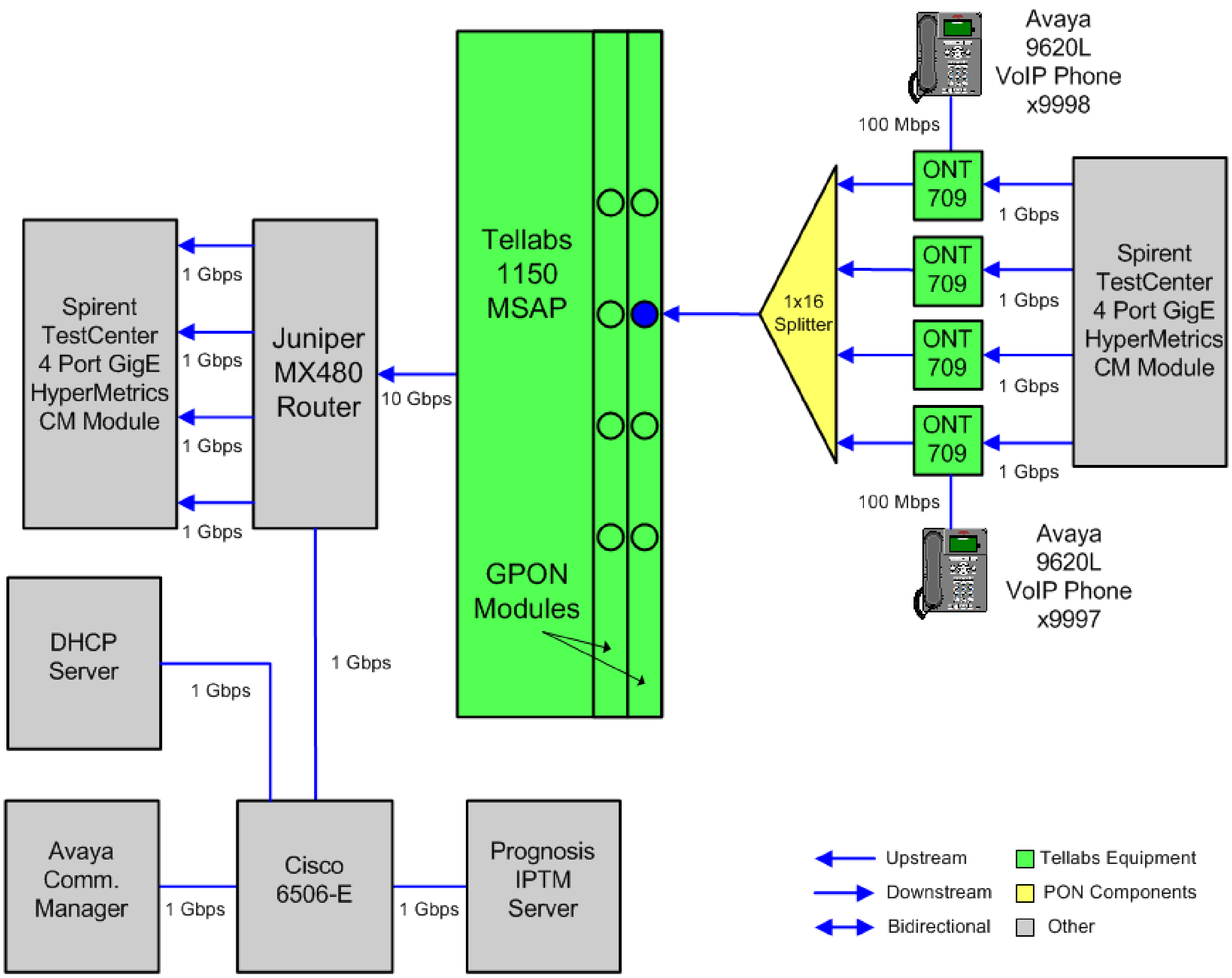
Table 3. VoIP Hardware and Software

Hardware and Software	Model or Version
Communication Manager	
Media Server Hardware	2x Hewlett Packard DL360G7
Media Gateway Hardware	5x Avaya G650
Software	Avaya Version 6.3.4
VoIP Telephone	2x Avaya 9620L
VoIP Signaling Protocol	H.323 Software Version 3.1 with Patch 3.941a
Voice CODEC	G.711 mu-law
DHCP Server	
Hardware	2x Hewlett Packard DL360G7
Operating System	Windows Server 2003 SP2
DHCP Software	Microsoft DHCP Version 5.2.3790.3959
Prognosis Server	
Hardware	Dell PowerEdge 1950 CPU - Intel Xeon 5160 @ 3.0 GHz 4 GB of RAM
Operating System	Windows Server 2003 SP2
VoIP Monitoring Software	Prognosis IP Telephony Manager Version 9.6.1

4.5 VoIP Testing with Competing Upstream Traffic

The first set of VoIP tests performed involved testing VoIP calls between two VoIP telephones as shown in Figure 35. For these tests, competing traffic is generated by the Spirent TestCenter in the upstream direction as shown by the direction of the arrows. The calls are made by manually dialing each VoIP telephone from the other VoIP telephone. The call quality is measured by the Prognosis IPTM server. These calls are monitored for 5 minutes and the results are recorded. The Spirent TestCenter traffic is then increased and the test repeated. These tests are performed for 64 and 1500 byte Ethernet frame Spirent TestCenter traffic. The Ethernet frames contained IP Experimental (Protocol = 253) packets.

Figure 35. Configuration for VoIP Testing with Competing Upstream Traffic

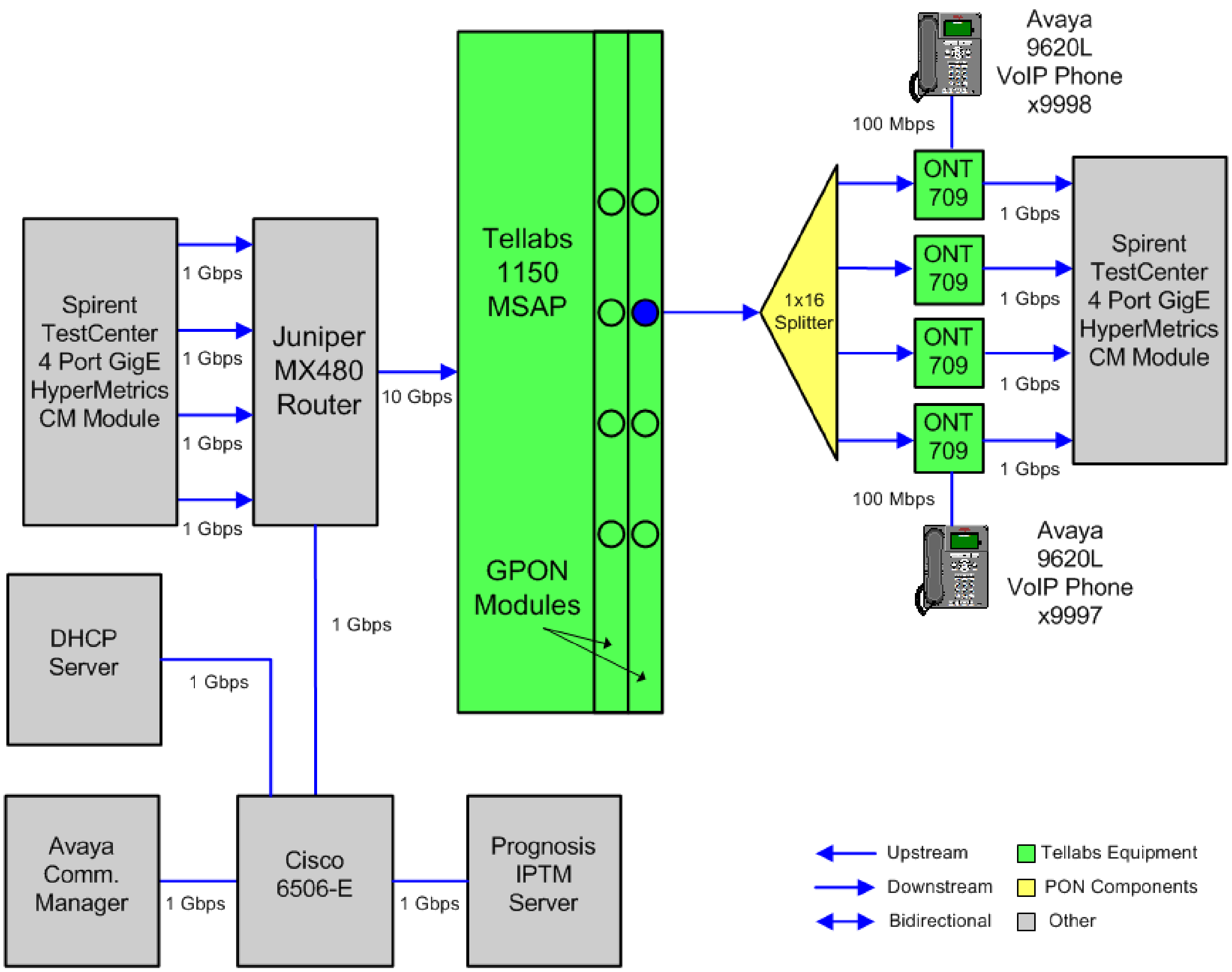


When the upstream is overloaded with traffic rates of 2400 Mbps for both 64 byte Ethernet frames and 1500 byte Ethernet frames MOS values of 4.39 are obtained when QoS is enabled.

4.6 VoIP Testing with Competing Downstream Traffic

The next set of VoIP tests involved testing VoIP calls between two VoIP telephones as illustrated in Figure 36. For these tests, competing traffic was generated by the Spirent TestCenter in the downstream direction as shown by the direction of the arrows. The test procedure was the same as described with competing upstream traffic, except that the Spirent TestCenter traffic is in the downstream direction and extra tests are performed at 2200 and 2400 Mbps to better simulate downstream congestion.

Figure 36. Configuration for VoIP Testing with Competing Downstream Traffic

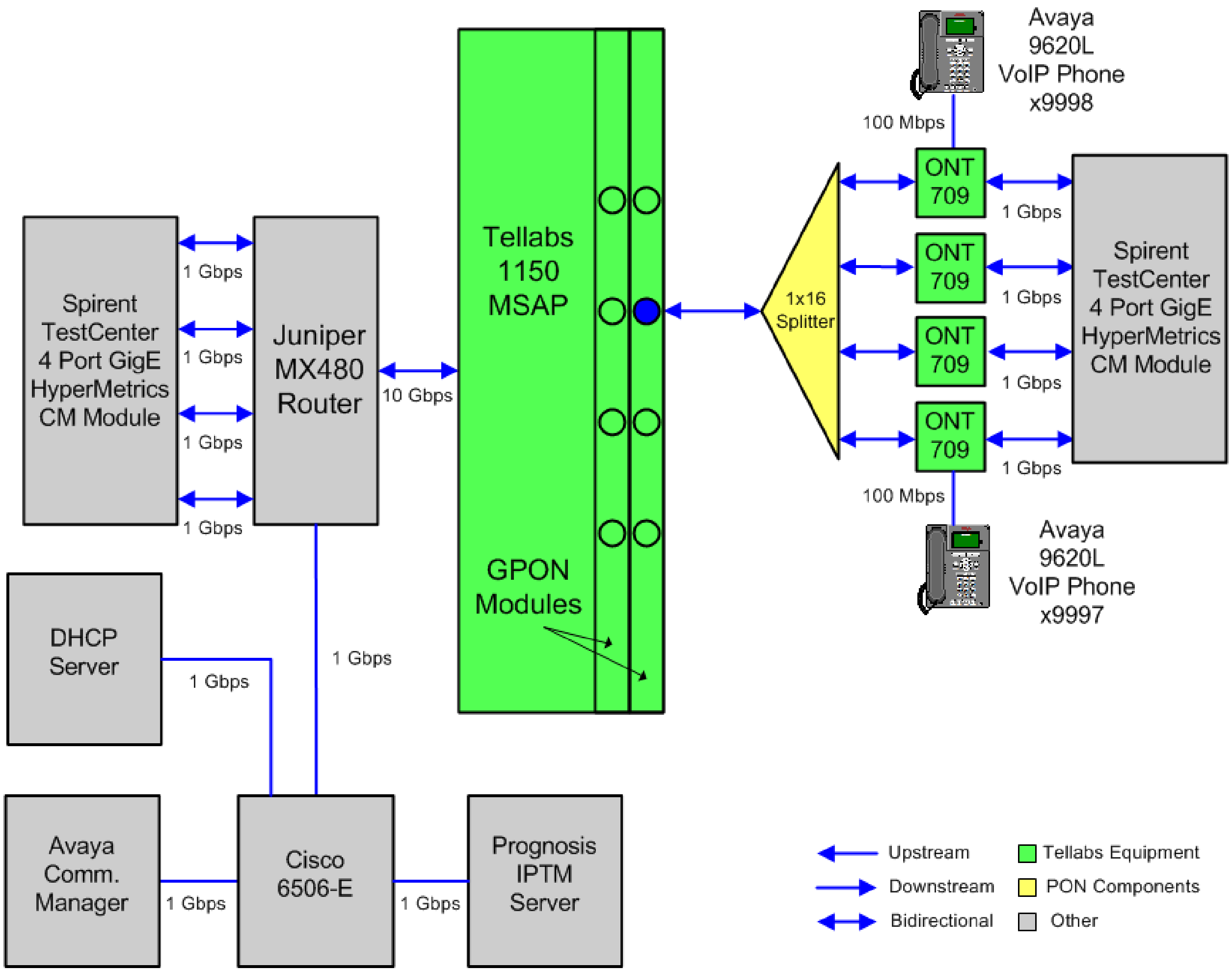


When the downstream was overloaded with traffic rates of 2400 Mbps for both 64 byte Ethernet and 1500 byte Ethernet frames, MOS values of 4.39 were obtained when QoS was enabled.

4.7 VoIP Testing with Competing Bidirectional Traffic

The final set of VoIP tests performed involved testing VoIP calls between two VoIP telephones as illustrated in Figure 37. For these tests, competing bidirectional traffic was generated by the Spirent TestCenter as shown by the direction of the arrows. The test procedure was the same as described with competing upstream traffic, except that the Spirent TestCenter traffic was bidirectional and extra tests with different values of competing traffic were performed to better simulate bidirectional congestion.

Figure 37. Configuration for VoIP Testing with Competing Bidirectional Traffic



When both the upstream and downstream were overloaded with traffic rates of 2400 Mbps for both 64 byte Ethernet and 1500 byte Ethernet frames, MOS values of 4.39 were obtained when QoS was enabled.

4.8 VoIP Testing Summary

Based on the results presented in this section, the Tellabs 1150 MSAP running Software Release FP27.1_015130 is capable of protecting VoIP traffic under GPON port overload conditions when QoS is enabled.

5. STREAMING VIDEO TESTING

5.1 Streaming Video at Sandia National Laboratories

The ability to provide streaming video is an important capability of any user network. Streaming video has a variety of informational and instructional uses at Sandia National Laboratories. GPON is touted as being capable of providing "triple play" which is voice, video, and data. This section presents the results of the streaming video testing using the Tellabs 1150 MSAP.

5.2 Streaming Video Test Configuration

The test configuration for testing streaming video on the Tellabs 1150 MSAP is shown in Figures 39-41. The computer acting as the video server for this test was on the legacy network. The computer acting as the video client was connected to an ONT709. Using the Remote Desktop Protocol (RDP), the video client connects to the video server using the Remote Desktop Connection application. A MPEG video was played on the video server and the video was displayed on the video client. It should be noted that the video server was not on a general user LAN. Also, before applying competing traffic with the Spirent TestCenter, tests were performed under nominal conditions to ensure that there was no other competing traffic or video server usage which would skew the results. The hardware and software used for these tests are presented in Table 4.

Table 4. Streaming Video Hardware and Software

Hardware and Software	Model or Version
Video Server	
Hardware	Hewlett-Packard Z400 CPU - Intel Xeon W3530 @ 2.67 GHz 16 GB RAM
Operating System	Windows 7 Enterprise, 64 Bit
Video Player	Microsoft Windows Media Player Version 12.0.7601.18150
Video Client	
Hardware	Dell Precision M6500 CPU - Intel Core i7 X 920 @ 2.00 GHz 16 GB RAM
Operating System	Windows 7 Enterprise, 64 Bit

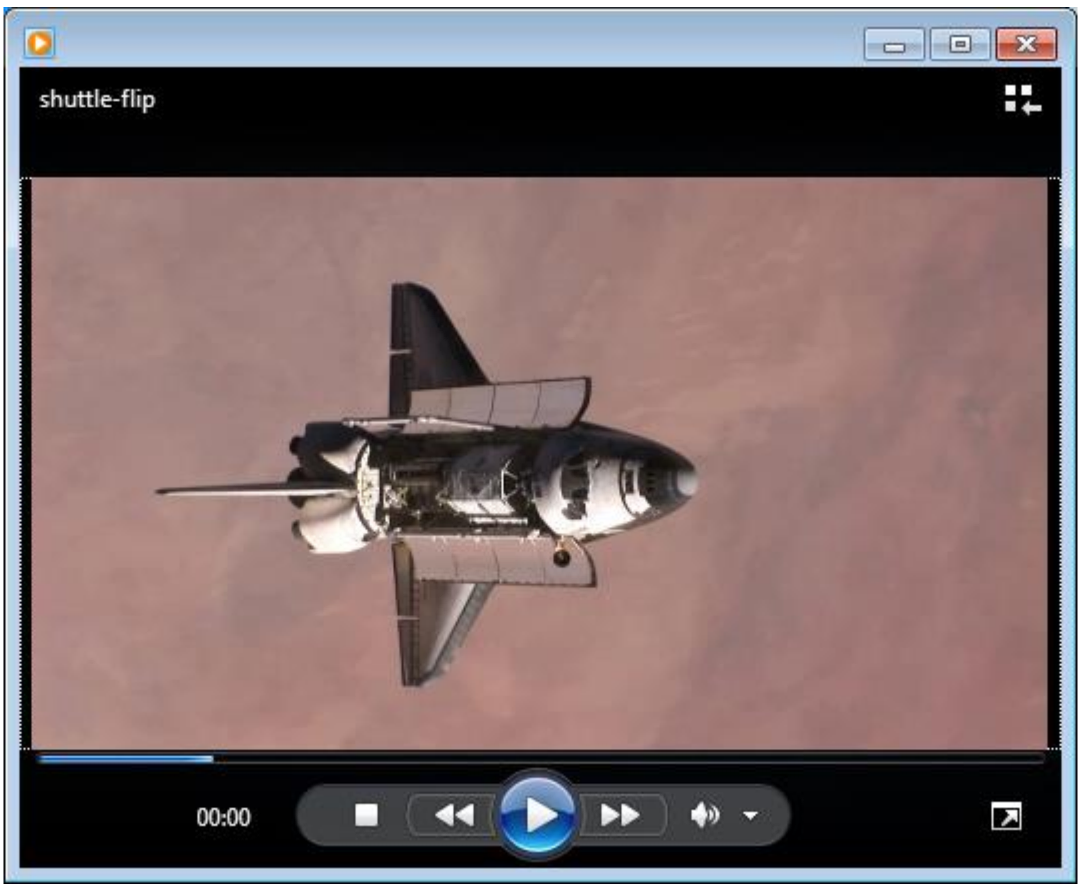
The video that was played on the video server was a NASA video clip of a space shuttle doing a flip. Table 5 presents the space shuttle flip video properties. Actual monitoring of the bandwidth utilization during playback of this video, showed network usage peaking at 21 Mbps, although the total bit rate of the video is listed as 18.5 Mbps.

Table 5. Space Shuttle Flip Video Properties

Video Properties	Value
Video Format	MPEG
Length	4 seconds
Frame Width	1280 pixels
Frame Height	720 pixels
Data Rate	18.5 Mbps
Total Bit Rate	18.5 Mbps
Frame Rate	29 frames per second

For completeness, Figure 38 presents a space shuttle flip video screen capture used for streaming video testing.

Figure 38. Space Shuttle Flip Video Screen Capture Used for Streaming Video Testing



5.3 Quality of Service for Streaming Video

QoS is very important for streaming video. Lost frames, excessive delay and jitter will cause poor quality video. Video buffering can provide some help. However, buffering has limits such as when buffer starvation occurs. The same QoS mechanism used to prioritize VoIP traffic was used to prioritize streaming video traffic. For a review of the QoS mechanism, please see Section 4.3.

5.4 Streaming Video Test Strategy

The test strategy used for streaming video is the same as for VoIP testing. For streaming video tests, the Spirent TestCenter was used to generate competing network traffic while an attempt was made to connect to the video server from the video client using the Remote Desktop Connection application. If the connection was successful, the MPEG video is played. The quality of the video displayed on the server was then empirically rated as presented in Table 6. The traffic generated by the Spirent TestCenter was varied for upstream, downstream, and bidirectional flows. Then a new connection was attempted and the streaming video quality was rated for that level of Spirent TestCenter traffic. The tests were divided into two sets. The first set of tests was completed without QoS enabled. The tests were then repeated a second time with QoS enabled.

Table 6. Video Quality Rating Scale

Video Rating	Video Quality
0	Video does not play
1	Video starts but is not usable
2	Video plays but is of low quality
3	Video plays and is usable
4	Video plays very good but not quite perfect
5	Video plays perfectly

5.5 Streaming Video Testing with Competing Upstream Traffic

The first set of streaming video tests involved testing video quality between the video server and client as shown in Figure 39. For these tests, traffic was generated by the Spirent TestCenter in the upstream direction as shown by the direction of the arrows. This Spirent TestCenter traffic was used to provide competing traffic for the streaming video that was sent from the video server to the video client. The Spirent TestCenter traffic was then increased and the test repeated. These tests were performed for 64 and 1500 byte Ethernet frame Spirent TestCenter traffic. The Ethernet frames contained IP Experimental (Protocol = 253) packets.

Figure 39. Configuration for Streaming Video Testing with Competing Upstream Traffic

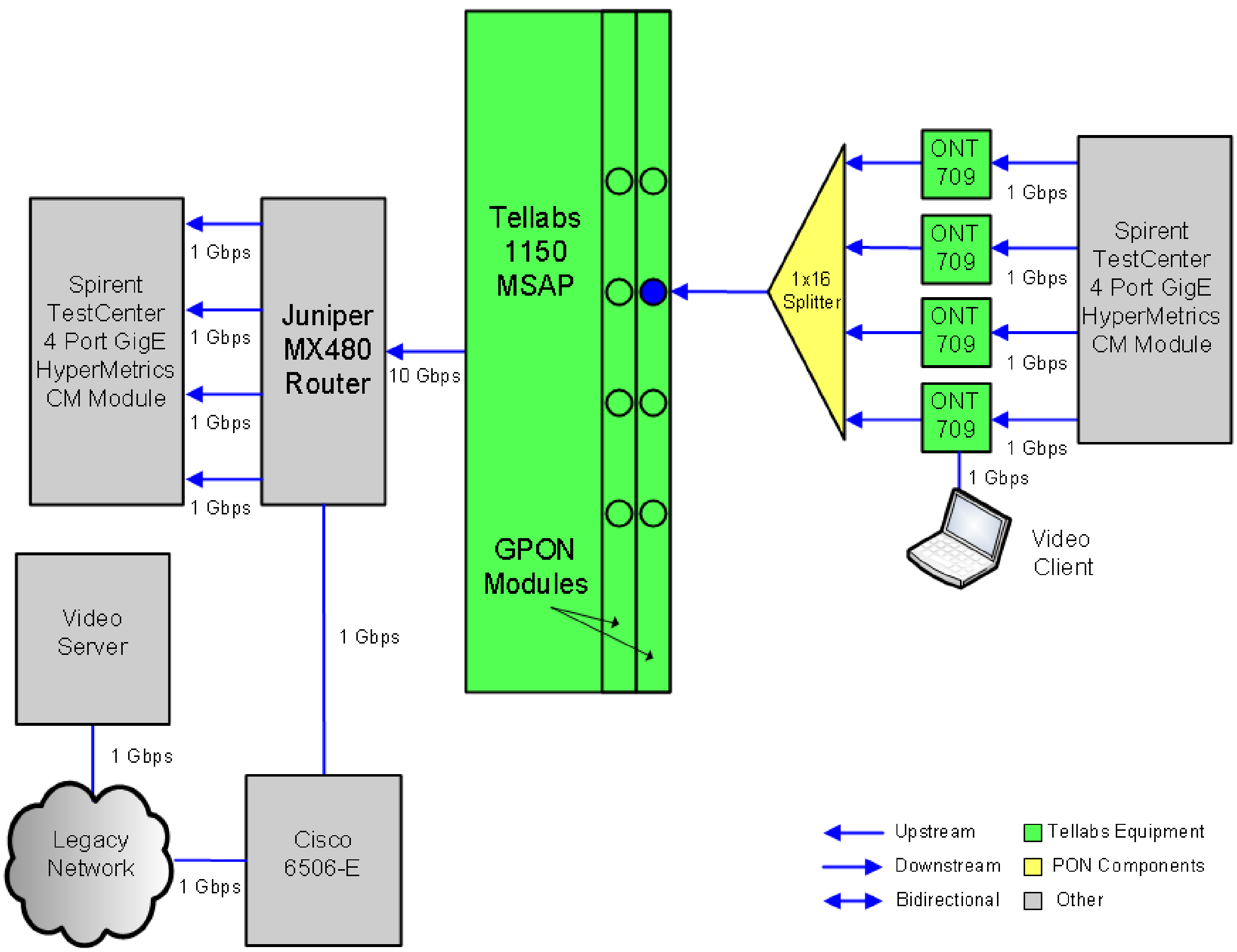


Table 7 presents the streaming video quality results with 64 byte Ethernet frame competing upstream traffic. As presented, when the upstream is overloaded with traffic rates greater than 1200 Mbps, a Remote Desktop Connection can either not be completed or maintained if QoS is not enabled. When QoS is enabled, a Remote Desktop Connection is possible at 4000 Mbps and perfect streaming video is displayed at any value of competing upstream traffic.

Table 7. Streaming Video Quality Results with 64 Byte Ethernet Frame Competing Upstream Traffic

Frame Size (bytes)	Upstream Traffic Rate Aggregate (Mbps)	Downstream Traffic Rate Aggregate (Mbps)	Remote Desktop Connection? No QoS	Video Quality No QoS	Remote Desktop Connection? With QoS	Video Quality With QoS
64	1100	0	Yes	5	Yes	5
64	1200	0	Yes	5	Yes	5
64	2000	0	No	0	Yes	5
64	3000	0	No	0	Yes	5
64	4000	0	No	0	Yes	5

Table 8 presents the streaming video quality results with 1500 byte Ethernet frame competing upstream traffic. For competing traffic exceeding 1100 Mbps, a Remote Desktop Connection can either not be completed or streaming video is of low quality if QoS is not enabled. When QoS is enabled, a Remote Desktop Connection is possible and perfect streaming video was displayed for all competing test traffic.

Table 8. Streaming Video Quality Results with 1500 Byte Ethernet Frame Competing Upstream Traffic

Frame Size (bytes)	Upstream Traffic Rate Aggregate (Mbps)	Downstream Traffic Rate Aggregate (Mbps)	Remote Desktop Connection? No QoS	Video Quality No QoS	Remote Desktop Connection? With QoS	Video Quality With QoS
1500	1100	0	Yes	5	Yes	5
1500	1200	0	Yes	2	Yes	5
1500	2000	0	No	0	Yes	5
1500	3000	0	No	0	Yes	5
1500	4000	0	No	0	Yes	5

5.6 Streaming Video Testing with Competing Downstream Traffic

The next set of streaming video tests involved testing video quality between the video server and client as shown in Figure 40. For these tests, traffic was generated by the Spirent TestCenter in the downstream direction as shown by the direction of the arrows. The Spirent TestCenter traffic is used to provide competing traffic for the video playback that was sent using the Remote Desktop Protocol from the video server to the video client. The Spirent TestCenter traffic is then increased and the test repeated. These tests are performed for 64 and 1500 byte Ethernet frame Spirent TestCenter traffic.

Figure 40. Configuration for Streaming Video Testing with Competing Downstream Traffic

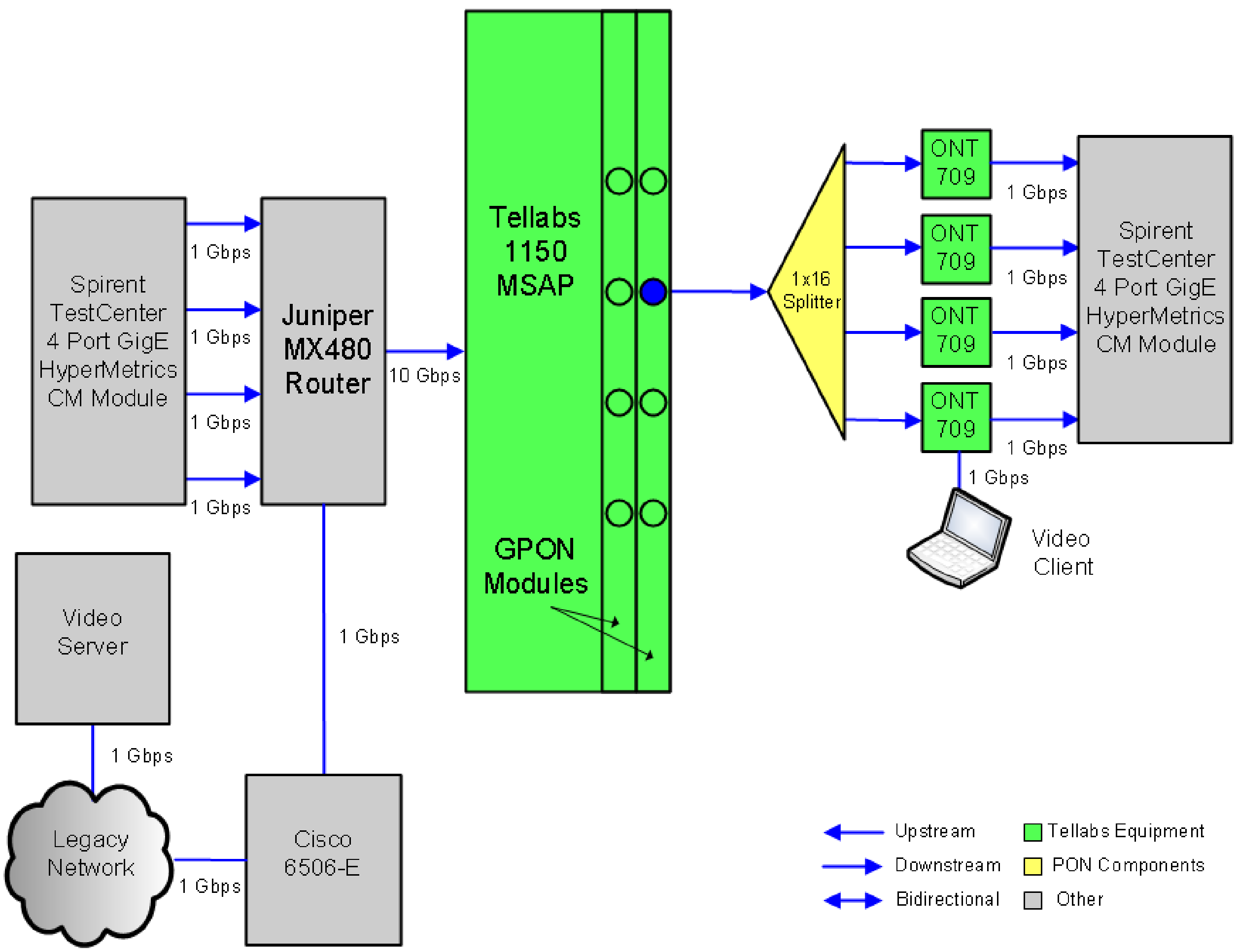


Table 9 presents the streaming video quality results with 64 byte Ethernet frame competing downstream traffic. As presented, when the downstream is overloaded with traffic rates of greater than 2400 Mbps, a Remote Desktop Connection can either not be completed or maintained or the streaming video will not play if QoS is not enabled. When QoS is enabled, a Remote Desktop Connection is possible at 4000 Mbps and perfect streaming video is displayed at any value of competing downstream traffic. However, the video would stop playing after several iterations at competing downstream traffic rates of 3000 and 4000 Mbps. This is not considered a problem as competing downstream traffic should never reach these rates.

Note: For these tests, 4 Mbps of traffic was transmitted in the upstream direction to prevent ARP aging on the ONT709 port.

Table 9. Streaming Video Quality Results with 64 Byte Ethernet Frame Competing Downstream Traffic

Frame Size (bytes)	Upstream Traffic Rate Aggregate (Mbps)	Downstream Traffic Rate Aggregate (Mbps)	Remote Desktop Connection? No QoS	Video Quality No QoS	Remote Desktop Connection? With QoS	Video Quality With QoS
64	4	1000	Yes	5	Yes	5
64	4	2000	Yes	5	Yes	5
64	4	2200	Yes	5	Yes	5
64	4	2400	Yes	5	Yes	5
64	4	3000	Yes	0	Yes	5*
64	4	4000	No	0	Yes	5*

The "*" denotes tests where video started and played with good quality but stopped after several iterations. This state was tested and shown to be repeatable.

Table 10 presents the streaming video quality results with 1500 byte Ethernet frame competing downstream traffic. As shown, when the downstream is overloaded with traffic rates exceeding 2200 Mbps streaming video quality values decrease or the Remote Desktop Connection cannot be completed if QoS is not enabled. When QoS is enabled, a Remote Desktop Connection is possible at 4000 Mbps and perfect streaming video is displayed at any value of competing downstream traffic. However, the video would stop playing after several iterations at competing downstream traffic rates of 3000 and 4000 Mbps. This is not considered a problem as competing downstream traffic should never reach these rates.

Note: For these tests, 4 Mbps of traffic was transmitted in the upstream direction to prevent ARP aging on the ONT709 port.

Table 10. Streaming Video Quality Results with 1500 Byte Ethernet Frame Competing Downstream Traffic

Frame Size (bytes)	Upstream Traffic Rate Aggregate (Mbps)	Downstream Traffic Rate Aggregate (Mbps)	Remote Desktop Connection No QoS	Video Quality No QoS	Remote Desktop Connection With QoS	Video Quality With QoS
1500	4	1000	Yes	5	Yes	5
1500	4	2000	Yes	5	Yes	5
1500	4	2200	Yes	5	Yes	5
1500	4	2400	Yes	1	Yes	5
1500	4	3000	Yes	0	Yes	5*
1500	4	4000	No	0	Yes	5*

The "*" denotes tests where video started and played with good quality but stopped after several iterations. This state was tested and shown to be repeatable.

5.7 Streaming Video Testing with Competing Bidirectional Traffic

The next set of streaming video tests involved testing video quality between the video server and client as shown in Figure 41. For these tests, bidirectional traffic was generated by the Spirent TestCenter as shown by the direction of the arrows. The Spirent TestCenter traffic was used to provide competing traffic for the streaming video that was sent using the Remote Desktop Protocol from the video server to the video client. The Spirent TestCenter traffic was then increased and the test repeated. These tests were performed for 64 and 1500 byte Ethernet frame Spirent TestCenter traffic.

Figure 41. Configuration for Streaming Video Testing with Competing Bidirectional Traffic

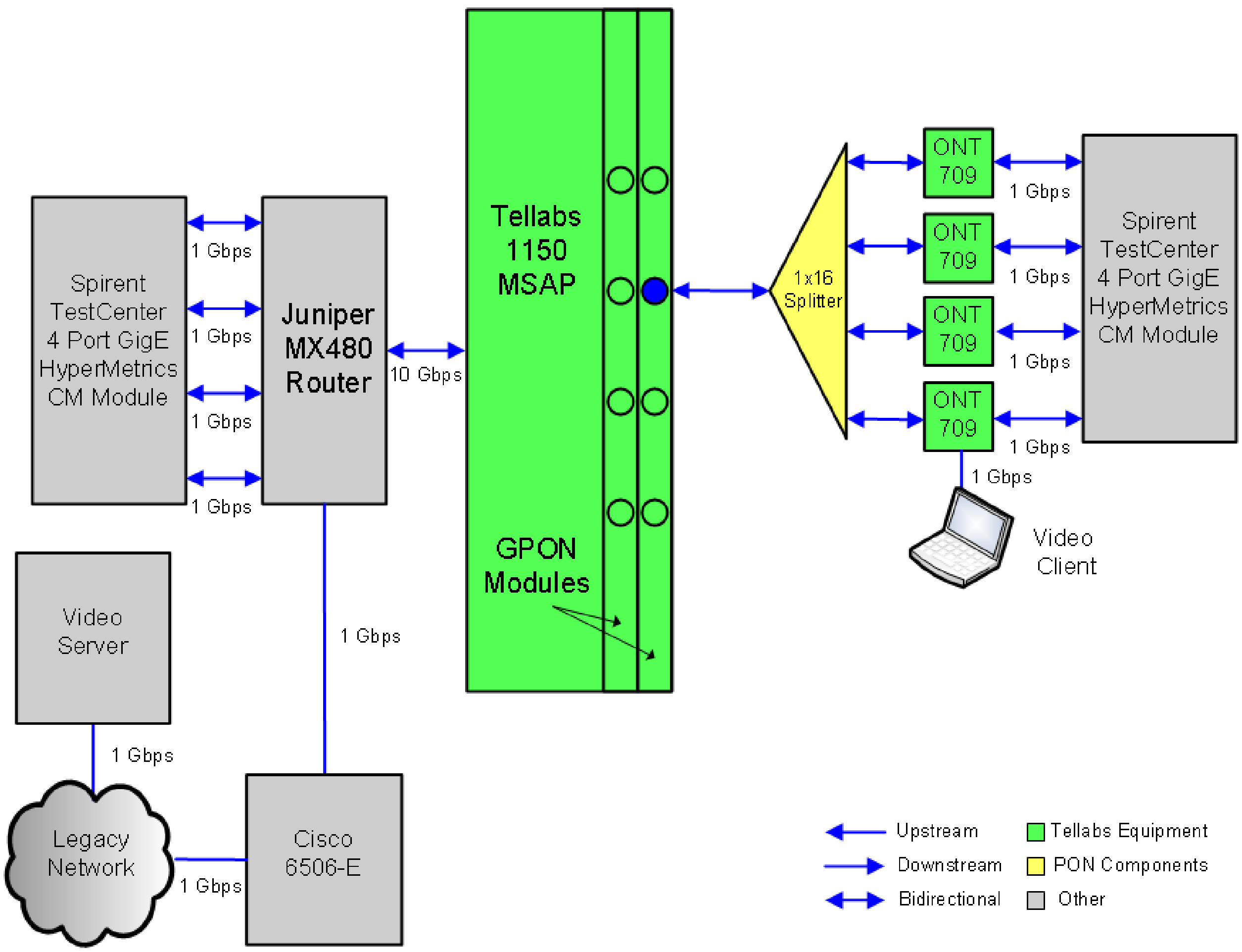


Table 11 presents the streaming video quality results with 64 byte Ethernet frame competing bidirectional traffic. As presented, without QoS enabled, when there is competing bidirectional traffic at rates of 2000 Mbps, a Remote Desktop Connection either cannot be completed/ maintained or the streaming video quality will be poor. When QoS is enabled, a Remote Desktop Connection is possible at 2000 Mbps and perfect streaming video is displayed at that value of competing bidirectional traffic. For competing bidirectional traffic at rates beyond 2000 Mbps, a Remote Desktop Connection either cannot be completed or the streaming video quality will be poor. This is not considered a problem as competing bidirectional traffic should never reach these rates.

Table 11. Streaming Video Quality Results with 64 Byte Ethernet Frame Competing Bidirectional Traffic

Frame Size (bytes)	Upstream Traffic Rate Aggregate (Mbps)	Downstream Traffic Rate Aggregate (Mbps)	Remote Desktop Connection No QoS	Video Quality No QoS	Remote Desktop Connection With QoS	Video Quality With QoS
64	1100	1000	Yes	5	Yes	5
64	1200	1200	Yes	5	Yes	5
64	1200	2200	Yes	5	Yes	5
64	1200	2300	Yes	5	Yes	5
64	2000	2000	No	0	Yes	5
64	2200	2200	No	0	Yes	2
64	2400	2400	No	0	Yes	1
64	3000	3000	No	0	Yes	1
64	4000	4000	No	0	No	0

Table 12 presents the streaming video quality results with 1500 byte Ethernet frame competing bidirectional traffic. As shown, when the upstream is overloaded with traffic rates of 2000 Mbps or greater, the Remote Desktop Connection cannot be completed when QoS is not enabled. When QoS is enabled, a Remote Desktop connection is possible at 4000 Mbps and perfect streaming video is displayed at any value of competing bidirectional traffic. However, the video would stop playing after several iterations at competing downstream traffic rates of 4000 Mbps. This is not considered a problem as competing bidirectional traffic should never reach these rates.

Table 12. Streaming Video Quality Results with 1500 Byte Ethernet Frame Competing Bidirectional Traffic

Frame Size (bytes)	Upstream Traffic Rate Aggregate (Mbps)	Downstream Traffic Rate Aggregate (Mbps)	Remote Desktop Connection? No QoS	Video Quality No QoS	Remote Desktop Connection? With QoS	Video Quality With QoS
1500	1100	1000	Yes	5	Yes	5
1500	1200	1200	Yes	1	Yes	5
1500	1200	2200	Yes	1	Yes	5
1500	1200	2300	Yes	1	Yes	5
1500	2000	2000	No	0	Yes	5
1500	2200	2200	No	0	Yes	5
1500	2400	2400	No	0	Yes	5
1500	3000	3000	No	0	Yes	5*
1500	4000	4000	No	0	Yes	5*

The "*" denotes tests where video started and played with good quality but stopped after several iterations. This state was tested and shown to be repeatable.

5.8 Streaming Video Testing Summary

Based on the results presented in this section, the following conclusions can be reached:

- Without QoS enabled:
    - streaming video will work well until the GPON port is overloaded in the upstream direction with competing traffic exceeding 1200 Mbps for 64 byte and 1100 Mbps for 1500 byte Ethernet frames
    - streaming video will work well until the GPON port is overloaded in the downstream direction with competing traffic exceeding 2400 Mbps for 64 byte Ethernet frames or 2200 Mbps for 1500 byte Ethernet frames
    - streaming video will work well until the GPON port is overloaded with bidirectional competing traffic at rates of 2000 Mbps for 64 byte and 1200 Mbps for 1500 byte Ethernet frames

- With QoS enabled:
    - streaming video works well at all competing upstream traffic rates tested
    - streaming video works very well at all competing downstream traffic rates tested However, the video would stop playing after several iterations at competing downstream traffic rates of 3000 and 4000 Mbps.
    - streaming video works well until the GPON port is overloaded with bidirectional competing traffic at rates exceeding 2000 Mbps for 64 byte Ethernet frames
    - streaming video works well until the GPON port is overloaded with bidirectional competing traffic at rates exceeding 2400 Mbps for 1500 byte Ethernet frames. However, the video would stop playing after several iterations at competing bidirectional traffic rates of 3000 and 4000 Mbps.

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6. ZERO CLIENT TESTING

6.1 Zero Clients at Sandia National Laboratories

Sandia National Laboratories is also deploying zero clients. These zero clients offer the potential to reduce costs by eliminating the need for individual PCs for many users. They also allow a much more secure environment by having security patches installed to a central server which maintains the zero client images. This section describes the tests performed and the results.

6.2 Zero Client Test Configuration

The architecture used for the Zero Client is the VMware Virtual Desktop Infrastructure (VDI). The test configuration for testing Zero Clients on the Tellabs 1150 MSAP is shown in Figures 42-44. The VMware View server for this test is located on the legacy network. The rationale was to attempt to characterize the Zero Client performance on the Tellabs 1150 MSAP as accurately as was possible without having to install another VMware View server that was dedicated for testing. The Zero Client is physically connected to an ONT709. The hardware and software used for these tests are presented in Table 13.

Table 13. Zero Client Hardware and Software

Hardware and Software	Model or Version
VMware View Server	
Hardware	HP ProLiant BL460C G6 CPU - Intel Xeon X5550 @ 2.67 GHz
Operating System	Windows 7 Enterprise, 64 bit
Video Player	Microsoft Windows Media Player Version 12.0.7601.18150
Web Browser	Internet Explorer 9.0
Wyse Zero Client	
Hardware	Wyse Model PxN
Software	Firmware Version 4.0.3

6.3 Quality of Service for Zero Clients

Because the Zero Client does not perform any local processing, its operation is totally dependent on the network connection. Packet loss, delay, and jitter are not issues under normal uncongested network conditions. However, during heavy network congestion, the Zero Client user can be adversely affected.

The solution to this problem is to prioritize PCoIP traffic with a QoS scheme. The same QoS mechanism used to prioritize VoIP traffic and streaming video traffic was used. For a review of the QoS mechanism, please see Section 4.3.

6.4 Zero Client Test Strategy

The test strategy used for Zero Clients was the same as for VoIP and streaming video testing. For Zero Client tests, the Spirent TestCenter was again used to generate competing network traffic while an attempt was made to connect to the VMware View server from the Zero Client. If the connection was successful and the virtual desktop of the user was displayed, the time for this connection to be established was recorded. After this, the Space Shuttle Flip MPEG video was played. The quality of the video displayed on the Zero Client was then empirically rated as presented in Table 6. Next, Internet Explorer was started and the time to display a web page was recorded. The competing network traffic generated by the Spirent TestCenter was then varied for upstream, downstream, and bidirectional flows. Then a new Zero Client connection was attempted, and if successful, the video and web browser tests were repeated. The tests were divided into two sets. The first set of tests was run without QoS enabled. The second set of tests was then run with QoS enabled. For all tests, the Spirent TestCenter competing network traffic was IP Experimental (Protocol = 253) packets. Tests were performed on a weekend to minimize factors such as increased network traffic or server loading that could potentially impact test results.

6.5 Zero Client Baseline Testing

Before running any tests with competing network traffic, Zero Client baseline testing was performed to measure Zero Client performance on both the legacy network and Tellabs 1150 MSAP with no competing traffic. Table 14 presents the Zero Client baseline performance results. As shown, both the legacy network and Tellabs 1150 MSAP network have similar performance. Note that the video quality is not perfect. Because these tests were conducted without competing traffic, there was no need to test with QoS enabled. Also, QoS has not been implemented in the legacy network, so it was not possible to test in that mode. Therefore, QoS columns have Not Applicable (NA) entries.

Table 14. Zero Client Baseline Performance Results

Network	US Traffic Rate Agg. (Mbps)	DS Traffic Rate Agg. (Mbps)	Server Conn. Time No QoS (s)	Home Page Display Time No QoS (s)	Video Quality No QoS	Server Conn. Time With QoS (s)	Web Page Display Time With QoS (s)	Video Quality With QoS
Legacy	0	0	8	4	3	NA	NA	NA
Tellabs 1150 MSAP	0	0	8	4	3	NA	NA	NA

6.6 Zero Client Testing with Competing Upstream Traffic

The next set of Zero Client tests performed involved testing the performance between the VMware View server and Zero Client as shown in Figures 42-44. For these tests, traffic was generated by the Spirent TestCenter in the upstream direction as shown by the direction of the arrows. This Spirent TestCenter traffic was used to provide competing traffic for the Zero Client connection attempts to the VMware View server, video playback, and web browser display that was sent using the PCoIP protocol from the VMware View server to the Zero Client. The Spirent TestCenter traffic was then increased and the test repeated. These tests were performed for 64 and 1500 byte Ethernet frame Spirent TestCenter traffic. The Ethernet frames contained IP Experimental (Protocol = 253) packets.

Figure 42. Configuration for Zero Client Testing with Competing Upstream Traffic

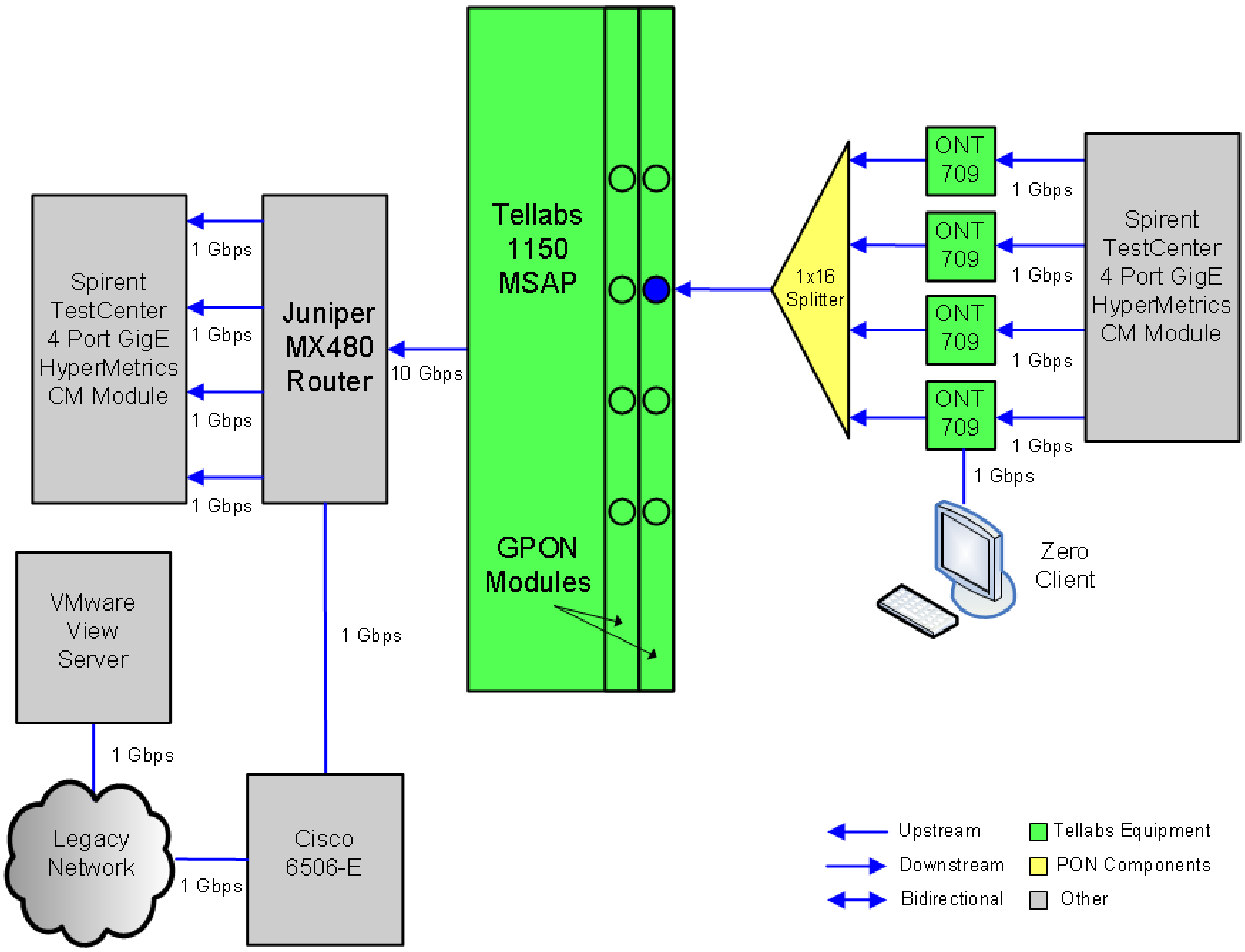

Table 15 presents the Zero Client performance results with 64 byte Ethernet frame competing upstream traffic. With competing traffic of 2000 Mbps, the Zero Client connection to the VMware View server cannot be made consistently. However, if a connection is made, keyboard entry and mouse actions respond slowly. Video quality is also degraded. Although 2000 Mbps well exceeds the ITU-T G.984 recommendations of 1.244 Gbps in the upstream direction, enough of the upstream connection frames are protected with the Upstream Sustained Rate of 5 Mbps, as illustrated in the connection profile in Figure 2, to permit a successful connection. When the upstream is overloaded with traffic rates of greater than 2000 Mbps, a Zero Client connection can either not be completed if QoS is not enabled. When QoS is enabled, a Zero Client connection is possible at 4000 Mbps with acceptable streaming video.

Table 15. Zero Client Performance Results with 64 Byte Ethernet Frame Competing Upstream Traffic

Frame Size (bytes)	US Traffic Rate Agg. (Mbps)	DS Traffic Rate Agg. (Mbps)	Server Conn. Time No QoS (s)	Home Page Display Time No QoS (s)	Video Quality No QoS	Server Conn. Time With QoS (s)	Web Page Display Time With QoS (s)	Video Quality With QoS
64	1000	0	11	4	3	8	5	3
64	1100	0	13	3	3	8	5	3
64	1200	0	12	3	3	8	5	3
64	2000	0	10 c	13	2	11	6	3
64	3000	0	cannot connect	NA	NA	10	3	3
64	4000	0	cannot connect	NA	NA	11	3	3

The "c" denotes that there were problems connecting consistently without QoS enabled.

Table 16 presents the Zero Client performance results with 1500 byte Ethernet frame competing upstream traffic. The results are the same as for 64 byte Ethernet frame competing upstream traffic. With competing traffic of 2000 Mbps, the Zero Client connection to the VMware View server cannot be made consistently. However, if a connection is made keyboard entry and mouse actions respond slowly. Video quality is also degraded. Although 2000 Mbps well exceeds the ITU-T G.984 recommendations of 1.244 Gbps in the upstream direction, enough of the upstream connection frames are protected with the Upstream Sustained Rate of 5 Mbps, as illustrated in the connection profile in Figure 2, to permit a successful connection. When the upstream is overloaded with traffic rates of greater than 2000 Mbps, a Zero Client connection can either not be completed or maintained if QoS is not enabled. When QoS is enabled, a Zero Client connection is possible at 4000 Mbps with acceptable streaming video.

Table 16. Zero Client Performance Results with 1500 Byte Ethernet Frame Competing Upstream Traffic

Frame Size (bytes)	US Traffic Rate Agg. (Mbps)	DS Traffic Rate Agg. (Mbps)	Server Conn. Time No QoS (s)	Home Page Display Time No QoS (s)	Video Quality No QoS	Server Conn. Time With QoS (s)	Web Page Display Time With QoS (s)	Video Quality With QoS
1500	1000	0	12	3	3	10	3	3
1500	1100	0	12	3	3	10	3	3
1500	1200	0	11	3	3	10	3	3
1500	2000	0	15 c	13	2	10	3	3
1500	3000	0	cannot connect	NA	NA	10	3	3
1500	4000	0	cannot connect	NA	NA	10	3	3

The “c” denotes that there were problems connecting consistently without QoS enabled.

6.7 Zero Client Testing with Competing Downstream Traffic

The next set of Zero Client tests involved testing the performance between the VMware View server and Zero Client as shown in Figure 43. For these tests, traffic is generated by the Spirent TestCenter in the downstream direction as shown by the direction of the arrows. This Spirent TestCenter traffic is used to provide competing traffic for the Zero Client connection attempts to the VMware View server, video playback, and web browser display that was sent using the PCoIP protocol from the VMware View server to the Zero Client. The Spirent TestCenter traffic is then increased and the test repeated. These tests are performed for 64 and 1500 byte Ethernet frame Spirent TestCenter traffic.

Figure 43. Configuration for Zero Client Testing with Competing Downstream Traffic

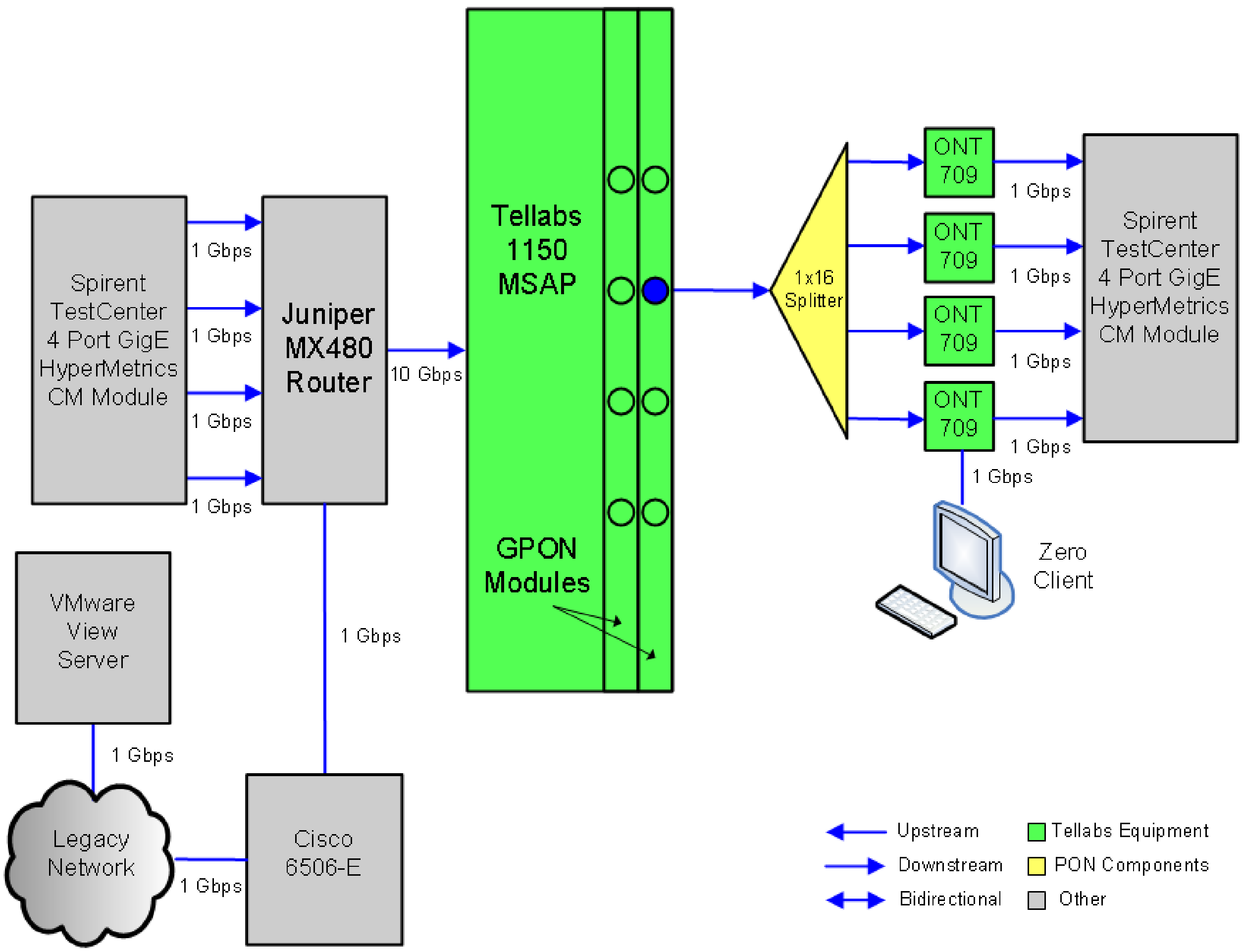

Table 17 presents the Zero Client performance results with 64 byte Ethernet frame competing downstream traffic. With competing traffic of 4000 Mbps, the Zero Client connection to the VMware View server can still be made. Although 4000 Mbps well exceeds the ITU-T G.984 recommendations of 2.488 Gbps in the downstream direction, the upstream connection packets have no competing traffic, so a connection is possible.

Even with competing traffic at 4000 Mbps, enough of the PCoIP packets sent from the VMware View server reach the Zero Client to permit some Zero Client usage. However, video quality is degraded when competing traffic is greater than 2400 Mbps if QoS is not enabled. When QoS is enabled, a Zero Client connection is possible at 4000 Mbps with low quality streaming video. Although after a few minutes the connection would drop. This is not considered a problem as competing downstream traffic should never reach these rates.

Note: For these tests, 4 Mbps of traffic was transmitted in the upstream direction to prevent ARP aging on the ONT709 port.

Table 17. Zero Client Performance Results with 64 Byte Ethernet Frame Competing Downstream Traffic

Frame Size (bytes)	US Traffic Rate Agg. (Mbps)	DS Traffic Rate Agg. (Mbps)	Server Conn. Time No QoS (s)	Home Page Display Time No QoS (s)	Video Quality No QoS	Server Conn. Time With QoS (s)	Web Page Display Time With QoS (s)	Video Quality With QoS
64	4	1000	12	3	3	10	3	3
64	4	2000	13	3	3	10	3	3
64	4	2200	12	3	3	10	3	3
64	4	2400	13	3	3	10	3	3
64	4	3000	13	3	2	10	3	3
64	4	4000	16 d	3	2	13 d	3	2

The “d” denotes that the connection dropped after a few minutes when QoS is not enabled and also when QoS is enabled.

Table 18 presents the Zero Client performance results with 1500 byte Ethernet frame competing downstream traffic. The results are the same as for 64 byte Ethernet frame competing downstream traffic. With competing traffic of 4000 Mbps, the Zero Client connection to the VMware View server can still be made. Although 4000 Mbps well exceeds the ITU-T G.984 recommendations of 2.488 Gbps in the downstream direction, the upstream connection packets have no competing traffic, so a connection is possible.

Even with competing traffic at 4000 Mbps, enough of the PCoIP packets sent from the VMware View server reach the Zero Client to permit some Zero Client usage. The mouse pointer would occasionally disappear at competing traffic rates of 2200 Mbps and above. Video quality is degraded when competing traffic is greater than 2400 Mbps if QoS is not enabled. When QoS is enabled, a Zero Client connection is possible at 4000 Mbps with low quality streaming video. Although after a few minutes the connection would drop for competing traffic at rates of both 3000 and 4000 Mbps. This is not considered a problem as competing downstream traffic should never reach these rates.

Note: For these tests, 4 Mbps of traffic was transmitted in the upstream direction to prevent ARP aging on the ONT709 port.

Table 18. Zero Client Performance Results with 1500 Byte Ethernet Frame Competing Downstream Traffic

Frame Size (bytes)	US Traffic Rate Agg. (Mbps)	DS Traffic Rate Agg. (Mbps)	Server Conn. Time No QoS (s)	Home Page Display Time No QoS (s)	Video Quality No QoS	Server Conn. Time With QoS (s)	Web Page Display Time With QoS (s)	Video Quality With QoS
1500	4	1000	12	3	3	10	3	3
1500	4	2000	11	3	3	10	3	3
1500	4	2200	11	3 m	3	10	3	3
1500	4	2400	12	3	3	10	3	3
1500	4	3000	11	6	2	10 d	3	3
1500	4	4000	12	5	2	10 d	3	2

The “m” denotes that the mouse pointer disappeared.

The “d” denotes that the connection dropped after a few minutes.

6.8 Zero Client Testing with Competing Bidirectional Traffic

The next set of Zero Client Tests involved testing the performance between the VMware View server and Zero Client as shown in Figure 44. For these tests, bidirectional traffic was generated by the Spirent TestCenter as shown by the direction of the arrows. This Spirent TestCenter traffic was used to provide competing traffic for the video playback and web browser display that was sent using the PCoIP protocol from the VMware View server to the Zero Client. The Spirent TestCenter traffic was then increased and the test repeated. These tests were performed for 64 and 1500 byte Ethernet frame Spirent TestCenter traffic.

Figure 44. Configuration for Zero Client Testing with Competing Bidirectional Traffic

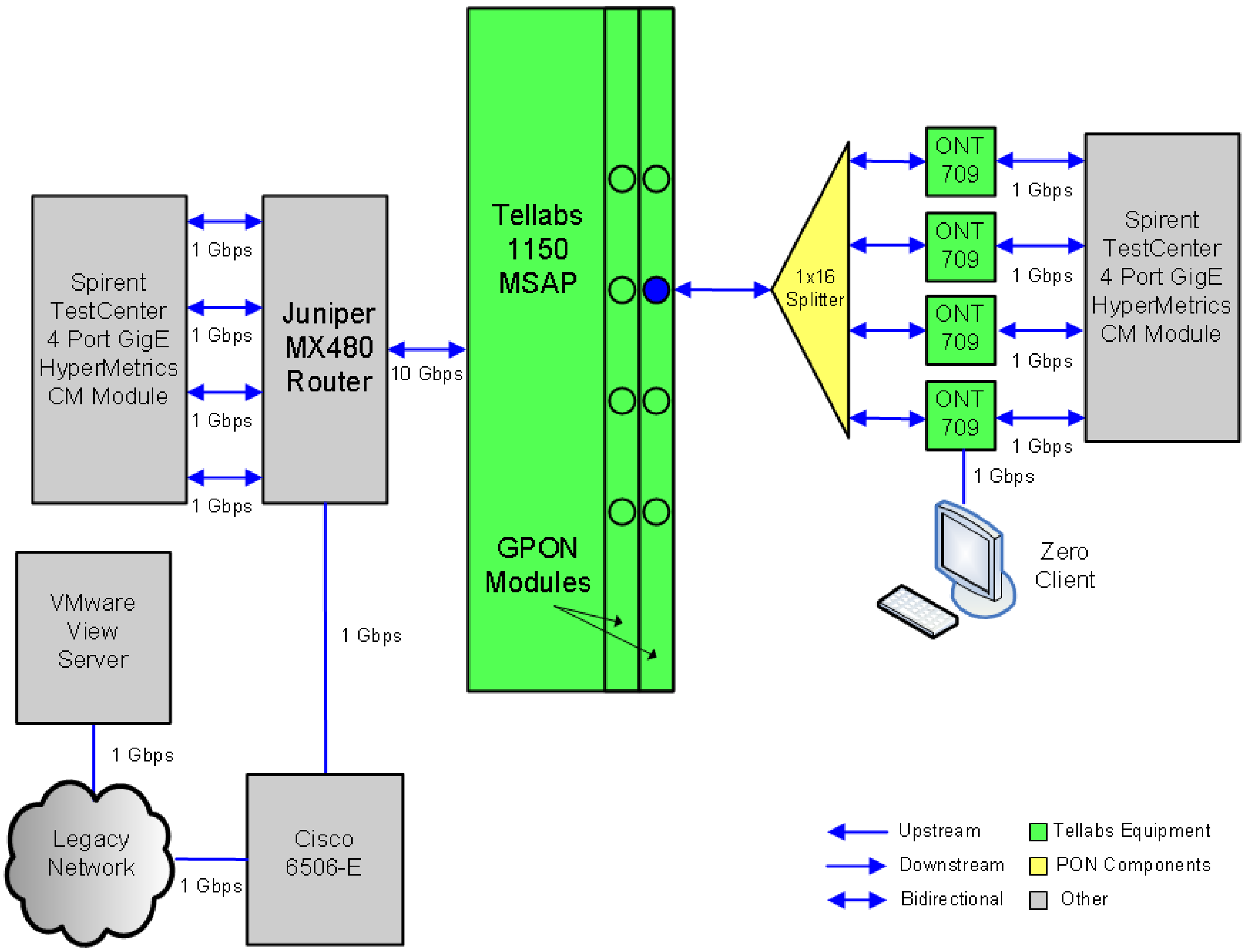

Table 19 presents the Zero Client performance results with 64 byte Ethernet frame competing bidirectional traffic. As presented, when both the upstream and downstream are overloaded with traffic rates of 2000 Mbps or greater, video quality is degraded or a Zero Client connection can either not be completed or maintained if QoS is not enabled. When QoS is enabled, a Zero Client connection is possible at 4000 Mbps but with low quality streaming video. There were problems with the connection dropping. This is denoted in Table 19. This is not considered a problem as competing bidirectional traffic should never reach these rates.

Table 19. Zero Client Performance Results with 64 Byte Ethernet Frame Competing Bidirectional Traffic

Frame Size (bytes)	US Traffic Rate Agg. (Mbps)	DS Traffic Rate Agg. (Mbps)	Server Conn. Time No QoS (s)	Home Page Display Time No QoS (s)	Video Quality No QoS	Server Conn. Time With QoS (s)	Web Page Display Time With QoS (s)	Video Quality With QoS
64	1000	1000	12	3	3	12	3	3
64	1200	1200	15	3	3	12	3	3
64	1200	2200	12	3	3	12	3	3
64	1200	2300	12 d2	3	3	12	3	3
64	2000	2000	12 c	3	2	12	3	3
64	2200	2200	cannot connect	NA	NA	12 d	3	3
64	2400	2400	cannot connect	NA	NA	12 d	3	3
64	3000	3000	cannot connect	NA	NA	12 d	3	2
64	4000	4000	cannot connect	NA	NA	13 d	3	2

The “c” denotes that there were problems connecting consistently.

The “d” denotes that the connection dropped after approximately 1 minute.

The “d2” denotes that the connection dropped after a few minutes.

The results for the tests with 1500 byte Ethernet frame competing bidirectional traffic are presented in Table 20. As presented, when both the upstream and downstream are overloaded with traffic rates of 1200 Mbps or greater, a Zero Client connection can either not be completed or maintained if QoS is not enabled. When QoS is enabled, a Zero Client connection is possible at 4000 Mbps with acceptable streaming video. However, at competing bidirectional traffic rates of 3000 and 4000 Mbps the connection would drop after about a minute of time. This is not considered a problem as competing bidirectional traffic should never reach these rates.

Table 20. Zero Client Performance Results with 1500 Byte Ethernet Frame Competing Bidirectional Traffic

Frame Size (bytes)	US Traffic Rate Agg. (Mbps)	DS Traffic Rate Agg. (Mbps)	Server Conn. Time No QoS (s)	Home Page Display Time No QoS (s)	Video Quality No QoS	Server Conn. Time With QoS (s)	Web Page Display Time With QoS (s)	Video Quality With QoS
1500	1000	1000	13	5	3	12	3	3
1500	1200	1200	cannot connect	NA	NA	12	3	3
1500	1200	2200	cannot connect	NA	NA	13	3	3
1500	1200	2300	cannot connect	NA	NA	12	3	3
1500	2000	2000	cannot connect	NA	NA	13	3	3
1500	2200	2200	cannot connect	NA	NA	11	3	3
1500	2400	2400	cannot connect	NA	NA	12	3	3
1500	3000	3000	cannot connect	NA	NA	10 d	3	3
1500	4000	4000	cannot connect	NA	NA	13 d	3	2

The “d” denotes that the connection dropped after approximately 1 minute.

6.9 Zero Client Testing Summary

Based on the results presented in this section, the following conclusions can be reached:

- Under normal conditions without competing traffic causing GPON port overload, Zero Clients work well and display acceptable video.
- Without QoS enabled:
  - Zero Clients work well until the GPON port is overloaded in the upstream direction with traffic at rates greater than 1200 Mbps for 64 byte and 1500 byte Ethernet frames
  - Zero Clients work well until the GPON port is overloaded in the downstream direction with traffic at rates greater than 2400 Mbps for 64 byte and 2200 Mbps for 1500 byte Ethernet frames
  - Zero Clients will work well until the GPON port is overloaded with bidirectional traffic at rates of 2000 Mbps for 64 byte Ethernet frames and 1200 Mbps for 1500 byte Ethernet frames
- When QoS is enabled:
  - Zero Clients work well at all tested competing upstream traffic rates on the Tellabs 1150 MSAP
  - Zero Clients work well at all tested competing downstream traffic rates up to 3000 Mbps for 64 byte and 1500 byte Ethernet on the Tellabs 1150 MSAP
  - Zero Clients work well at all tested competing bidirectional traffic rates up to 2000 Mbps for 64 byte Ethernet frames and 2400 Mbps for 1500 byte Ethernet frames on the Tellabs 1150 MSAP
- There were some dropped connections even with QoS enabled for competing downstream traffic at rates of 3000 and 4000 Mbps.
- There were some dropped connections even with QoS enabled for competing bidirectional traffic.

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7. SECURITY TESTING

7.1 Security Testing Introduction

An important aspect of any network device or system is security. Testing the security for the Tellabs 1150 MSAP consisted of tests of the Tellabs implementation of GPON. The Panorama PON Network Manager was also analyzed and tested for vulnerabilities with administrative management. Vulnerabilities to GPON systems in general are beyond the scope of this document and are not covered.

7.2 Tellabs 1150 MSAP GPON Implementation

As will be covered in more detail in Chapter 9, there are two methods of managing the Tellabs 1150 MSAP. These are the Panorama PON Network Manager or CLI access when logged in directly to the 1150 MSAP. Both methods require the user to authenticate with a password. User accounts can be given different levels of privileges. User accounts can be automatically disabled after a defined number of unsuccessful login attempts. These user account settings have been verified in laboratory tests.

The Tellabs 1150 MSAP also enhances security with features including access control lists (ACLs), 802.1X host authentication, and unexpected ONT detection. Unexpected ONTs are ONTs that were added or relocated without proper provisioning. All of these security features have been verified in laboratory tests.

7.3 Security Testing Summary

The Tellabs 1150 MSAP and Panorama PON Network Manager have many features which allow the GPON administrator to enhance security. These include ACLs and 802.1X host authentication. It also detects and prevents the operation of unexpected ONTs. Panorama PON Network Manager users can be given different levels of privileges. Both Panorama PON Network Manager users and those users who are directly logged on to the 1150 MSAP can have accounts automatically disabled after a defined number of login attempts.

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8. END USER FIELD TESTING

8.1 End User Field Testing

In addition to laboratory testing, end user field testing was also performed. Because Sandia National Laboratories has deployed over 14,000 ONTs, it was possible to test the Tellabs 1150 MSAP running FP27.1_015130 in a production environment. This section presents the field test results for many of the applications that are used every day.

8.2 Tests Performed and Results

The tests performed included a wide variety of applications used in daily tasks. These included web access, DHCP, multicast, diskless booting, email, file transfers to and from corporate storage systems, corporate streaming video, streaming audio, and printing.

8.2.1 Web Access

Users accessed both corporate internal web sites and external web sites using different versions of Firefox, Microsoft Internet Explorer, and Google Chrome. All browsers worked well.

8.2.2 DHCP

This test was performed by having hosts running Windows, Linux, Solaris, and Mac OS, which were connected to ONT709s and ONT709GPs. DHCP worked for all hosts.

8.2.3 Multicast

Hosts acting as multicast subscribers which were running different versions of Windows, Linux, Solaris, and Mac OS, were connected to ONT709s and ONT709GPs. These hosts were all able to receive corporate multicast transmissions.

8.2.4 Diskless Booting

In addition to laboratory testing of Zero Clients, production testing was also performed. There were some intermittent problems with the mouse pointer disappearing. This is considered to be a Zero Client software problem, not a FP27.1_015130 issue.

8.2.5 Email

Microsoft Outlook clients on Windows 7, Windows 8, and Windows Vista, were all able to send and receive email from the corporate email server. All clients worked well.

8.2.6 File Transfers to and from Corporate Storage Systems

This test used various Windows, Linux, Solaris, and Mac OS file transfer applications to save and retrieve files from the corporate storage systems. Peer-to-peer file transfers were also performed. All file transfer applications worked well.

8.2.7 Corporate Streaming Video

In addition to laboratory testing of streaming video, production testing of corporate streaming video was also performed. There were no issues in production testing. Corporate streaming video worked well.

8.2.8 Streaming Audio

Various versions of Microsoft Windows Media Player as well as the previously mentioned web browsers were used to play streaming audio from external streaming audio sites. Streaming audio worked well.

8.2.9 Printing

Many network printers from Hewlett-Packard, Dell, Konica Minolta, and others were connected to ONTs throughout the Sandia National Laboratories campus in Albuquerque, NM. All worked well.

8.3 End User Field Testing Summary

A large number of user applications were tested using the Tellabs 1150 MSAP due to the fact that Sandia National Laboratories has deployed over 14,000 ONT709s and ONT709GPs. All of the user applications tested on the Tellabs 1150 MSAP worked well using FP27.1_015130.

9. TELLABS 1150 MSAP MANAGEMENT

9.1 Tellabs 1150 MSAP Management Overview

As with the previous release, there are two main methods of managing the Tellabs 1150 MSAP. The easiest and most complete method is to use the Panorama PON Network Manager which was formerly called the Panorama Integrated Network Manager (INM). The other method is to use the CLI on the Tellabs 1150 MSAP. This chapter will briefly discuss management using FP27.1_015130.

9.2 The Panorama PON Network Manager

9.2.1 Panorama Network Manager Description and Operation

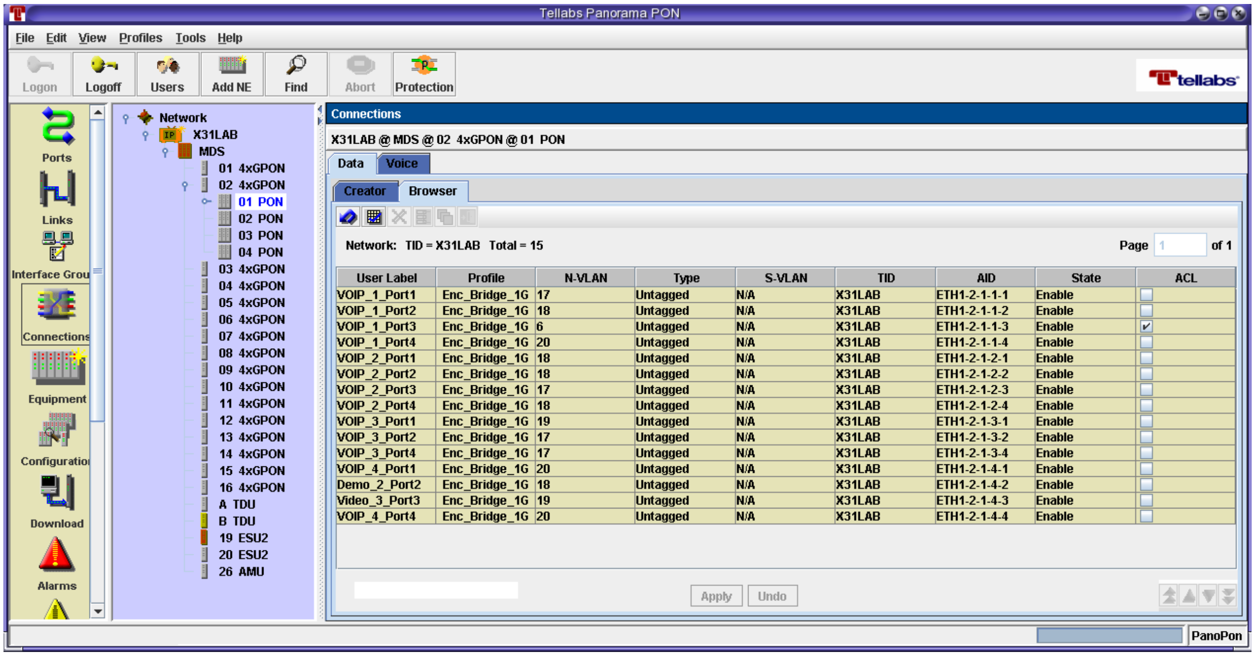
The Panorama PON Network Manager is a full featured network manager capable of performing all of the functions needed to manage a Tellabs 1150 MSAP once initial startup is performed. It differs from the Panorama INM that was in the previous release as it is more specific to the Tellabs 1150 MSAP. Also, all the functions used to perform the provisioning, alarm reporting, backup and restore, and report generation are now included in one application.

The Panorama PON Network Manager is a server running the Panorama application. It is possible to run a Windows or Solaris Panorama PON Network Manager server. To access the Panorama PON Network Manager server, a Panorama client is required. There are clients for both Windows-based systems and Solaris-based systems. Information is exchanged between the client and server using XML commands. It is possible to run both the server and a client on the same machine. This has been verified in laboratory tests.

9.2.2 Panorama PON Network Manager Screenshots

Figure 45 is a screenshot of the Panorama PON Network Manager. The Connections utility is currently selected. Before a port on an ONT can be placed into service, it must be provisioned using the Connections utility.

Figure 45. The Panorama PON Connections Utility



The columns have the following definitions:

User Label The user label is an administrator defined name of the port. There can be multiple entries with the same name.

Profile The profile denotes which traffic profiles are used by this connection. An example is presented in Figure 2.

N-VLAN The N-VLAN denotes the number of the network VLAN for this port.

Type The Subscriber Type denotes the type of host. This example is for a host connected to this port that will be sending and receiving untagged traffic.

S-VLAN This field denotes the number of the subscriber VLAN used. Because the type is defined in the N-VLAN field as untagged, this is not applicable in this example.

TID The Target Identifier is the name of the network element or Tellabs 1150 MSAP that is being provisioned.

AID The Access Identifier denotes the port of the ONT being provisioned.

State The state indicates if the port is active or not.

ACL The ACL indicates if the port has an associated access control list on it.

9.3 Command Line Interface

The CLI is also used to manage the Tellabs 1150 MSAP. This is performed by connecting to the Tellabs 1150 MSAP by using its management address using GPON or a serial port. Many functions can be performed with the CLI. The CLI works the same as it did with the previous release.

The CLI is quite useful for provisioning. A large (more than a few hundred) deployment of ONTs would require a technician to make various selections and entries into the Panorama PON Network Manager GUI for each ONT. Although this is possible, this has the potential to be slow and error prone. Most provisioning functions, with the exception of an ACL, can be performed using the CLI.

The advantages of the CLI are that these commands can be generated by scripts. The output of these scripts can be copied and pasted into a terminal window when connected to a Tellabs 1150 MSAP or the Panorama PON Network Manager. At that point, they are executed. Sandia National Laboratories has deployed most of their 14,000 ONTs using this method. It has saved a great deal of time and effort.

9.4 Management Testing Summary

The Tellabs 1150 MSAP has two options for management. These include the Panorama PON Network Manager and the CLI. Although the Panorama INM has been renamed to the Panorama PON Network Manager, there are only minor differences between the two managers. Both were tested in the laboratory and field tested and verified to work. For most daily operations the Panorama PON Network Manager will be sufficient. However, for large deployments, the CLI can be quite useful.

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10. TELLABS 1150 MSAP ENERGY CONSUMPTION

10.1 The Need for Energy Consumption Testing

GPON has been touted as a green technology. Because of that, GPON needed to be tested for energy consumption to determine how much energy it actually consumes. The passive components including the optical splitters, the Fiber Distribution Hubs (FDHs), and Rapid Fiber Distribution Terminals (RDTs) do not consume power. They do not need to be tested. Therefore only the ONTs and OLT need to be tested.

10.2 ONT Energy Consumption

Both the ONT709 and ONT709GP models of ONTs were tested. The actual energy consumption was measured with a Kill A Watt® EZ power meter. The ONTs were tested in two states, no load and full load. For no load testing, there was no additional traffic other than to have a host connected to have an active link on one port on the ONT. For full load testing, the Spirent TestCenter provided 1000 Mbps in the upstream and downstream directions on all four ports to provide an aggregate of 4000 Mbps in each direction. The Tellabs power consumption specifications are also presented. As shown, the power consumption is actually less than the Tellabs specifications. Note that because the ONT70GP can provide Power over Ethernet (PoE), the power consumption will be a function of the device it is powering. Therefore no testing was performed for PoE. The values listed in Table 21 are the average of 3 different ONTs for each ONT model.

Table 21. ONT Power Consumption

ONT Model	Power No Load (Watts)	Power Max. Load (Watts)	Tellabs Spec. (Watts)
ONT709	4.1	6.7	7.5
ONT709GP	6.7	11.3	7.5

10.3 OLT Energy Consumption

Because the Tellabs 1150 MSAP OLT uses DC power, it is connected to a Valere Rectifier. These rectifiers provide a display where the DC voltage and current can be viewed. Therefore it is possible to calculate the DC power as follows:

$$P_{watts} = V_{DC} * I_{DC}$$

A fu1ly loaded 1150 MSAP OLT was measured and the values are presented in Table 22.

Table 22. OLT Power Consumption

Tellabs 1150 MSAP OLT	DC Voltage (Volts)	DC Current (Amperes)	Power (Watts)	Tellabs Spec. Nominal Power (Watts)	Tellabs Spec. Peak Power (Watts)
#1	54	22	1188	1336	1518

11. CONCLUSION

This report presents the results of extensive laboratory and field testing of the Tellabs 1150 MSAP with Software Release FP27.1_015130. The tests performed included Spirent performance tests, VoIP tests, streaming video tests, Zero Client tests, security tests, management tests, and end user field tests.

The results of the testing confirm that the Tellabs 1150 MSAP performs at the ITU-T G.984 recommendations with specified performance levels of 1.244 Gbps in the upstream direction and 2.448 Gbps in the downstream direction minus protocol overhead. Software Release FP27.1_015130 has better small Ethernet frame performance than the previous release FP25.5.1. The Tellabs 1150 MSAP was once again proven to support QoS for VoIP, streaming video, and Zero Clients.

The Tellabs 1150 MSAP provides two main methods for management. These methods are the Panorama PON Network Manager and the CLI. Both were tested and worked well. The CLI enabled Sandia National Laboratories to deploy over 14,000 ONT709s via scripts.

The Tellabs 1150 MSAP was also tested for security. It protects the user from network eavesdropping, prevents unauthorized ONT additions or moves, supports 802.1X authentication, and has access control lists. All of these features were tested and worked well.

Because of the large production deployment, the Tellabs 1150 MSAP was extensively field tested for numerous corporate applications including web access, DHCP, multicast, diskless booting, email, file transfers to and from corporate storage systems, corporate streaming video, streaming audio, and printing. All of these applications worked well.

The Tellabs 1150 MSAP with Software Release FP27.1_015130 has performed well in all testing.

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12. REFERENCES

1. Brenkosh, et al. *Evaluation of the Tellabs 1150 GPON Multiservice Access Platform (U),* SAND2012-9525. Sandia National Laboratories, Albuquerque, NM, October 2012. [Unclassified] October 3, 2012. http://prod.sandia.gov/techlib/access-control.cgi/2012/129525.pdf

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APPENDIX A: UPSTREAM PERFORMANCE RESULTS

The configuration for these tests is illustrated in Figure 4. Mean latency is unidirectional and includes the latency of the Juniper MX480. Forwarding rate is the number of frames per second (fps) that were successfully sent and received by the Spirent TestCenter without any frame loss occurring.

Table 23. Upstream Performance Results for 1 Stream Block

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	1	145.68	630113	630129	630117	630112	630130	630120	8	322621495
128	1	110.18	506095	624877	517990	583313	595187	565492	45849	579064289
256	1	98.56	376467	427428	421059	347812	414689	397491	30520	814061650
512	1	327.50	231655	231652	231649	231652	231649	231651	3	948844265
1024	1	439.33	118885	118887	118886	118884	118888	118886	1	973915636
1500	1	425.45	81658	81661	81658	81659	81659	81659	1	979905864
1518	1	424.61	80700	80699	80700	80702	80704	80701	2	980035616

Table 24. Upstream Performance Results for 2 Stream Blocks

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	2	186.67	904457	820767	946320	820760	862617	870984	48806	445943897
128	2	210.07	1024059	1012188	952804	1000310	1012169	1000306	24910	1024313221
256	2	292.04	561876	568226	568245	568236	542762	561869	9866	1150707511
512	2	453.30	288187	288189	288184	288184	288175	288184	5	1180401689
1024	2	414.77	145171	145165	145169	145172	145172	145170	3	1189230412
1500	2	360.51	98553	98555	98553	98556	98556	98555	1	1182654144
1518	2	360.28	97400	97398	97399	97395	97401	97398	2	1182806728

Table 25. Upstream Performance Results for 3 Stream Blocks

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	3	230.06	1199688	1199733	1199734	1199745	1199745	1199729	21	614261068
128	3	309.87	698753	716541	734330	716516	698740	712976	13313	730087432
256	3	351.91	565754	556200	565741	565756	565740	563838	3819	1154740646
512	3	330.78	283599	283599	283602	283594	283602	283599	3	1161622389
1024	3	324.03	141991	141991	141986	141989	141991	141989	2	1163177099
1500	3	362.69	97521	97523	97525	97523	97520	97523	2	1170272160
1518	3	362.57	96380	96380	96385	96384	96384	96382	2	1170468619

Table 26. Upstream Performance Results for 4 Stream Blocks

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	4	275.40	1934497	1976308	1976303	1976310	1934457	1959575	20492	1003302369
128	4	296.84	1074183	1074179	1074184	1074186	1074182	1074183	2	1099963210
256	4	355.86	563268	563268	563264	563233	563276	563262	15	1153560191
512	4	303.16	279008	279008	279008	279009	279009	279008	0	1142818644
1024	4	345.01	142177	142177	142170	142177	142177	142176	3	1164702712
1500	4	421.92	97653	97653	97653	97653	97650	97653	1	1171830480
1518	4	412.33	96508	96509	96506	96508	96510	96508	1	1171992375

APPENDIX B: DOWNSTREAM PERFORMANCE RESULTS

The configuration for these tests is illustrated in Figure 6. Mean latency is unidirectional and includes the latency of the Juniper MX480. Forwarding rate is the number of frames per second (fps) that were successfully sent and received by the Spirent TestCenter without any frame loss occurring.

Table 27. Downstream Performance Results for 1 Stream Block

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	1	72.70	1216053	1216053	1216053	1226468	1216053	1218136	4166	623685537
128	1	34.26	844595	844595	844595	844595	844595	844595	0	864864803
256	1	38.24	452899	452899	452899	452899	452899	452899	0	927536169
512	1	46.37	234962	234962	234962	234962	234962	234962	0	962405982
1024	1	61.71	119732	119732	119732	119732	119732	119732	0	980842856
1500	1	75.67	82237	82237	82237	82237	82237	82237	0	986842032
1518	1	76.28	81274	81274	81274	81274	81274	81274	0	986996046

Table 28. Downstream Performance Results for 2 Stream Blocks

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	2	32.20	2432106	2432105	2432106	2432105	2432106	2432106	0	1245238017
128	2	34.54	1689189	1689189	1689189	1689189	1689189	1689189	0	1729729610
256	2	38.72	905797	905797	905797	905797	905797	905797	0	1855072375
512	2	47.30	469925	469925	469925	469925	469925	469925	0	1924811997
1024	2	63.53	239464	239464	239464	239464	239464	239464	0	1961685811
1500	2	78.27	164474	164474	164474	164474	164474	164474	0	1973684304
1518	2	78.95	162549	162549	162549	162549	162549	162549	0	1973992263

Table 29. Downstream Performance Results for 3 Stream Blocks

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	3	32.67	3679548	3679548	3679548	3679548	3679548	3679548	0	1883928369
128	3	34.34	2111565	2111565	2111565	2111565	2111565	2111565	0	2162242796
256	3	40.33	1088454	1088458	1088457	1088457	1088455	1088456	1	2229158265
512	3	49.32	544228	544227	544228	544228	544228	544228	0	2229156987
1024	3	66.41	272114	272114	272114	272114	272114	272114	0	2229157364
1500	3	81.09	185763	185763	185763	185763	185763	185763	0	2229156216
1518	3	81.79	183561	183561	183560	183561	183560	183560	0	2229157838

Table 30. Downstream Performance Results for 4 Stream Blocks

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	4	32.14	3720369	3720374	3720376	3720376	3720374	3720374	2	1904831489
128	4	34.42	2111565	2111565	2111561	2111565	2111565	2111564	2	2162241569
256	4	41.76	1088457	1088455	1088454	1088457	1088456	1088456	1	2229157634
512	4	50.78	544227	544226	544227	544228	544228	544227	1	2229155242
1024	4	67.45	272114	272113	272114	272113	272114	272114	0	2229154644
1500	4	85.03	185763	185763	185763	185763	185763	185763	0	2229155328
1518	4	85.88	183560	183560	183561	183560	183560	183560	0	2229156259

APPENDIX C: BIDIRECTIONAL PERFORMANCE RESULTS

The configuration for these tests is illustrated in Figure 8. Mean latency is bidirectional and includes the latency of the Juniper MX480. Forwarding rate is the number of frames per second (fps) that were successfully sent and received by the Spirent TestCenter without any frame loss occurring.

Table 31. Bidirectional Performance Results for 1 Stream Block

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	1	88.74	1260221	1260211	1260226	1260209	1260214	1260216	6	645230709
128	1	66.47	1154719	1166585	1214105	1178473	1190351	1180847	20436	1209186943
256	1	80.55	772041	829370	772026	797518	823001	798791	24310	1635924566
512	1	187.45	463316	463304	463304	463294	463297	463303	8	1897689629
1024	1	250.64	237769	237768	237770	237769	237769	237769	1	1947803353
1500	1	247.36	163312	163309	163311	163310	163310	163310	1	1959723672
1518	1	248.07	161400	161400	161401	161399	161399	161400	1	1960039633

Table 32. Bidirectional Performance Results for 2 Stream Blocks

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	2	109.8	1641505	1641506	1892630	1892622	1892655	1792183	123028	917597944
128	2	124.42	2143111	2024353	2048095	1929337	1905578	2010095	85774	2058337290
256	2	160.33	1136435	1123714	1123721	1136468	1085515	1121171	18715	2296157811
512	2	259.66	576342	576381	576376	576380	576354	576367	16	2360797905
1024	2	253.43	290344	290344	290339	290343	290333	290341	4	2378470441
1500	2	219.98	197100	197108	197099	197108	197104	197104	4	2365248072
1518	2	218.36	194800	194795	194792	194801	194794	194796	4	2365608137

Table 33. Bidirectional Performance Results for 3 Stream Blocks

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	3	131.83	2273919	2273913	2273915	2273930	2273910	2273918	7	1164245803
128	3	173.79	1468728	1433115	1433091	1397480	1433045	1433092	22531	1467485964
256	3	191.5	1131512	1131510	1131512	1131502	1131457	1131498	21	2317308826
512	3	184.9	567198	567200	567200	567181	567198	567195	7	2323232121
1024	3	193.38	283980	283980	283982	283980	283980	283981	1	2326368649
1500	3	218.55	195049	195051	195045	195041	195046	195046	4	2340555408
1518	3	219.54	192768	192766	192767	192767	192767	192767	1	2340961355

Table 34. Bidirectional Performance Results for 4 Stream Blocks

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	4	149.14	3952619	3868842	3868927	3031909	3952613	3734982	353525	1912310807
128	4	165.91	2148372	2148358	2148365	2148365	2148365	2148365	4	2199925805
256	4	206.35	1126543	1126514	1126509	1126451	1126552	1126514	35	2307100295
512	4	175.79	558018	558017	558013	557998	558019	558013	8	2285621150
1024	4	206.88	284354	284355	284355	284355	284345	284353	4	2329417925
1500	4	255.58	195305	195306	195299	195306	195307	195304	3	2343652632
1518	4	250.34	193013	193012	193010	193017	193013	193013	2	2343952106

APPENDIX D: GPON PORT TO GPON PORT USING DIFFERENT GPON MODULES PERFORMANCE RESULTS

The configuration for these tests is illustrated in Figures 10 and 12. Mean latency is unidirectional for the unidirectional tests and bidirectional for the bidirectional tests and does not include the latency of the Juniper MX480. Forwarding rate is the number of frames per second (fps) that were successfully sent and received by the Spirent TestCenter without any frame loss occurring.

Table 35. Unidirectional Performance Results for 1 Stream Block Using Different GPON Modules

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	1	152.06	661524	651038	651039	598721	577792	628023	33357	321547655
128	1	109.03	654563	618932	470466	506112	607056	571426	70565	585140167
256	1	111.39	379650	401948	382840	401946	382845	389846	9949	798404522
512	1	81.65	225052	218449	220099	220095	225052	221749	2763	908284985
1024	1	406.67	118887	118888	118888	118884	118890	118888	2	973926941
1500	1	386.67	81657	81658	81661	81659	81661	81659	2	979907880
1518	1	385.4	80703	80704	80703	80699	80703	80702	2	980049144

Table 36. Unidirectional Performance Results for 2 Stream Blocks Using Different GPON Modules

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	2	190.46	904485	946321	967246	904464	946309	933765	25107	478087652
128	2	193.72	988417	1000292	1012171	988424	929033	983667	28701	1007275440
256	2	260.13	568236	568227	555498	542758	542758	555495	11392	1137654587
512	2	285.92	284886	284886	284885	284887	284886	284886	1	1166893818
1024	2	302.95	143491	143489	143486	143491	143488	143489	2	1175462658
1500	2	386.82	98556	98549	98554	98556	98545	98552	4	1182626064
1518	2	387.28	97399	97399	97402	97398	97400	97400	1	1182822831

Table 37. Unidirectional Performance Results for 3 Stream Blocks Using Different GPON Modules

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	3	219.38	885859	885854	885852	885863	885852	885856	5	453558223
128	3	288.05	770008	770000	716551	716569	716566	737939	26181	755649360
256	3	320.14	565756	565753	565753	565740	565756	565752	6	1158659318
512	3	310.81	283598	283602	283600	283598	283598	283599	2	1161622299
1024	3	387.43	144513	144516	144511	144516	144513	144514	2	1183858868
1500	3	2821.58	99194	99191	99191	99193	99190	99192	1	1190303112
1518	3	2752.45	98038	98036	98031	98034	98034	98035	2	1190532960

Table 38. Unidirectional Performance Results for 4 Stream Blocks Using Different GPON Modules

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	4	266	1934460	1934453	1934460	1683358	1515951	1800536	172351	921874660
128	4	284.95	1026673	1074186	1074167	1074184	1074227	1064687	19007	1090239822
256	4	359.97	563261	563272	563249	563265	563262	563262	8	1153560080
512	4	300.55	279002	279010	279010	278995	279009	279005	6	1142804955
1024	4	349.11	142178	142177	142174	142172	142177	142176	2	1164703121
1500	4	439.99	97650	97652	97648	97650	97647	97649	2	1171793040
1518	4	423.27	96510	96509	96511	96511	96510	96510	1	1172017707

Table 39. Bidirectional Performance Results for 1 Stream Block Using Different GPON Modules

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	1	266.89	611483	611505	653360	632419	611506	624055	16744	319516034
128	1	178.13	643999	632097	679634	632123	620247	641620	20437	657019038
256	1	135.07	491815	536410	485448	491809	600101	521116	43502	1067246490
512	1	134.53	456706	387317	430272	430267	400535	421020	24496	1724496011
1024	1	402.49	236092	236087	236092	236093	236090	236091	2	1934055342
1500	1	326.47	161004	161003	160999	161002	161000	161002	2	1932019344
1518	1	328.53	159113	159120	159120	159119	159115	159117	3	1932320370

Table 40. Bidirectional Performance Results for 2 Stream Blocks Using Different GPON Modules

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	2	268.45	1097436	1097378	1097424	1097425	1097456	1097424	26	561881029
128	2	230.69	1050449	1121646	979150	1050391	1050451	1050417	45061	1075627391
256	2	187.98	958104	881718	919941	983623	996353	947948	42165	1941397045
512	2	310.48	556532	556535	556564	556540	556544	556543	11	2279600275
1024	2	328.52	280226	280241	280227	280243	280245	280236	8	2295696671
1500	2	394.33	192479	192472	192477	192475	192479	192477	3	2309719032
1518	2	395.54	190223	190229	190228	190222	190229	190226	3	2310109669

Table 41. Bidirectional Performance Results for 3 Stream Blocks Using Different GPON Modules

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	3	295.75	1583296	1646138	1646004	1646081	1520468	1608398	50240	823499593
128	3	297.44	1326235	1290549	1290556	1326210	1397500	1326210	39052	1358039179
256	3	391.04	1112354	1112339	1112398	1112360	1112330	1112356	23	2278105448
512	3	348.58	557284	557246	557263	557270	557280	557269	13	2282572734
1024	3	340.61	278929	278918	278929	278923	278931	278926	5	2284961546
1500	3	388.67	191573	191574	191577	191575	191573	191574	2	2298893496
1518	3	390.58	189340	189331	189336	189325	189334	189333	5	2299261142

Table 42. Bidirectional Performance Results for 4 Stream Blocks Using Different GPON Modules

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	4	250.53	2027468	3868908	4036314	2027462	4036311	3199293	958744	1638037894
128	4	294	2195872	2195776	2195809	2195870	2195802	2195826	39	2248525718
256	4	280.26	1126547	1126529	1126497	1126543	1126545	1126532	19	2307137663
512	4	304.09	571232	571232	571215	571232	571226	571227	7	2339746742
1024	4	419.46	291077	291086	291089	291073	291088	291082	6	2384547709
1500	4	343.59	195307	195306	195306	195306	195307	195306	0	2343676176
1518	4	340.33	193017	193021	193021	193020	193020	193020	1	2344031698

APPENDIX E: GPON PORT TO GPON PORT USING THE SAME GPON MODULE PERFORMANCE RESULTS

The configuration for these tests is illustrated in Figures 14 and 16. Mean latency is unidirectional for the unidirectional tests and bidirectional for the bidirectional tests and does not include the latency of the Juniper MX480. Forwarding rate is the number of frames per second (fps) that were successfully sent and received by the Spirent TestCenter without any frame loss occurring.

Table 43. Unidirectional Performance Results for 1 Stream Block Using the Same GPON Module

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	1	152.56	661501	598726	671970	671967	651043	651041	27284	333333203
128	1	112.55	547665	500157	565485	458591	541727	522725	38559	535270478
256	1	126.61	373298	366922	376472	373298	382840	374566	5172	767111225
512	1	106.82	230004	223401	218444	220094	228356	224060	4505	917748367
1024	1	418.06	118886	118891	118886	118885	118884	118886	2	973917012
1500	1	396.13	81658	81656	81657	81656	81655	81656	1	979877400
1518	1	392.25	80704	80701	80705	80703	80700	80703	2	980051621

Table 44. Unidirectional Performance Results for 2 Stream Blocks Using the Same GPON Module

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	2	189	925394	946315	904474	904467	904454	917021	16741	469514518
128	2	200.49	1024075	703375	703369	1035928	988425	891034	154022	912419256
256	2	303.43	568209	542770	568208	568245	568221	563131	10180	1153291305
512	2	288.84	284892	284888	284885	284892	284884	284888	3	1166902321
1024	2	305.45	143497	143480	143488	143488	143489	143488	5	1175456629
1500	2	386.8	98553	98554	98556	98552	98554	98554	1	1182647208
1518	2	387.24	97396	97399	97401	97398	97403	97399	2	1182818799

Table 45. Unidirectional Performance Results for 3 Stream Blocks Using the Same GPON Module

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	3	245.23	948643	948625	948624	948641	948642	948635	8	485701150
128	3	265.29	698754	770003	716565	752204	698748	727255	28945	744709077
256	3	271.36	556202	556202	556198	556198	556205	556201	3	1139099795
512	3	314.16	283604	283593	283598	283600	283598	283599	4	1161620914
1024	3	319.14	141986	141983	141991	141991	141990	141988	3	1163167515
1500	3	361.55	97525	97523	97527	97523	97525	97525	2	1170295344
1518	3	371.57	96383	96377	96384	96384	96384	96382	3	1170468497

Table 46. Unidirectional Performance Results for 4 Stream Blocks Using the Same GPON Module

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	4	274.82	1808901	1934432	1976309	1808904	1976303	1900970	76712	973296508
128	4	272.83	1074181	1026681	979173	1074152	1074185	1045674	37999	1070770479
256	4	357.41	563237	563244	563259	563262	563265	563253	11	1153543037
512	4	298	279002	278998	279009	278999	279008	279003	5	1142797902
1024	4	344.96	142170	142173	142171	142170	142177	142172	3	1164676153
1500	4	432.06	97650	97648	97653	97649	97651	97650	2	1171801824
1518	4	421.43	96510	96502	96510	96506	96511	96508	3	1171991598

Table 47. Bidirectional Performance Results for 1 Stream Block Using the Same GPON Module

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	1	152.06	1343923	1302071	1197445	1322992	1343907	1302068	54564	666658595
128	1	115.79	988441	1119086	1012188	1083459	952840	1031203	61294	1055951847
256	1	112.23	752936	752943	727467	721110	733806	737652	13112	1510711988
512	1	67.45	436872	443492	440182	446799	450100	443489	4677	1816530625
1024	1	257.13	237771	237780	237774	237771	237772	237774	3	1947841364
1500	1	256.01	163315	163310	163318	163313	163319	163315	3	1959783096
1518	1	256.35	161398	161399	161400	161401	161411	161402	5	1960061200

Table 48. Bidirectional Performance Results for 2 Stream Blocks Using the Same GPON Module

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	2	247.18	1181147	1390415	1390390	1306688	1306655	1315059	76716	673310141
128	2	234.31	1074142	1121701	1240455	1169202	1216726	1164445	60853	1192392145
256	2	178.62	970882	983618	881732	1034570	958142	965789	49394	1977935610
512	2	258.35	563169	563172	563162	563161	563175	563168	5	2306736587
1024	2	265.98	283609	283608	283614	283612	283610	283610	2	2323336086
1500	2	261.47	192485	192481	192482	192486	192485	192484	2	2309806560
1518	2	263.32	190233	190229	190229	190229	190230	190230	2	2310150205

Table 49. Bidirectional Performance Results for 3 Stream Blocks Using the Same GPON Module

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	3	264.71	1897254	1897256	1897247	1897254	1897242	1897251	5	971392326
128	3	230.05	1718170	1575649	1789431	1825075	1611276	1703920	97191	1744814309
256	3	242.65	1112411	1112398	1112404	1112399	1112399	1112402	5	2278199472
512	3	243.12	557284	557284	557285	557287	557283	557285	1	2282638402
1024	3	1900.79	283717	278929	283691	283719	278932	281798	2341	2308486889
1500	3	290.22	191580	191580	191580	191580	191581	191580	0	2298965520
1518	3	295.76	189339	189339	189338	189339	189338	189339	0	2299328906

Table 50. Bidirectional Performance Results for 4 Stream Blocks Using the Same GPON Module

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	4	352.89	2027273	2027265	2027352	2111016	2111025	2060786	41016	1055122444
128	4	247.43	2053352	1958338	2100857	2100852	2053346	2053349	52040	2102629280
256	4	262.25	1101069	1101074	1101054	1101072	1101070	1101068	7	2254987350
512	4	276.11	558016	557996	557992	558016	558015	558007	11	2285596606
1024	4	1582.91	284019	284320	284342	284024	284135	284168	139	2327905239
1500	4	318.39	190681	190678	190680	190681	190680	190680	1	2288162112
1518	4	327.54	188449	188445	188449	188449	188450	188448	2	2288517685

APPENDIX F: UPSTREAM SINGLE ONT709 PERFORMANCE RESULTS

The configuration for these tests is illustrated in Figure 18. Mean latency is unidirectional and includes the latency of the Juniper MX480. Forwarding rate is the number of frames per second (fps) that were successfully sent and received by the Spirent TestCenter without any frame loss occurring.

Table 51. Upstream Performance Results for 1 Stream Block Using a Single ONT709

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	1	145.68	630113	630129	630117	630112	630130	630120	8	322621495
128	1	110.18	506095	624877	517990	583313	595187	565492	45849	579064289
256	1	98.56	376467	427428	421059	347812	414689	397491	30520	814061650
512	1	327.5	231655	231652	231649	231652	231649	231651	3	948844265
1024	1	439.33	118885	118887	118886	118884	118888	118886	1	973915636
1500	1	425.45	81658	81661	81658	81659	81659	81659	1	979905864
1518	1	424.61	80700	80699	80700	80702	80704	80701	2	980035616

Table 52. Upstream Performance Results for 2 Stream Blocks Using a Single ONT709

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	2	123.59	632437	632409	632438	632440	632440	632433	12	323805616
128	2	93.90	560864	596501	525230	513355	596496	558489	34751	571893049
256	2	59.29	421773	428136	383549	440871	415394	417945	19151	855950610
512	2	63.22	232030	232034	232025	232029	232025	232029	3	950389506
1024	2	84.71	118235	118239	118236	118235	118237	118236	1	968592736
1500	2	103.47	81211	81209	81209	81211	81212	81210	1	974523864
1518	2	104.01	80261	80257	80260	80259	80258	80259	2	974665782

Table 53. Upstream Performance Results for 3 Stream Blocks Using a Single ONT709

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	3	124.18	634764	634789	634784	634765	634789	634778	11	325006413
128	3	97.47	520608	520616	502809	680963	520628	549125	66279	562304031
256	3	59.96	441585	441577	441582	355598	441584	424385	34393	869140722
512	3	64.55	229095	229092	229092	229090	229090	229092	2	938359759
1024	3	89.45	119264	119267	119266	119268	119265	119266	1	977028006
1500	3	109.8	81917	81916	81917	81916	81919	81917	1	983002800
1518	3	110.47	80960	80957	80959	80958	80957	80958	1	983156697

Table 54. Upstream Performance Results for 4 Stream Blocks Using a Single ONT709

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	4	129.43	595240	595236	595240	595252	595250	595244	6	304764703
128	4	83.72	504118	622898	622890	646658	599139	599140	49831	613519827
256	4	79.69	397709	359499	372231	423179	435920	397707	29044	814504862
512	4	67.38	232760	232762	232760	232764	232760	232761	2	953389359
1024	4	93.35	118609	118612	118609	118610	118609	118610	1	971651629
1500	4	115.72	81468	81468	81466	81467	81466	81467	1	977605008
1518	4	116.58	80513	80514	80515	80512	80513	80514	1	977758081

APPENDIX G: DOWNSTREAM SINGLE ONT709 PERFORMANCE RESULTS

The configuration for these tests is illustrated in Figure 20. Mean latency is unidirectional and includes the latency of the Juniper MX480. Forwarding rate is the number of frames per second (fps) that were successfully sent and received by the Spirent TestCenter without any frame loss occurring.

Table 55. Downstream Performance Results for 1 Stream Block Using a Single ONT709

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	1	72.70	1216053	1216053	1216053	1226468	1216053	1218136	4166	623685537
128	1	34.26	844595	844595	844595	844595	844595	844595	0	864864803
256	1	38.24	452899	452899	452899	452899	452899	452899	0	927536169
512	1	46.37	234962	234962	234962	234962	234962	234962	0	962405982
1024	1	61.71	119732	119732	119732	119732	119732	119732	0	980842856
1500	1	75.67	82237	82237	82237	82237	82237	82237	0	986842032
1518	1	76.28	81274	81274	81274	81274	81274	81274	0	986996046

Table 56. Downstream Performance Results for 2 Stream Blocks Using a Single ONT709

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	2	64.69	1218368	1197452	1197452	1197452	1197452	1201635	8367	615237054
128	2	34.33	834037	834037	834037	834037	834037	834037	0	854054044
256	2	38.74	447237	447237	447237	447237	447237	447237	0	915942031
512	2	47.97	232025	232025	232025	232025	232025	232025	0	950375940
1024	2	65.46	118235	118235	118235	118235	118235	118235	0	968582365
1500	2	81.32	81209	81209	81209	81209	81209	81209	0	974506584
1518	2	82.11	80258	80258	80258	80258	80258	80258	0	974658641

Table 57. Downstream Performance Results for 3 Stream Blocks Using a Single ONT709

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	3	84.73	1199766	1199761	1199774	1199765	1199764	1199766	4	614280208
128	3	35.03	841295	841295	841295	841295	841295	841295	0	861486475
256	3	39.95	451129	451129	451129	451129	451129	451129	0	923913036
512	3	50.13	234045	234045	234045	234045	234045	234045	0	958646591
1024	3	69.69	119264	119264	119264	119264	119264	119264	0	977011458
1500	3	87.5	81916	81916	81916	81916	81916	81916	0	982987224
1518	3	88.36	80957	80957	80957	80957	80957	80957	0	983140666

Table 58. Downstream Performance Results for 4 Stream Blocks Using a Single ONT709

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	4	33.59	1181175	1181176	1181176	1181176	1181176	1181176	0	604761862
128	4	35.66	836676	836676	836677	836676	836676	836676	0	856756734
256	4	40.96	448653	448653	448653	448653	448653	448653	0	918840574
512	4	52.21	232760	232760	232760	232760	232760	232760	0	953383477
1024	4	73.85	118609	118609	118609	118609	118609	118609	0	971647533
1500	4	93.55	81466	81466	81466	81466	81466	81466	0	977590488
1518	4	94.48	80512	80512	80512	80512	80512	80512	0	977743071

APPENDIX H: BIDIRECTIONAL SINGLE ONT709 PERFORMANCE RESULTS

The configuration for these tests is illustrated in Figure 22. Mean latency is bidirectional and includes the latency of the Juniper MX480. Forwarding rate is the number of frames per second (fps) that were successfully sent and received by the Spirent TestCenter without any frame loss occurring.

Table 59. Bidirectional Performance Results for 1 Stream Block Using a Single ONT709

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	1	88.74	1260221	1260211	1260226	1260209	1260214	1260216	6	645230709
128	1	66.47	1154719	1166585	1214105	1178473	1190351	1180847	20436	1209186943
256	1	80.55	772041	829370	772026	797518	823001	798791	24310	1635924566
512	1	187.45	463316	463304	463304	463294	463297	463303	8	1897689629
1024	1	250.64	237769	237768	237770	237769	237769	237769	1	1947803353
1500	1	247.36	163312	163309	163311	163310	163310	163310	1	1959723672
1518	1	248.07	161400	161400	161401	161399	161399	161400	1	1960039633

Table 60. Bidirectional Performance Results for 2 Stream Blocks Using a Single ONT709

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	2	77.7	1264862	1264870	1264881	1264879	1264881	1264875	7	647615755
128	2	63.29	1050465	1026710	1169236	1216744	1074219	1107475	72984	1134054136
256	2	55.11	856261	779828	868999	818038	856261	835877	32826	1711877050
512	2	55.76	464051	464051	464051	464051	464051	464051	0	1900751421
1024	2	75.9	236470	236470	236470	236470	236470	236470	0	1937163960
1500	2	93.12	162418	162418	162418	162418	162418	162418	0	1949012040
1518	2	93.72	160517	160510	160517	160517	160517	160516	3	1949300718

Table 61. Bidirectional Performance Results for 3 Stream Blocks Using a Single ONT709

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	3	80.48	1206742	1206752	1206752	1206728	1206725	1206740	12	617850903
128	3	63.8	1148113	1041227	1183752	1219384	969964	1112488	92915	1139187712
256	3	57.81	883152	806718	844939	787611	883152	841115	38973	1722602529
512	3	57.73	458177	458177	458177	458177	458177	458177	0	1876691370
1024	3	80.21	238528	238528	238528	238528	238528	238528	0	1954021982
1500	3	99.51	163831	163831	163831	163831	163831	163831	0	1965973776
1518	3	100.18	161914	161914	161914	161914	161914	161914	0	1966280556

Table 62. Bidirectional Performance Results for 4 Stream Blocks Using a Single ONT709

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	4	81.61	1190476	1190476	1190477	1190477	1123512	1177084	26786	602666807
128	4	63.13	1245762	960719	1245777	1340770	1103252	1179256	133019	1207558304
256	4	52.66	871830	871830	871830	795393	846354	851447	29713	1743763948
512	4	60.14	465519	465501	465519	465503	465513	465511	8	1906733679
1024	4	84.38	237219	237219	237219	237208	237219	237217	4	1943277781
1500	4	105.44	162932	162932	162932	162926	162932	162930	2	1955165112
1518	4	106.17	161025	161025	161017	161025	161025	161023	3	1955466251

APPENDIX I: UPSTREAM SINGLE ONT709GP PERFORMANCE RESULTS

The configuration for these tests is illustrated in Figure 24. Mean latency is unidirectional for the unidirectional tests and bidirectional for the bidirectional tests and includes the latency of the Juniper MX480. Forwarding rate is the number of frames per second (fps) that were successfully sent and received by the Spirent TestCenter without any frame loss occurring.

Table 63. Upstream Performance Results for 1 Stream Block Using a Single ONT709GP

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	1	113.65	818468	923099	881252	985823	954486	912626	58429	467264328
128	1	67.25	624880	725838	648623	773341	624867	679510	59791	695818181
256	1	259.26	443356	443348	443341	443352	443345	443348	5	907977585
512	1	280.25	231654	231661	231663	231658	231656	231659	3	948874117
1024	1	398.91	118887	118889	118890	118889	118888	118889	1	973935231
1500	1	376.96	81659	81660	81659	81657	81658	81659	1	979902936
1518	1	372.09	80703	80702	80702	80702	80701	80702	1	980044699

Table 64. Upstream Performance Results for 2 Stream Blocks Using a Single ONT709GP

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	2	93.69	820781	778934	883582	946336	988201	883567	77173	452386229
128	2	45.28	798419	786529	679646	632133	810292	741404	71814	759197565
256	2	47.46	440876	440870	440870	440868	440885	440874	6	902909903
512	2	60.24	232025	232025	232030	232025	232033	232028	3	950386729
1024	2	81.74	118235	118238	118237	118240	118237	118237	2	968601321
1500	2	99.95	81210	81209	81211	81211	81210	81210	1	974521200
1518	2	100.74	80260	80261	80260	80260	80259	80260	1	974676566

Table 65. Upstream Performance Results for 3 Stream Blocks Using a Single ONT709GP

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	3	90.96	917299	885882	980078	948659	791713	904726	64642	463219855
128	3	50.52	663139	716592	787851	627512	645323	688083	58114	704597412
256	3	48.88	441580	441592	441579	441577	441579	441581	5	904358740
512	3	61.92	229090	229091	229093	229092	229106	229095	6	938371244
1024	3	86.28	119268	119267	119264	119268	119268	119267	1	977035493
1500	3	106.68	81919	81917	81918	81916	81916	81917	1	983007072
1518	3	107.29	80958	80958	80959	80957	80960	80959	1	983160243

Table 66. Upstream Performance Results for 4 Stream Blocks Using a Single ONT709GP

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	4	89.38	971923	888216	930065	971923	804503	913326	62642	467622934
128	4	52.12	694168	717907	717908	812941	622889	713163	60845	730278636
256	4	49.54	435922	435921	435915	435927	435926	435922	4	892768756
512	4	64.58	232766	232766	232761	232760	232766	232764	3	953399804
1024	4	90.19	118610	118614	118611	118609	118611	118611	2	971660722
1500	4	112.47	81466	81466	81466	81466	81466	81466	0	977590464
1518	4	113.35	80512	80515	80513	80515	80514	80514	1	977759879

APPENDIX J: DOWNSTREAM SINGLE ONT709GP PERFORMANCE RESULTS

The configuration for these tests is illustrated in Figure 26. Mean latency is unidirectional for the unidirectional tests and bidirectional for the bidirectional tests and includes the latency of the Juniper MX480. Forwarding rate is the number of frames per second (fps) that were successfully sent and received by the Spirent TestCenter without any frame loss occurring.

Table 67. Downstream Performance Results for 1 Stream Block Using a Single ONT709GP

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	1	196.31	1121848	1121847	1121846	1121848	1121846	1121847	1	574385661
128	1	34.37	844595	844595	844594	844595	844595	844595	0	864864780
256	1	38.19	452899	452899	452899	452899	452899	452899	0	927536173
512	1	46.33	234962	234962	234962	234962	234962	234962	0	962405966
1024	1	61.59	119732	119732	119732	119732	119732	119732	0	980842824
1500	1	75.56	82237	82237	82237	82237	82237	82237	0	986842080
1518	1	76.17	81274	81274	81274	81274	81274	81274	0	986996071

Table 68. Downstream Performance Results for 2 Stream Blocks Using a Single ONT709GP

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	2	32.95	1092820	1092820	1092820	1092820	1092820	1092820	0	559523766
128	2	34.68	834037	834037	834037	834037	834037	834037	0	854054017
256	2	38.76	447237	447237	447237	447237	447237	447237	0	915942031
512	2	48.06	232025	232025	232025	232025	232025	232025	0	950375924
1024	2	65.37	118235	118235	118235	118235	118235	118235	0	968582414
1500	2	81.31	81209	81209	81209	81209	81209	81209	0	974506584
1518	2	82.09	80258	80258	80258	80258	80258	80258	0	974658617

Table 69. Downstream Performance Results for 3 Stream Blocks Using a Single ONT709GP

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	3	33.32	1074219	1074219	1074219	1074219	1074219	1074219	0	549999960
128	3	35.13	841295	841295	841295	841295	841295	841295	0	861486473
256	3	40.04	451129	451129	451129	451129	451129	451129	0	923913032
512	3	50.25	234045	234045	234045	234045	234045	234045	0	958646624
1024	3	69.59	119264	119264	119264	119264	119264	119264	0	977011491
1500	3	87.52	81916	81916	81916	81916	81916	81916	0	982987272
1518	3	88.36	80957	80957	80957	80957	80957	80957	0	983140618

Table 70. Downstream Performance Results for 4 Stream Blocks Using a Single ONT709GP

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	4	33.79	1055618	1055618	1055617	1055617	1055617	1055617	0	540476156
128	4	35.69	836677	836677	836677	836676	836676	836677	0	856756746
256	4	41.03	448653	448653	448653	448653	448653	448653	0	918840582
512	4	52.32	232760	232760	232760	232760	232760	232760	0	953383469
1024	4	73.75	118609	118609	118609	118609	118609	118609	0	971647533
1500	4	93.57	81466	81466	81466	81466	81466	81466	0	977590536
1518	4	94.49	80512	80512	80512	80512	80512	80512	0	977743071

APPENDIX K: BIDIRECTIONAL SINGLE ONT709GP PERFORMANCE RESULTS

The configuration for these tests is illustrated in Figure 28. Mean latency is unidirectional for the unidirectional tests and bidirectional for the bidirectional tests and includes the latency of the Juniper MX480. Forwarding rate is the number of frames per second (fps) that were successfully sent and received by the Spirent TestCenter without any frame loss occurring.

Table 71. Bidirectional Performance Results for 1 Stream Block Using a Single ONT709GP

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	1	74.67	1615967	1615978	1971683	1908928	1615960	1745703	160127	893800123
128	1	51.64	1546664	1273490	1404128	1297244	1416004	1387506	97536	1420806316
256	1	149.92	886670	886685	886661	886690	886690	886679	12	1815918850
512	1	161.13	463316	463297	463302	463295	463306	463303	7	1897690309
1024	1	229.89	237768	237780	237776	237770	237771	237773	4	1947835171
1500	1	223.62	163315	163310	163309	163317	163317	163314	3	1959762288
1518	1	224.12	161403	161398	161406	161398	161399	161401	3	1960051437

Table 72. Bidirectional Performance Results for 2 Stream Blocks Using a Single ONT709GP

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	2	60.44	1850807	1808966	1976370	1641555	1892645	1834069	111043	939043087
128	2	43.56	1287998	1620566	1478040	1478041	1501795	1473288	106659	1508646873
256	2	43.65	881737	843523	881737	881737	881737	874094	15285	1790144754
512	2	54.35	464051	464051	464051	464051	464051	464051	0	1900751446
1024	2	74.31	236470	236470	236470	236470	236470	236470	0	1937163911
1500	2	91.46	162418	162418	162418	162418	162418	162418	0	1949012016
1518	2	91.95	160517	160517	160517	160517	160517	160517	0	1949316311

Table 73. Bidirectional Performance Results for 3 Stream Blocks Using a Single ONT709GP

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	3	62.89	1834542	1583426	1771741	1897321	1771764	1771759	105049	907140552
128	3	45.20	1326277	1326277	1326277	1504434	1504434	1397540	87279	1431081103
256	3	45.03	883152	883152	883152	883152	883152	883152	0	1808695517
512	3	56.30	458177	458177	458177	458177	458177	458177	0	1876691337
1024	3	78.56	238528	238528	238528	238528	238528	238528	0	1954021900
1500	3	97.50	163831	163831	163831	163831	163831	163831	0	1965973728
1518	3	98.35	161914	161914	161914	161914	161914	161914	0	1966280531

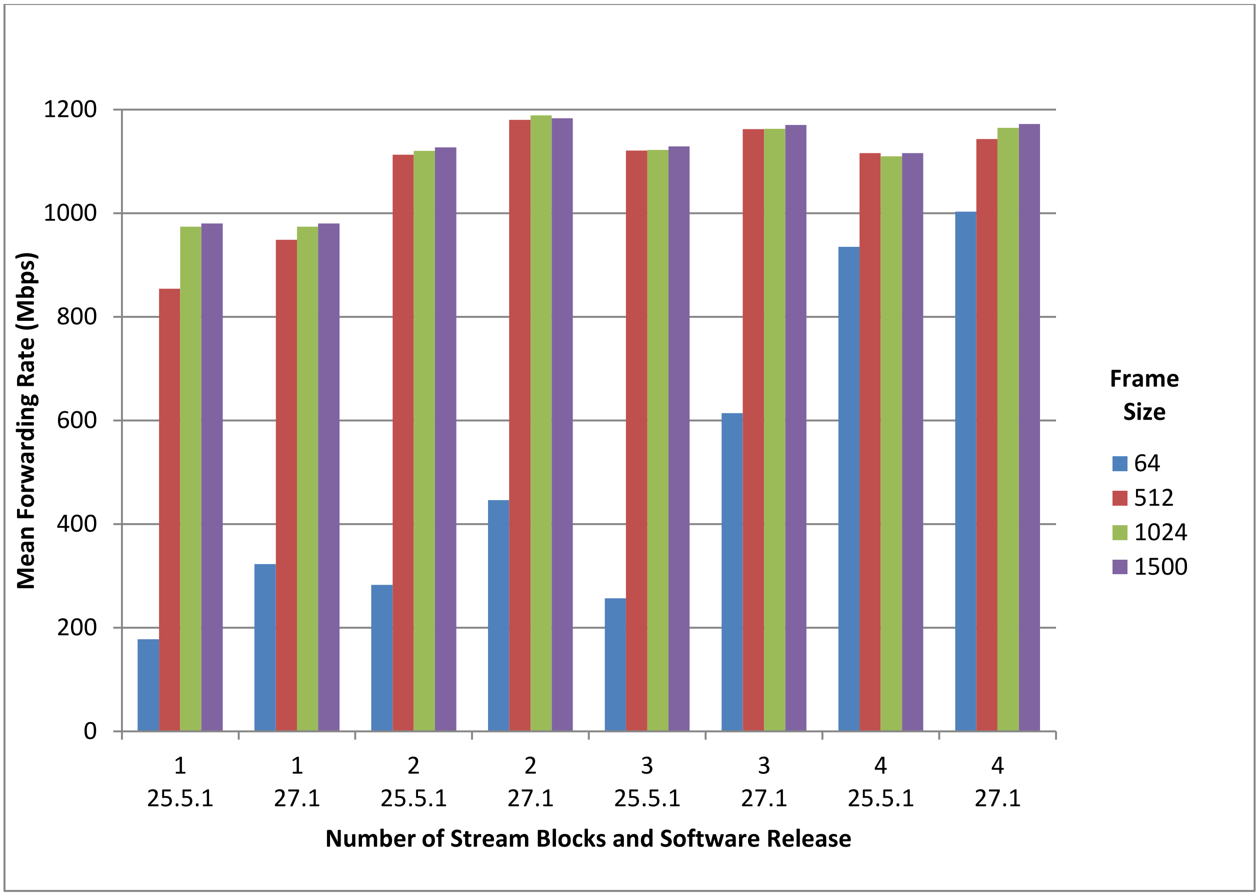
Table 74. Bidirectional Performance Results for 4 Stream Blocks Using a Single ONT709GP

Frame Size (bytes)	Number of Stream Blocks	Mean Latency (µs)	Forwarding Rate Trial 1 (fps)	Forwarding Rate Trial 2 (fps)	Forwarding Rate Trial 3 (fps)	Forwarding Rate Trial 4 (fps)	Forwarding Rate Trial 5 (fps)	Mean Forwarding Rate (fps)	Std. Dev. Forwarding Rate (fps)	Mean Forwarding Rate (bps)
64	4	62.51	1860119	1776414	1776379	1692694	1776406	1776402	52944	909518017
128	4	45.55	1293286	1435811	1530826	1483319	1293286	1407306	97826	1441080898
256	4	45.80	871830	871830	871830	871830	871830	871830	0	1785507164
512	4	58.70	465519	465519	465519	465519	465519	465519	0	1906766463
1024	4	82.62	237219	237219	237218	237219	237219	237219	0	1943294165
1500	4	103.52	162932	162932	162932	162932	162932	162932	0	1955179824
1518	4	104.34	161025	161025	161025	161025	161025	161025	0	1955485050

APPENDIX L: FP27.1_015130 VERSUS FP25.5.1_013274 COMPARISONS

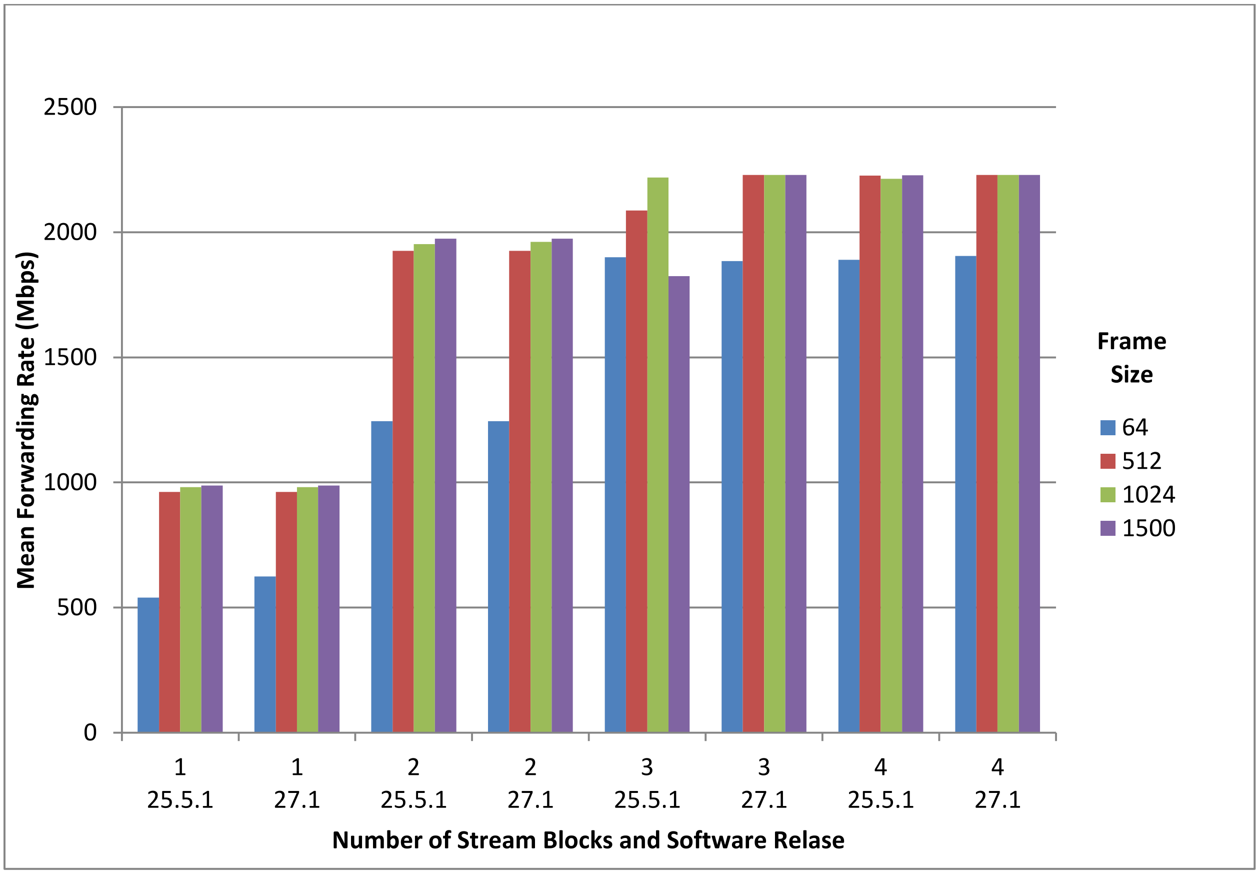
By using the data from this report and SAND2012-9525[1], it was possible to compare software releases FP27.1_015130 and FP25.5.1_013274. The first comparison is for upstream performance. As illustrated in Figure 46, FP27.1_015130 has better upstream performance for 64 and 512 byte Ethernet frames.

Figure 46. Mean Upstream Forwarding Rate Performance Comparison Results



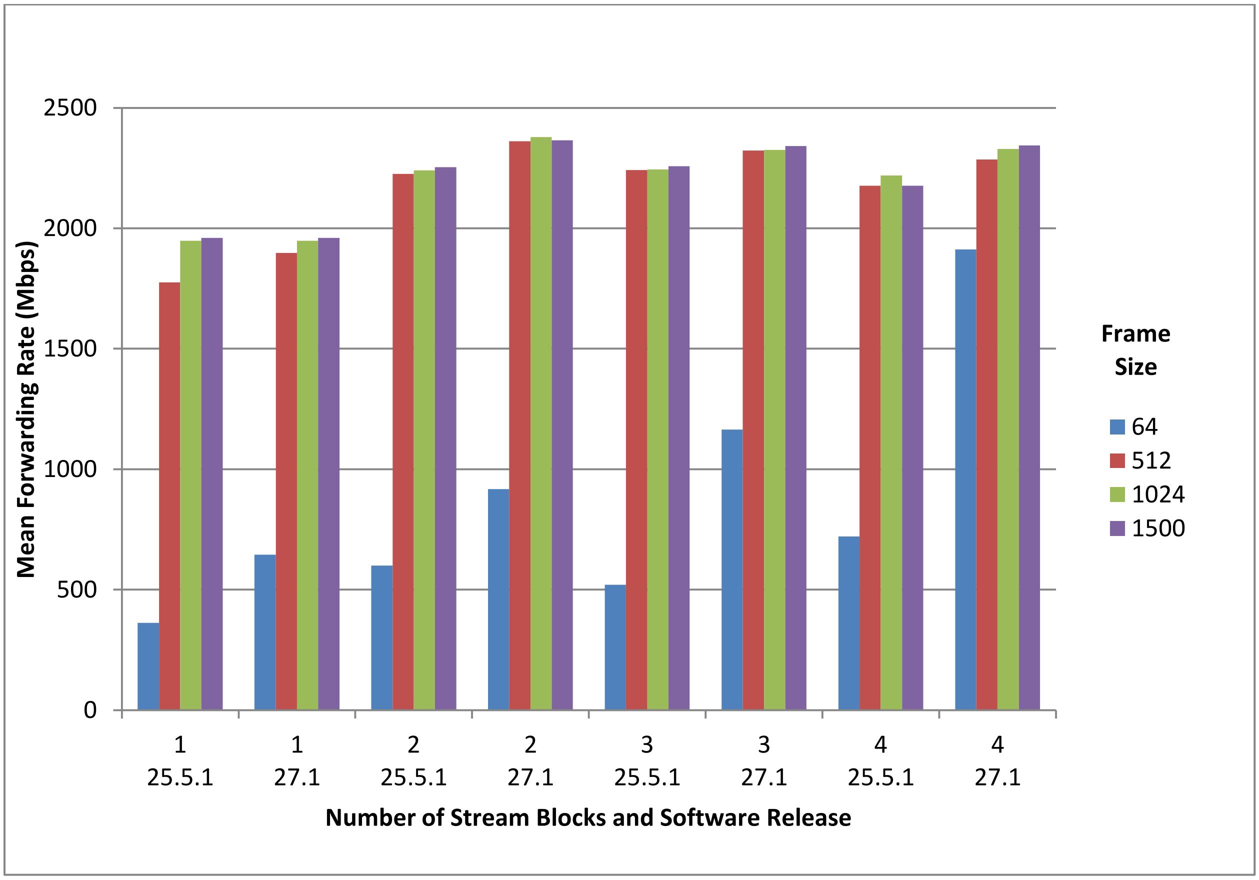
The next comparison is for downstream performance. As illustrated in Figure 47, there is no significant difference in performance between the two software releases.

Figure 47. Mean Downstream Forwarding Rate Performance Comparison Results



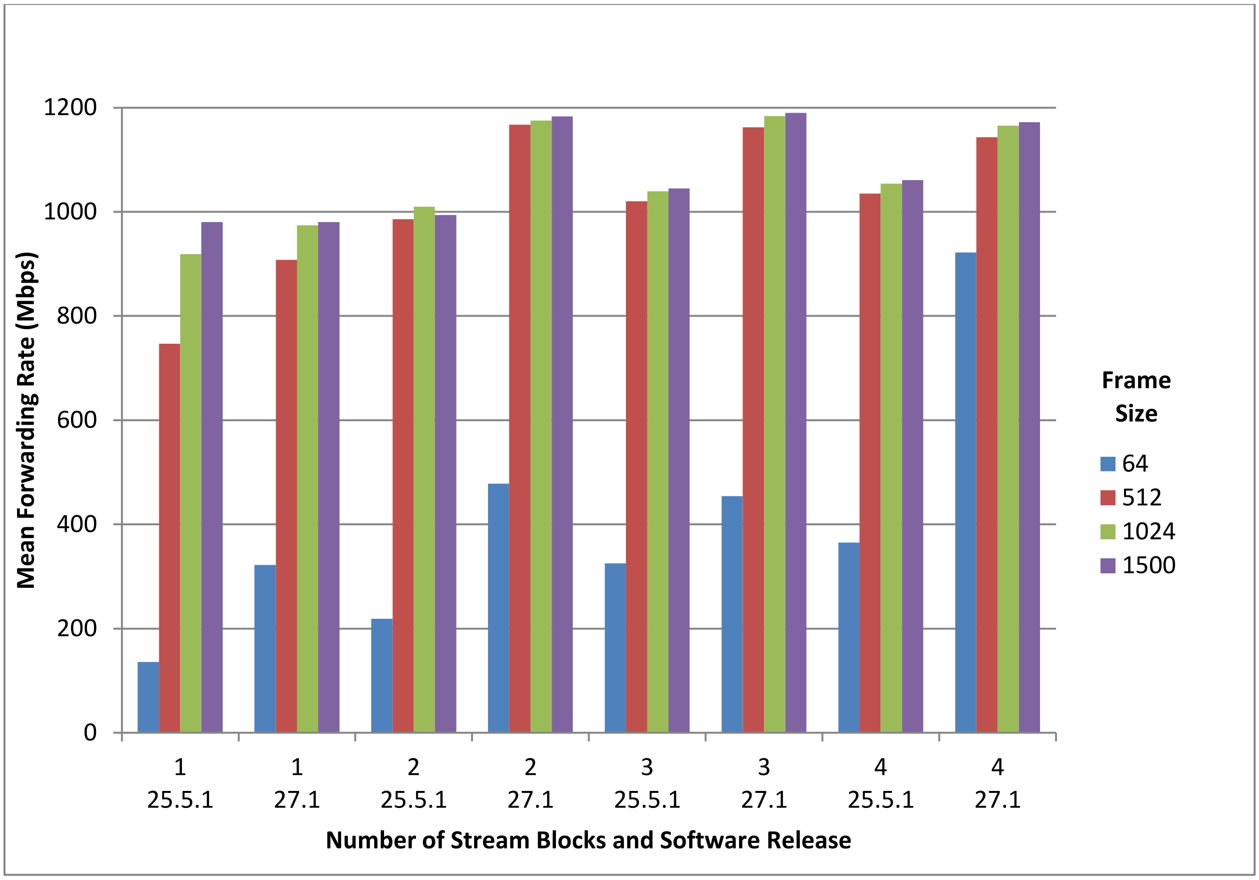
The next comparison is for bidirectional performance. As illustrated in Figure 48, FP27.1_015130 has better bidirectional performance.

Figure 48. Mean Bidirectional Forwarding Rate Performance Comparison Results



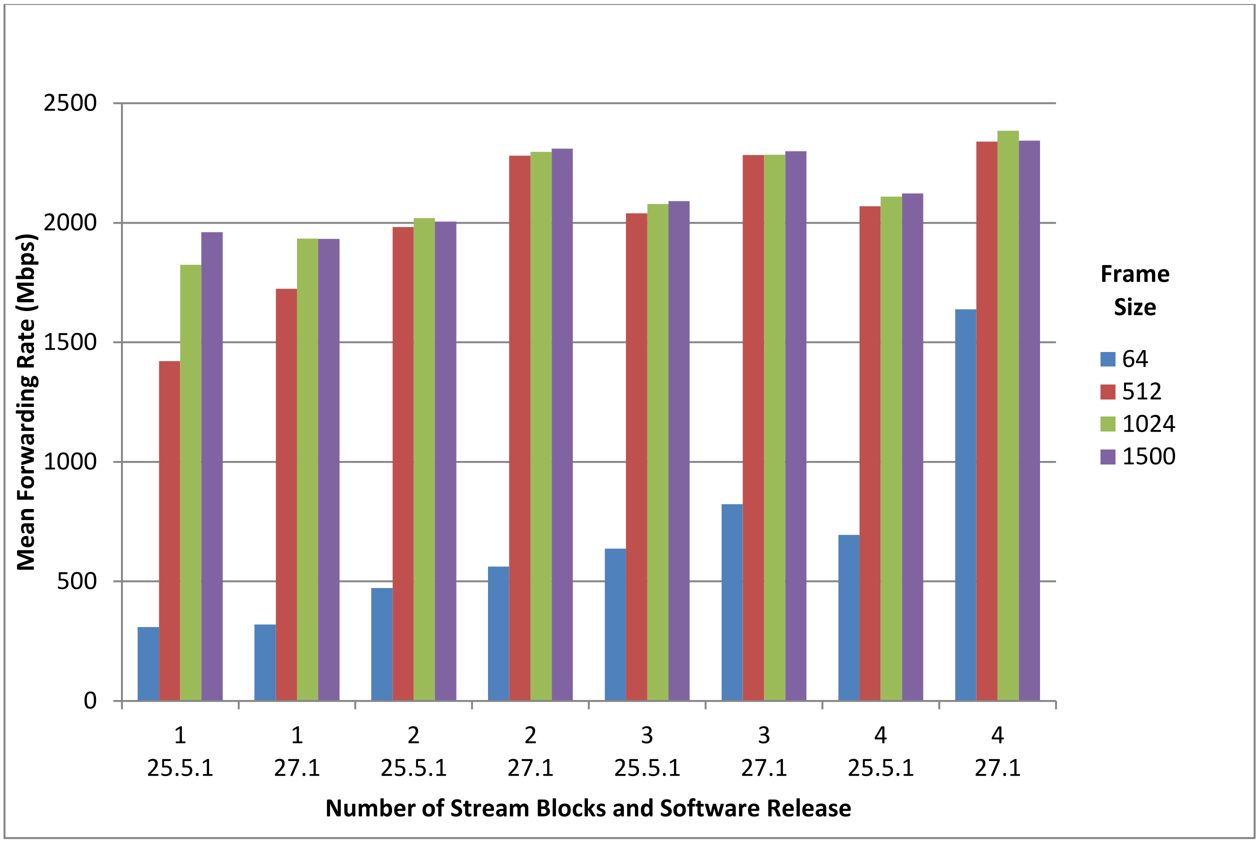
Comparisons between the two software releases were also performed for GPON port to GPON port unidirectional performance using different GPON modules. As illustrated in Figure 49, FP27.1_015130 has better performance.

Figure 49. Mean Unidirectional Forwarding Rate Performance Comparison Results Using Different GPON Modules



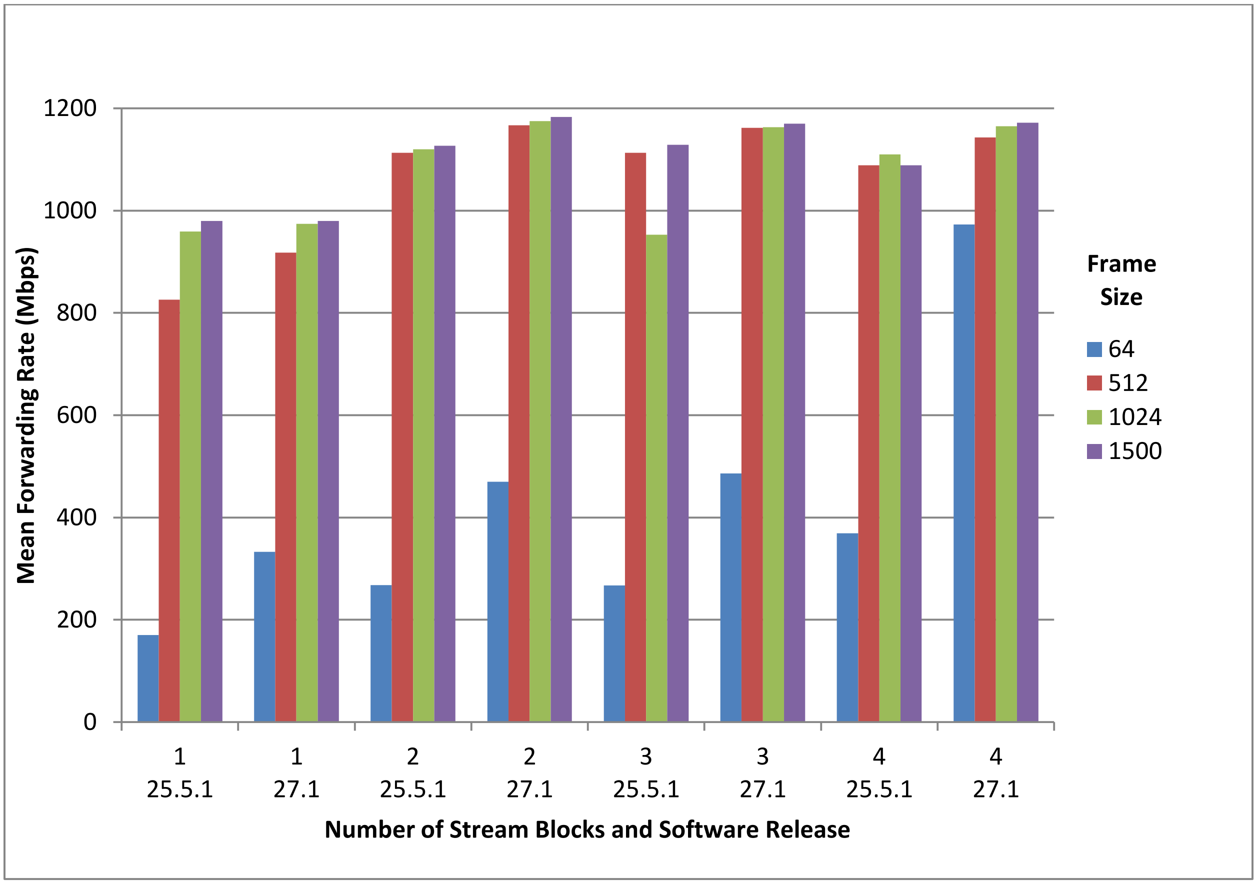
The next comparisons between the two software releases were GPON port to GPON port bidirectional performance using different GPON modules. As illustrated in Figure 50, FP27.1_015130 has better performance.

Figure 50. Mean Bidirectional Forwarding Rate Performance Comparison Results Using Different GPON Modules



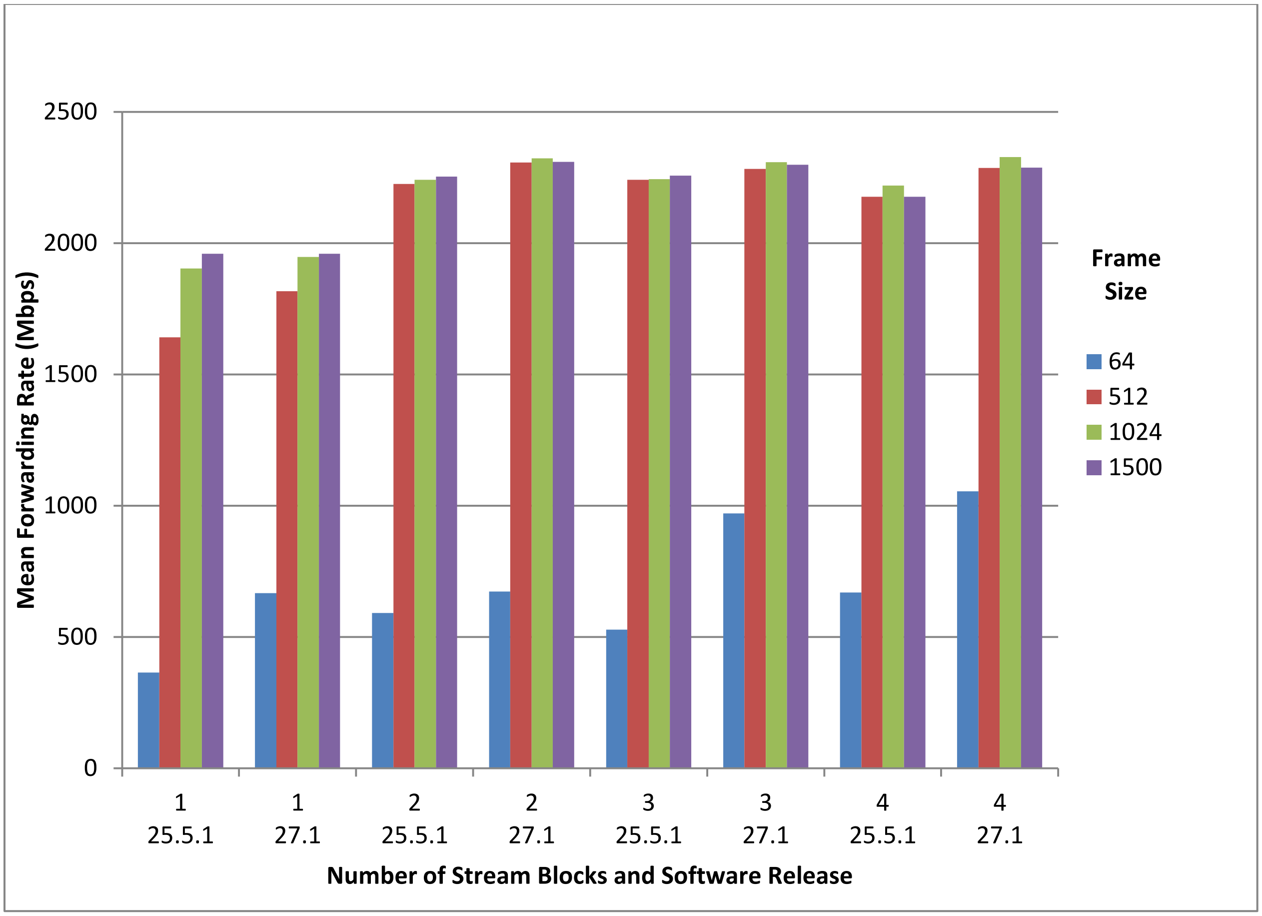
Comparisons between the two software releases were also performed for GPON port to GPON port unidirectional performance using the same GPON modules. As illustrated in Figure 51, FP27.1_015130 has better performance.

Figure 51. Mean Unidirectional Forwarding Rate Performance Comparison Results Using the Same GPON Modules



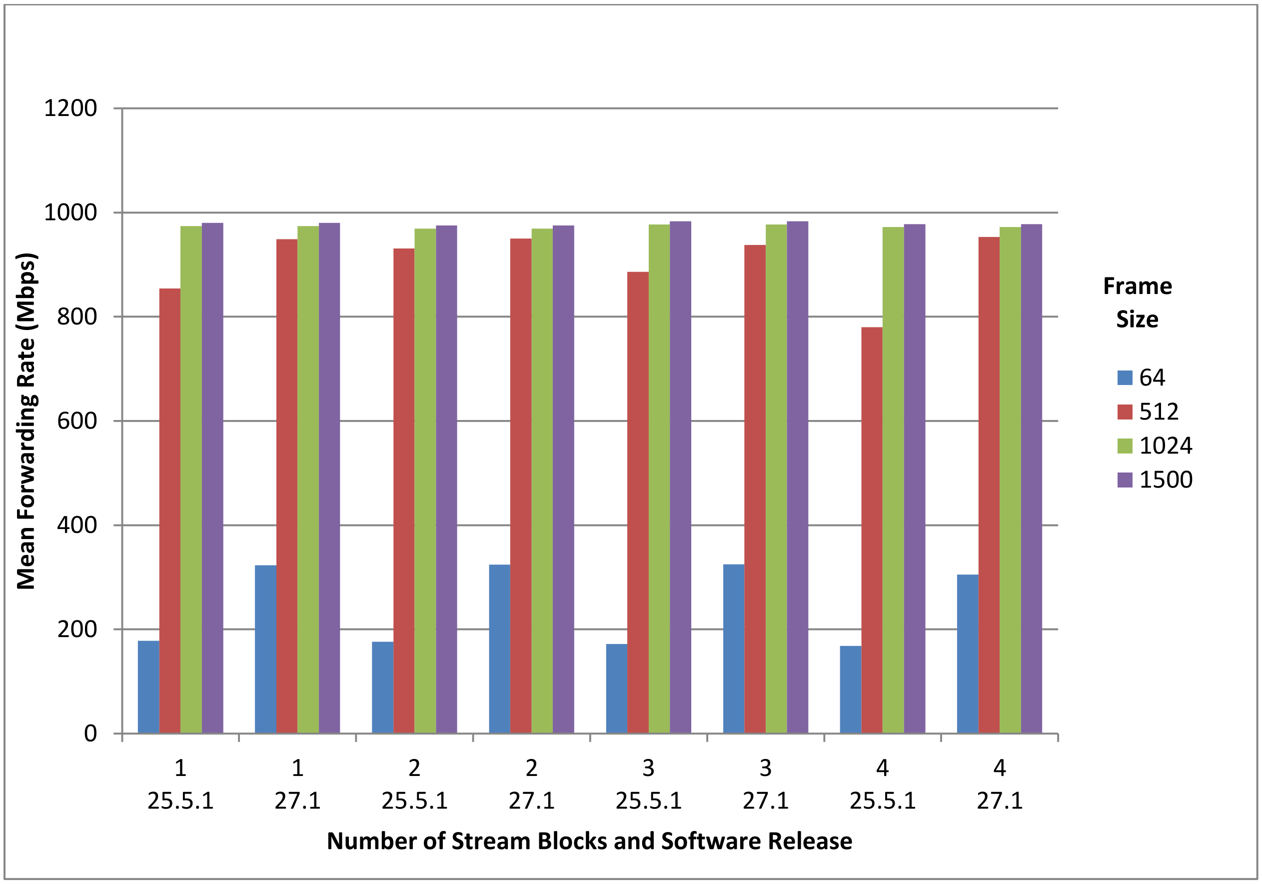
The next comparisons between the two software releases were GPON port to GPON port bidirectional performance using the same GPON modules. As illustrated in Figure 52, FP27.1_015130 has better performance.

Figure 52. Mean Bidirectional Forwarding Rate Performance Comparison Results Using the Same GPON Modules



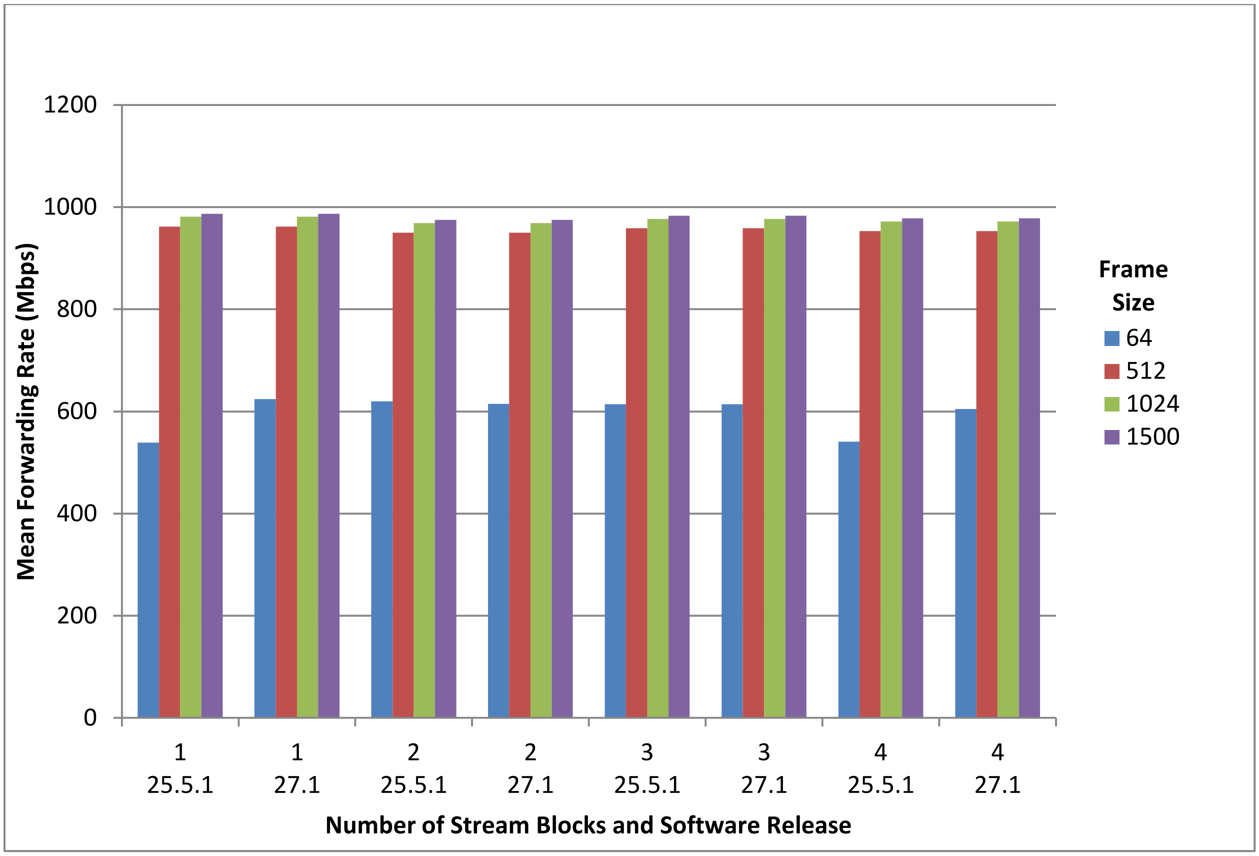
Comparisons between the two software releases were also performed for a single ONT709. The first comparison is for upstream performance. As illustrated in Figure 53, FP27.1_015130 has better performance for 64 byte Ethernet frames.

Figure 53. Mean Upstream Forwarding Rate Performance Comparison Results Using a Single ONT709



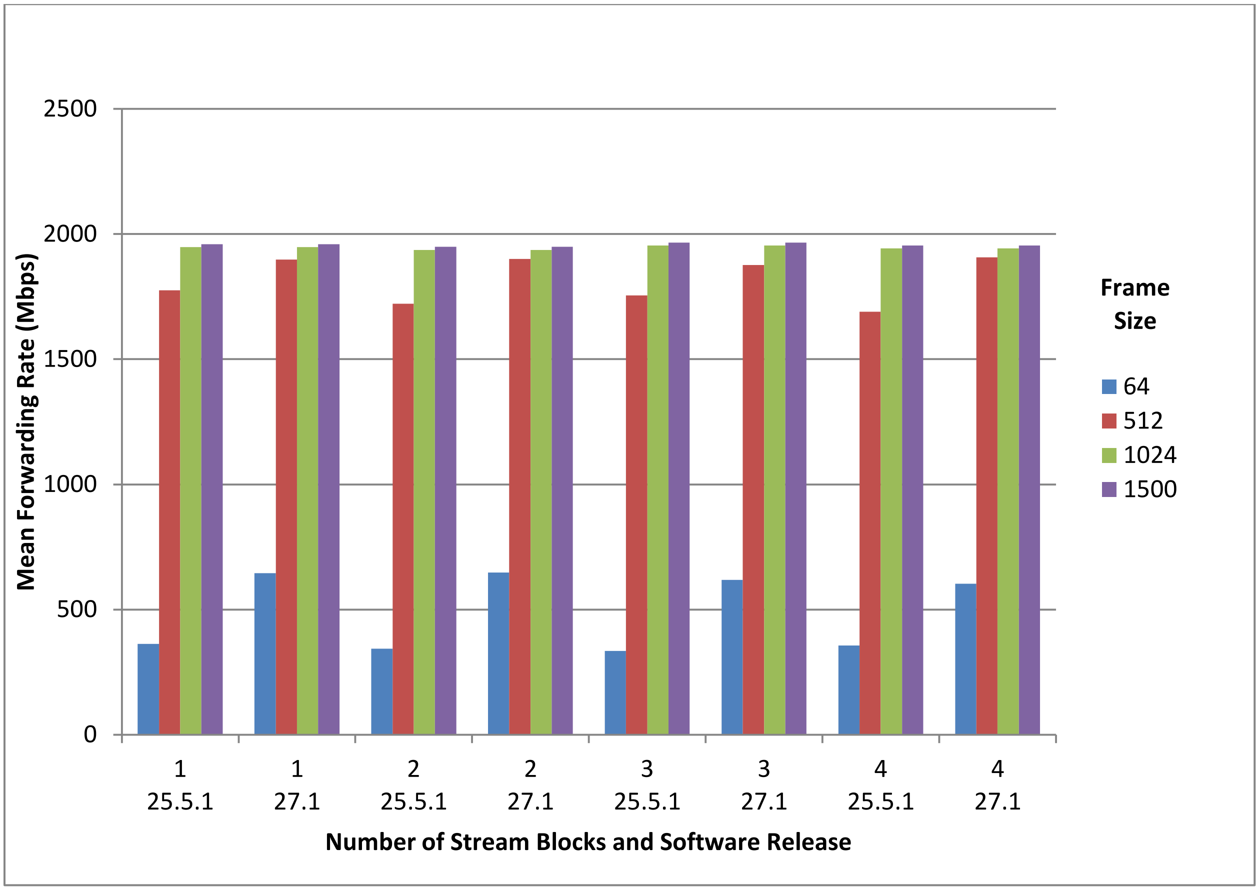
The next comparison for a single ONT709 is downstream performance. As illustrated in Figure 54, FP27.1_015130 has slightly better performance for 64 and 1500 byte Ethernet frames.

Figure 54. Mean Downstream Forwarding Rate Performance Comparison Results Using a Single ONT709



Bidirectional single ONT709 performance was also compared. As illustrated in Figure 55, FP27.1_015130 has slightly better performance for 64 and 1500 byte Ethernet frames.

Figure 55. Mean Bidirectional Forwarding Rate Performance Comparison Results Using a Single ONT709



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