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White Paper: White Box Performance Validation

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Abstract

This white paper describes a methodology for testing the performance of white box network devices through the presentation of a use case, the Private Peering Node.

Table of Contents

Table of Figures

Executive Summary

A network team might suspect that a white box solution would not provide the same performance as traditional network devices. This document describes an approach to validating the white box performance. As a white box can run one of several network operating systems (NOS), the approach is to test the performance of the combination of the control plane, the data plane and the hardware chosen in the context of the selected use case. This approach is not specific to white boxes and can be used also for a traditional network device.

A list of tests to be conducted should be specified based on guidelines provided by the several Requests for Comments (RFCs). By following this specification, it is possible to make an objective comparison between different hardware and/or operating system (OS) vendors. An analysis of the results will validate whether the selected combination is appropriate for the use case in question.

As an example, the “Private Peering Node (PPN) Level 2” use case (similar to a typical L2 switch use case) was tested on a combination of a Wedge 100BF-32X [Wedge] with the NOS freeRtr [freeRtr] running on the Router for Academia, Research and Education (RARE) [RARE] data plane. The conclusion is that this combination provides the appropriate performance to handle the PPN Level 2 use case in production.

The test specification could be reused to create a database of tests that could be shared between the European National Research and Education Networks (NRENs). It is also possible to share a test platform or a code framework, especially as there are now open-source traffic generators such as the Realistic Traffic Generator (TRex) [TRex].

1 Introduction

The development of network devices in hardware platforms, software features and by vendors is fast and versatile. Compared with the traditional approaches where vendors provide compact hardware-software platforms, emerging solutions offer decoupled hardware and network operating system (NOS), defined and used in this document as the white box (WB) model.

Nevertheless, this raises a performance question for the users: would one combination of a selected hardware platform and a NOS provide the same or similar level of performance as a traditional single-vendor-box solution or another combination of hardware and NOS?

To check the performance of a white box, the users need to carry out the same tests as they usually do when they purchase traditional hardware. Moreover, performance tests for the combination of NOS and hardware should be selected according to the chosen use case (e.g. L2 switch, customer premise equipment (CPE), etc.) as the hardware and software might not provide the same level of performance for all use cases, and might even have been designed for a specific use case that dominates the current market, such as data centre (DC) switches.

This white paper describes the performance validation of the combination of a Wedge 100BF-32X [Wedge] with the freeRtr [freeRtr] control plane and the Router for Academia, Research and Education (RARE) [RARE] data plane for the "Private Peering Node (PPN) Level 2" use case, which corresponds to a typical Level 2 switch use case. It describes the use case in Section 2 and the selected performance validation tests in Section 3. The tests are described in detail, so that the test results could be compared with the results of similar tests provided by vendors, including chosen parameters, the type of test, how the tests were realised and the results reported. The results are presented and discussed in Section 4. Conclusions are drawn in Section 5, and detailed software-generated test-results reports are provided in Appendix A.

2 Private Peering Node Use Case

2.1 Use Case Description

In scope for the performance tests is an L2 switch in a Private Peering Node (PPN) use case. This use case is similar to a typical L2 switch scenario and could thus also be convenient for an Internet exchange point (IX) use case, with the exception that the configuration of the device under test (DUT) would be different (for example, implemented access lists might differ).

In the PPN use case, a switch or router is set up to deliver private peering connections with large telecom companies such as Google, Akamai, etc. Private peering connection nodes are used to reduce the use of the Internet via an Internet service provider (ISP) by redirecting traffic (towards and from these large telecom companies) through a direct connection established between the NREN and the telecom companies in a carrier hotel such as Interxion, Telehouse, or wherever these telecom companies are present. In general, these private peering partners accept two connections (two pairs of fibres) at 10 Gbps but if more capacity is required (> 20 Gbps) then the partners ask for a 100 Gbps link which is cheaper for them (only one pair of fibres, one cross-connect in a meet-me room). The cost of 100 Gbps ports could be relatively high for traditional router suppliers in contrast to new switch suppliers (the private peering node could provide very cheap 100 Gbps ports). When the traffic with this partner exceeds 20 Gbps, it does not reach 100 Gbps immediately. It is therefore possible to multiplex this traffic onto a small number of 100 Gbps ports at the entrance to the NREN. For instance, 10 private peerings can be connected at 100 Gbps to only one 400 Gbps aggregate port (see Figure 2.1). The private peering node provides this multiplex, dramatically reducing the cost of the backbone routers.

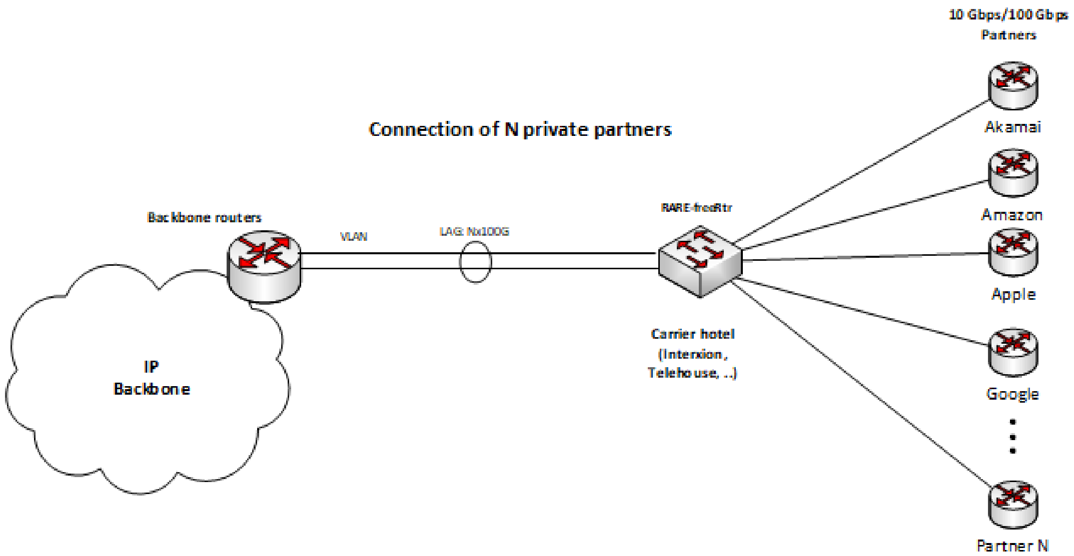


Figure 2.1: Private peering use case principle

In the case of a L2 PPN, the Border Gateway Protocol (BGP) peering is not made on the PPN but between the backbone router and the private partner router. The L2 VPN only forwards and aggregates the traffic towards the back, as shown in Figure 2.2.

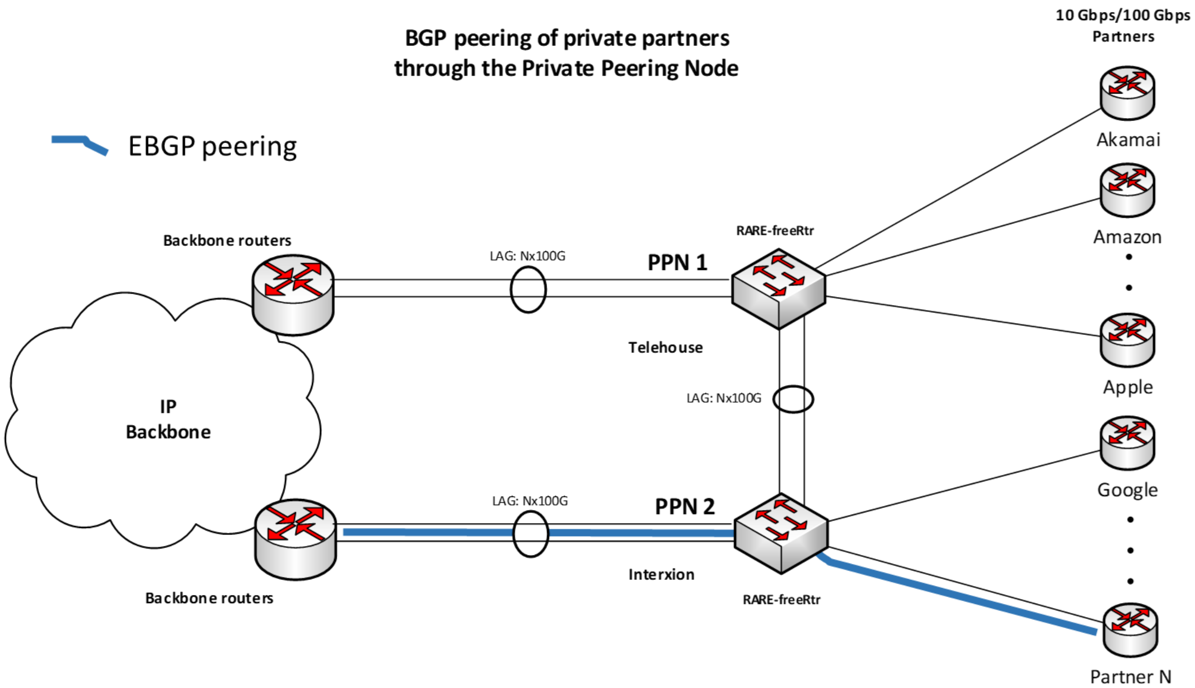


Figure 2.2: Example of BGP peering in L2 PPN deployment context

2.2 Requirements

This section describes the requirements for the L2 PPN use case in terms of protocols, features, number of addresses, etc.

Parameters and protocols implemented

- 1,000 MAC addresses
- 50 IPv4 and 50 IPv6 addresses for machine administration
- MAC ACLs are configured to control which hosts are connected to the port and can access the PPN Level 2 network. The MAC address filter is implemented on each connected port to control the device connected to the port.
- Broadcast storm protection
- VLANs (802.1Q)
- Link aggregation (LACP)

Performance requirements

- The solution must be capable of transmitting at least 200 Gbps and preferably at 500 Gbps.
- It would be desirable to check whether the switch can forward at a wire speed of 6.4 Tbps (16 ports sending at 100G to 16 other receiver ports) without any blocking effect, as specified by the Wedge 100BF-32X datasheet. This kind of test is very difficult to achieve, taking into consideration the status of the performance tester available.

The full configuration of a L2 switch for the Private Peering Node will be implemented on the device under test (DUT), including all the parameters required for these use cases (MAC addresses, L2 filter, protocol implemented, etc.).

3 Required Tests

The aim of this section is to describe procedures that can be used for testing the performance of white box devices for the PPN L2 use case. The testing in scope is the behaviour of the device under a very high load. No other tests are performed, including functional (capabilities and correct operation testing), negative (unexpected or malformed packets), conformance (compliance to industry standards) or stability (extreme conditions) tests.

The presentation of all the tests is standardised and includes:

- The standards that are used for testing.
- The purpose of the test.
- A short description of the test methodology.
- General test network topology (e.g. connection between DUT and tester, etc.).
- Definition of the parameters and variables that could be used in the test procedure (protocols, IP addresses, number of routes, packet-size ranges, etc.).
- Test configuration examples.
- Results (e.g. metrics, tables, graphs, etc.).

It is necessary to have a detailed description of the tests in order to be able to make comparisons with other performance tests provided by others sources (hardware datasheet). For an objective comparison, it is necessary to take into consideration the test parameters (number of routes, size of packets used, etc.).

All the presented tests could be executed individually or in the same or any other test plan chosen by the network administrator. Execution of the tests implies the existence of a tester device with appropriate testing capabilities that can measure performance in network conditions that are as realistic as possible.

3.1 Overview of Tests Selected

This section outlines the list of tests needed for performance validation of the L2 PPN use case. A detailed description of each test can be found in the next section (Section 3.2).

Some of the tests should include MAC ACLs to control and broadcast storm protection but as these features are not available on freeRtr, these options will be skipped in the test.

The list of performance tests for the L2 switch for the Private Peering Node use case is as follows:

- Address Learning Rate: This test determines the rate of address learning of a LAN switching device.
- Address Caching Capacity: This test determines the address caching capacity of a LAN switching device.
- Broadcast Frame Forwarding: This test determines the throughput of the DUT when forwarding broadcast traffic.
- Broadcast Frame Latency: This test determines the latency of the DUT when forwarding broadcast traffic.
- Forwarding Test: This test determines the throughput, frame loss, and forwarding rates of the DUT offered fully meshed, one-to-many, many-to-one, or one-to-one traffic as defined in RFC 2285 [RFC2285] (IPv4 and IPv6).
- Congestion:
    - Head of Line Blocking (HOLB): This occurs when a data packet in a queue is waiting to be transmitted when it can be, but the packet at the head of the queue (line) cannot move forward due to congestion, so it blocks the entire packet queue.
    - Congestion Control and Back Pressure: This test determines how a DUT handles congestion, specifically whether the device implements congestion control and whether congestion on one port affects an uncongested port.
    - Forward Pressure Rate: This test overloads a DUT port by sending traffic with an interframe gap of 88 bits. If the DUT egress port transmits frames with an interframe gap that is less than 96 bits, then forward pressure is detected.
- Errored Frames Filtering: This test determines the behaviour of the DUT under error or abnormal frame conditions. The results of the test indicate whether the DUT filters or forwards the errored frames.

3.2 Detailed Description of the Selected Tests

The device under test is evaluated using a traffic generator whose tools allow it to perform predefined tests based on RFC documentation. In this case, RFC 2889 and RFC 2544 [RFC2889], [RFC2544] were used in the Spirent traffic generator [SpirentTC]. Therefore, some of the descriptions below are based on the Spirent documentation and test definitions from those two RFC documents.

The tests are performed in such a way that the device under test has some initial configuration that is not changed during the whole test. At least one parameter is chosen whose values are varied during the test, and the device behaviour is then observed based on the changed parameter values. Each test repetition is called a “trial”. The number of trials is defined as the number of times the test is repeated with its initial configuration, with the varied value of the chosen parameter. At the start of the next trial, these parameters revert to their initial values.

3.2.1 Forwarding Test

Standard: RFC 2889 sections 5.1, 5.2, 5.3 and 5.4.

Purpose: This test determines the throughput, frame loss and transfer rates of the DUT with the option of choosing traffic defined in RFC 2285 [RFC2285] as fully meshed, one-to-many, many-to-one or one-to-one.

Methodology description: The test equipment emulates one or multiple L2 MAC addresses per port. Learning frames are sent to the DUT and verified. Full mesh traffic is then sent from every test port in a round-robin fashion through the DUT to every other test port. Traffic can also be sent one way, reverse, or bi-directionally from one-to-many ports or many-ports-to-one. Various frame sizes and port loads are used across test trials (iterations).

General test network topology:

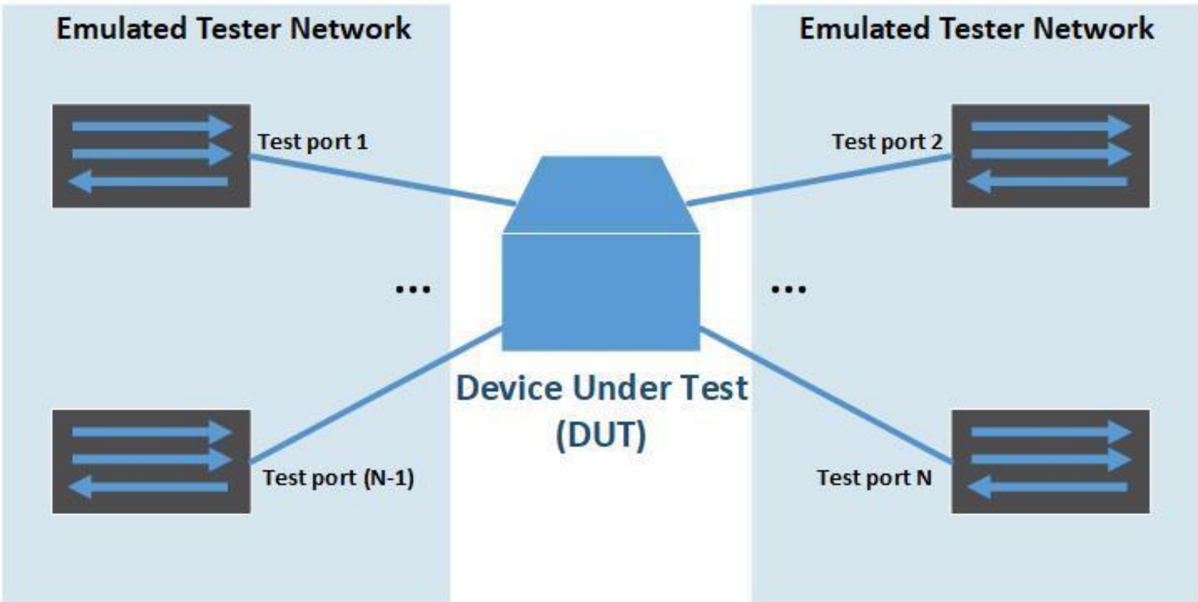


Figure 3.1: General test network topology – Forwarding Test

Parameters and variables:

General RFC 2889 test parameters:

- *Trial Duration* – The recommended trial duration is 30 seconds. The trial duration should be adjustable by at least between 1 and 300 seconds.
- *Frame Size* – The frame size can vary between 64 and 16,383. Recommended frame sizes are 64, 128, 256, 512, 1,024, 1,280 and 1,518 bytes, per RFC 2544 section 9. It is also necessary to notify the user how the frame sizes will vary through successive test trials (including the CRC).
- *Duplex Mode* – In this use case the traffic will be full-duplex.
- *Intended Load (Iload)* – The intended load per port is expressed as a percentage of the medium's maximum theoretical load, regardless of traffic orientation or duplex mode. Certain test configurations will theoretically over-subscribe the DUT/SUT (see RFC 2889 section 5.1.2).

- *Burst Size* – The burst size defines the number of frames sent back-to-back at the minimum legal interframe gap (IFG) before pausing transmission to receive frames. Burst sizes should vary between 1 and 930 frames. A burst size of 1 will simulate a constant load.

Specific Forwarding Test parameters:

- *Orientation* – Traffic can be generated in one direction, the reverse direction, or both directions.
- *Encapsulation* – The frame encapsulation for existing endpoints (Ethernet II).

General testbed setup (DUT and tester):

In an ideal situation the test network topology should include all available DUT ports in the testing procedure. Usually, due to resource restrictions, tests are done on a limited number of DUT and tester ports. For the example shown, a configuration of 4 DUT ports is used for the testing procedure. The tester network emulates 1 device per port. Traffic in the test is generated based on the configured end ports. Traffic flow is bi-directional with one-to-many mapping.

Measurements that the user should expect for the performance assessment (test result format):

Forwarding Rate by frame size (it is important to test several frame sizes)

- Frame Size (bytes)
- Burst Size (if provided)
- Throughput
- Intended Load
- Offered Load
- Forwarding Rate (fps)
- Tx Frame Count
- Rx Frame Count
- Frames Lost
- Flood Count
- Frames other than your own measurement stream that could have been generated, such as signalisation

3.2.2 Address Caching Capacity Test

Standard: RFC 2889 section 5.7.

Purpose: This test determines the address caching capacity of a LAN switching device.

Methodology description: The test equipment learning port transmits learning frames at a configurable rate (frames per second) to the DUT with varying source addresses and a single destination address to the test port. Test frames are then sent from the test port destined for the learning port. The test equipment monitoring port listens for flooded or misforwarded frames. A binary search method determines the maximum number of addresses that are correctly learned and forwarded by the DUT without flooding or misforwarding any frames.

General test network topology:

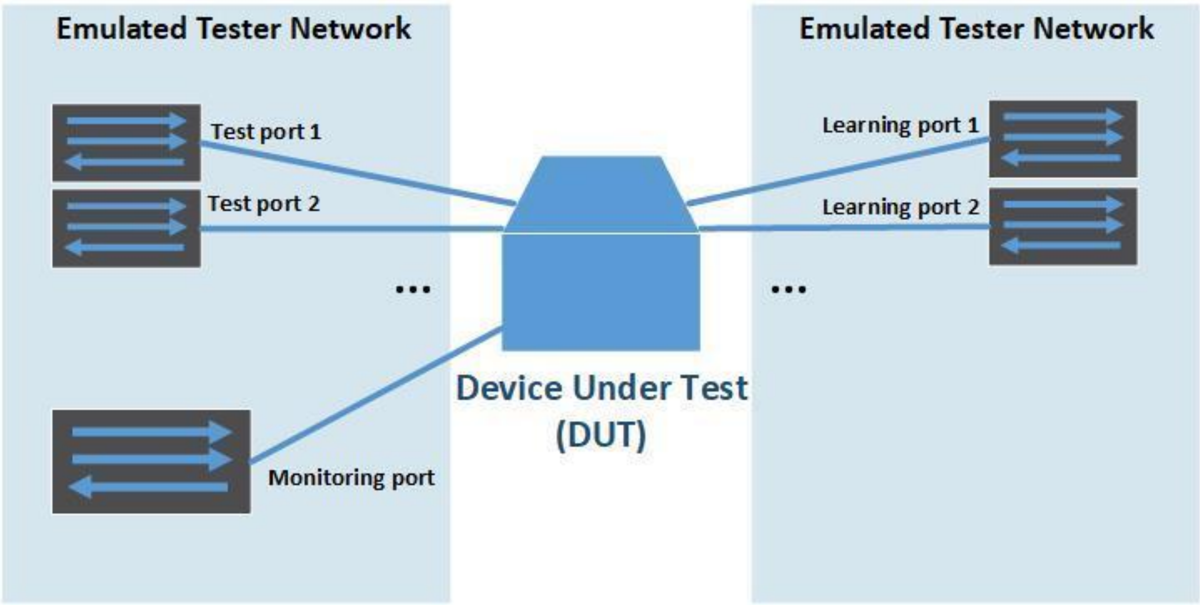


Figure 3.2: General test network topology – Address Caching Capacity Test

Parameters and variables:

General RFC 2889 test parameters:

- *Number of Addresses:*
  - Min – The minimum number of addresses (between 1 and 65,536) to be sent to the DUT. If this value is reached during the test, the test stops automatically.
  - Max – The maximum number of addresses (between 1 and 65,536) to be sent to the DUT. If this value is reached during the test, the test stops automatically.
  - Initial – The number of addresses to be sent to the DUT in the first iteration. The number must be between 1 and the maximum number supported by the implementation.
  - Ageing Time – The ageing time value (seconds) for the DUT. MAC addresses are removed from the cache when this time expires. Ageing time must be large enough for the test to complete, based on the values for Initial and Min.
- *Learning Rate* – Frames per second (fps): the rate at which learning frames are transmitted.

Specific Address Caching Capacity Test parameters:

- *Encapsulation* – The frame encapsulation for existing endpoints (Ethernet II).

General testbed setup (DUT and tester):

In an ideal situation the test network topology should include all available DUT ports in the testing procedure. Usually, due to resource restrictions, tests are done on a limited number of DUT and tester ports. For the example shown, a configuration of 2 DUT ports is used for the testing procedure. The tester network emulates 1 device per port. Traffic in the test is generated based on the configured end ports.

Measurements that the user should expect for the performance assessment (test result format):

Address Caching Capacity by frame size (it is important to test several frame sizes)

- Frame Size
- Address Count
- Tx Signaling/Protocol Frames
- Rx Signaling/Protocol Frames
- Rx Frames
- Expected Rx Frames
- Flood Frames
- Expected Frames
- Lost Frames
- Frame Loss (%)
- Learned Percentage (%)
- Caching Capacity

3.2.3 Address Learning Rate Test

Standard: RFC 2889 section 5.8.

Purpose: This test determines the rate of address learning of a LAN switching device.

Methodology description: The test equipment learning port transmits learning frames at a specified rate to the DUT with varying source addresses and a single destination address to the test port. The source addresses used are equal to those determined by the results of the Address Caching Capacity test. Test frames are then sent from the test port destined for the learning port. The test equipment monitoring port listens for flooded or misforwarded frames. A binary search method determines the maximum learning rate (frames per second) at which the DUT learns addresses without flooding or misforwarding frames.

General test network topology:

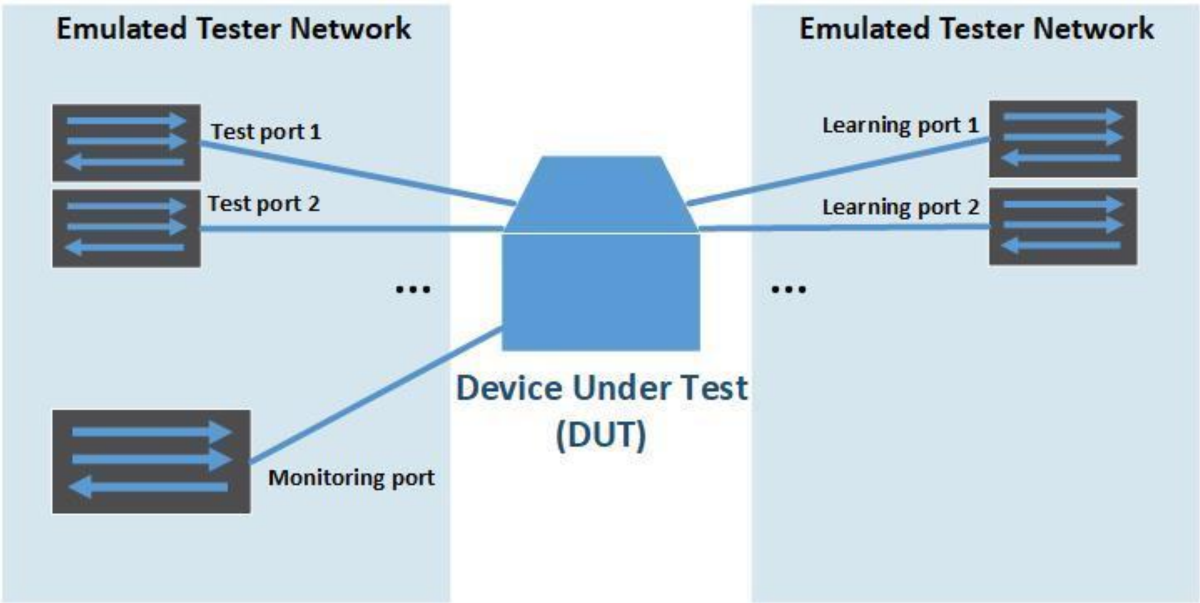


Figure 3.3: General test network topology – Address Learning Rate Test

Parameters and variables:

General RFC 2889 test parameters:

- *Number of Addresses*
  - Min – The minimum number of addresses (between 1 and 65,536) to be sent to the DUT. If this value is reached during the test, the test stops automatically.
  - Max – The maximum number of addresses (between 1 and 65,536) to be sent to the DUT. If this value is reached during the test, the test stops automatically.
  - Initial – The number of addresses to be sent to the DUT in the first iteration. The number must be between 1 and the maximum number supported by the implementation.
  - Ageing Time – The ageing time value (seconds) for the DUT. MAC addresses are removed from the cache when this time expires. Ageing time must be large enough for the test to complete, based on the values for Initial and Min.

Specific Address Learning Rate parameters:

- *Learning Rate* – Frames per second (fps): the rate at which learning frames are transmitted. If possible, a minimum, maximum and initial rate can be defined.
  - Min – The minimum learning rate (frames per second) to be sent to the DUT.
  - Max – The maximum learning rate (frames per second) to be sent to the DUT. Configuration options for Max: 1–14,880, default 14,880.
  - Initial – The learning rate (frames per second) to be sent to the DUT in the first iteration.
- *Encapsulation* – The frame encapsulation for existing endpoints (Ethernet II).

General testbed setup (DUT and tester):

In an ideal situation the test network topology should include all available DUT ports in the testing procedure. Usually, due to resource restrictions, tests are done on a limited number of DUT and tester ports. For the example shown, a configuration of 2 DUT ports is used for the testing procedure. The tester network emulates 1 device per port. Traffic in the test is generated based on the configured end ports.

Measurements that the user should expect for the performance assessment (test result format):

Address Learning Rate by frame size (it is important to test several frame sizes)

- Frame Size
- Address Count
- Intended Load
- Tx Signaling/Protocol Frames
- Rx Signaling/Protocol Frames
- Rx Frames
- Expected Rx Frames
- Flood Frames
- Expected Frames
- Lost Frames
- Learning Rate (fps)

3.2.4 Congestion Control Test

Standard: RFC 2889 section 5.5.

Purpose: This test determines how a DUT handles congestion, specifically whether the device implements congestion control and whether congestion on one port affects an uncongested port.

Methodology description: The test uses one or more groups of four ports. Two of the four ports in a group are transmitters, while the other two ports are receivers. Test traffic is sent from both transmitters at 100% load. One of the two receiver ports (the uncongested port) receives 50% of traffic from one transmitter and no traffic from the other port. The other receiver port (the congested port) receives the remaining traffic, for a total of 150% of the traffic. If the results show frame loss at the uncongested port, then Head of Line Blocking (HOLB) is present. If there is no frame loss at the congested port, then Back Pressure is present.

HOLB performance degradation occurs when a queued packet in a device port input queue must wait for transfer through the fabric because it is blocked by another packet in first in, first out (FIFO) buffer architecture. Back Pressure performance degradation occurs when the device port buffer is full and the packet’s originating device is informed to hold off sending packets until the device buffers become emptied. The Back Pressure condition propagates in the opposite direction compared with the data flows.

General test network topology:

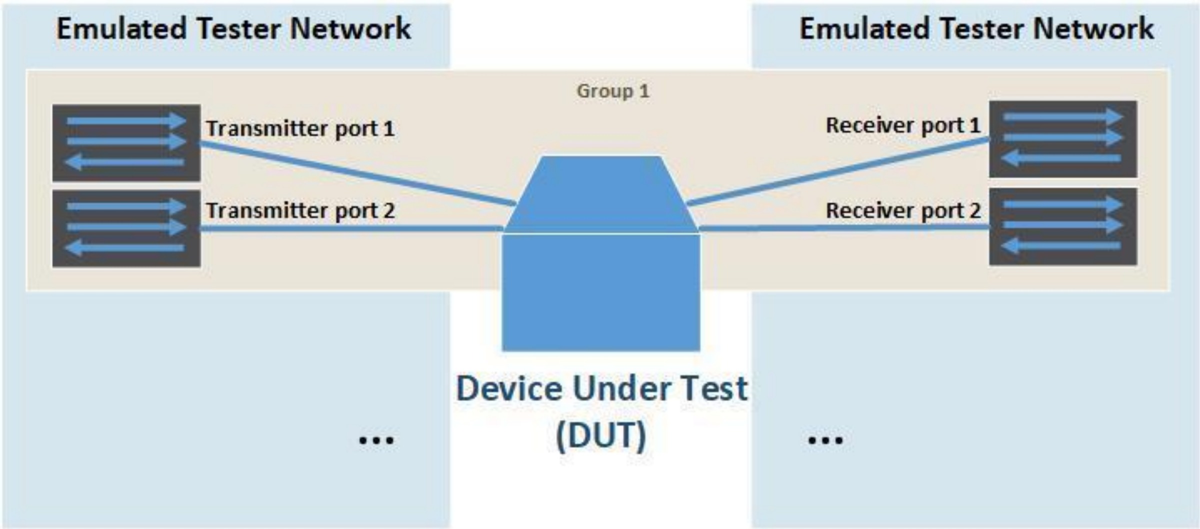


Figure 3.4: General test network topology – Congestion Control Test

Parameters and variables:

General RFC 2889 test parameters:

- *Trial Duration* – The recommended trial duration is 30 seconds. The trial duration should be adjustable by at least between 1 and 300 seconds.
- *Frame Size* – The frame size can vary between 64 and 16,383. Recommended frame sizes are 64, 128, 256, 512, 1,024, 1,280 and 1,518 bytes, per RFC 2544 section 9. It is also necessary to notify the user how the frame sizes will vary through successive test trials (note that the frame size includes the CRC).
- *Addresses per Port* – Represents the number of addresses which are being tested for each port. The number of addresses should be a binary exponential (i.e. 1, 2, 4, 8, 16, 32, 64, 128, 256, etc.). The recommended value is 1.
- *Duplex Mode* – In this use case the traffic will be full-duplex.

Specific Congestion Control Test parameters:

- *Encapsulation* – The frame encapsulation for existing endpoints (Ethernet II).
- *Intended Load* – The intended load per port is expressed as a percentage of the medium's maximum theoretical load, regardless of traffic orientation or duplex mode (see RFC 2889 section 5.5.3). Optionally, the intended load can be increased successively and vary through successive test trials. It could be defined as follows:
    - Step increases the intended load for each trial from that of the previous trial.
    - Start defines the intended load (as a percentage of the medium's maximum theoretical load) used for the first test trial.
    - End defines the maximum intended load (as a percentage of the medium's maximum theoretical load) used in the test.
- *Burst Size* – Defines burst sizes and how they vary through successive test trials. It could be defined as follow:

  - Step increases the burst size for each trial from that of the previous trial.
  - Start defines the burst size (in frames) used for the first test trial.
  - End defines the maximum burst size (in frames) used in the test.

General testbed setup (DUT and tester):

In an ideal situation the test network topology should include all available DUT groups of 4 ports in the testing procedure. Usually, due to resource restrictions, the tests are done on a limited number of DUT and tester ports. For the example shown, a configuration of 4 DUT ports is used for the testing procedure. The tester network emulates 1 device per port. Traffic in the test is generated based on the configured end ports.

Measurements that the user should expect for the performance assessment (test result format):

Congestion Control by frame and burst size

- Frame Size
- Burst Size
- Intended Load
- Head of Line Blocking – Yes/No
- Back Pressure – Yes/No

3.2.5 Forward Pressure Rate Test

Standard: RFC 2889 section 5.6.

Purpose: The test overloads a DUT port by sending traffic with an interframe gap of 88 bits, which is higher than the wire rate load (the IEEE 802.3 standard allows sending no less than 96 bits of interframe gap). If the DUT egress port transmits frames with an interframe gap that is less than 96 bits, then Forward Pressure is detected. Switches that transmit with an interframe gap of less than 96 bits violate the IEEE 802.3 standard and other switches may not interoperate properly with the switch in violation.

Methodology description: Traffic is sent from one test port through the DUT to the other test port. The load for each frame size is greater than the link’s theoretical utilisation, using an interframe gap of 88 bits. The load used for each frame size is greater than the transmit medium’s maximum theoretical utilisation (thereby using an interframe gap of 88 bits). The Forward Pressure test functions in full duplex mode.

General test network topology:

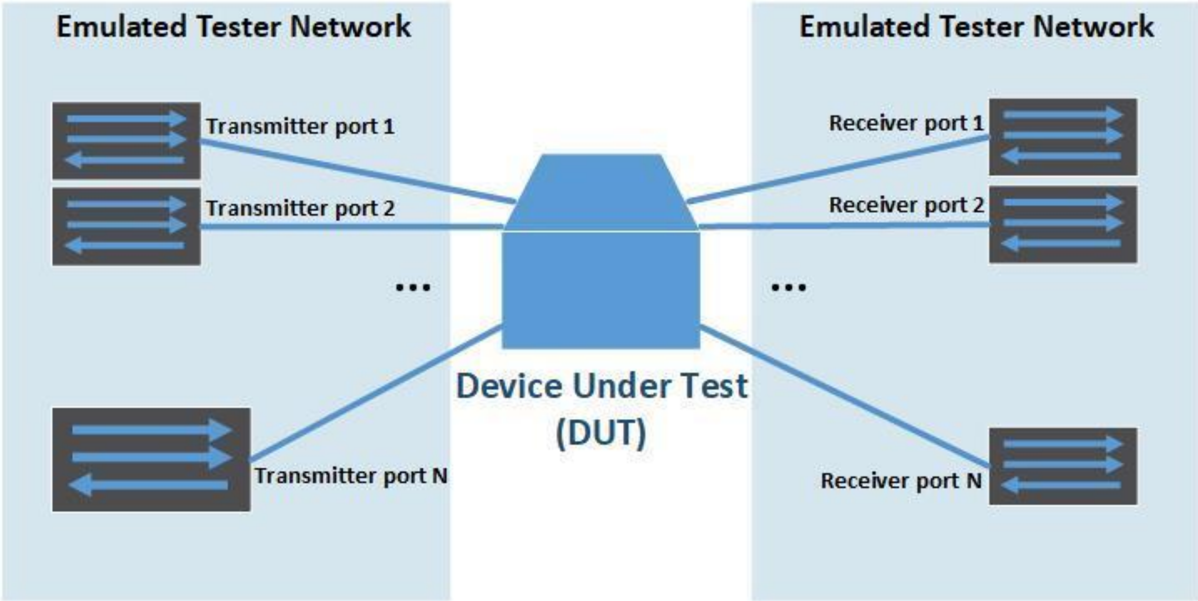


Figure 3.5: General test network topology – Forward Pressure Rate Test

Parameters and variables:

General RFC 2889 test parameters:

- *Trial Duration* – The recommended trial duration is 30 seconds. The trial duration should be adjustable by at least between 1 and 300 seconds.
- *Frame Size* – The frame size can vary between 64 and 16,383. Recommended frame sizes are 64, 128, 256, 512, 1,024, 1,280 and 1,518 bytes, per RFC 2544 section 9. It is also necessary to notify the user how the frame sizes will vary through successive test trials (note that the frame size includes the CRC).
- *Duplex Mode* – In this use case the traffic will be full-duplex.
- *Step Size* – The minimum incremental resolution that the Intended Load (Iload) will be incremented in frames per second. The smaller the step size, the more accurate the measurement and the more iterations required.

Specific Forward Pressure Rate Test parameters:

- *Encapsulation* – The frame encapsulation for existing endpoints (Ethernet II).

General testbed setup (DUT and tester):

In an ideal situation the test network topology should include all available DUT ports in the testing procedure. Usually, due to resource restrictions, tests are done on a limited number of DUT and tester ports. For the example shown, a configuration of 2 DUT ports is used for the testing procedure. The tester network emulates 1 device per port. Traffic in the test is generated based on the configured end ports.

Measurements that the user should expect for the performance assessment (test result format):

Forward Pressure Rate by frame size (it is important to test several frame sizes)

- Frame Size
- Forward Pressure – Yes/No
- Intended Load
- Offered Load
- Forwarding Rate
- Frame Loss
- Tx Frame Count
- Rx Frame Count
- Other Frames
- Expected Frames
- Flood Count

3.2.6 Errored Frames Filtering Test

Standard: RFC 2889 section 5.9.

Purpose: This test determines the behaviour of the DUT under error or abnormal frame conditions. The test results indicate whether the DUT filters or forwards the errored frames.

Methodology description: For the test execution a minimum of two test ports and two DUT ports are required. Multiple groups of two ports can be added to the test if desired. The test equipment emulates a single L2 MAC address per port. Learning frames are sent to the DUT and verified. Errored traffic is then sent in one direction from one test port through the DUT destined for the other test port. Various frame sizes and port loads are used across multiple test trials (iterations).

General test network topology:

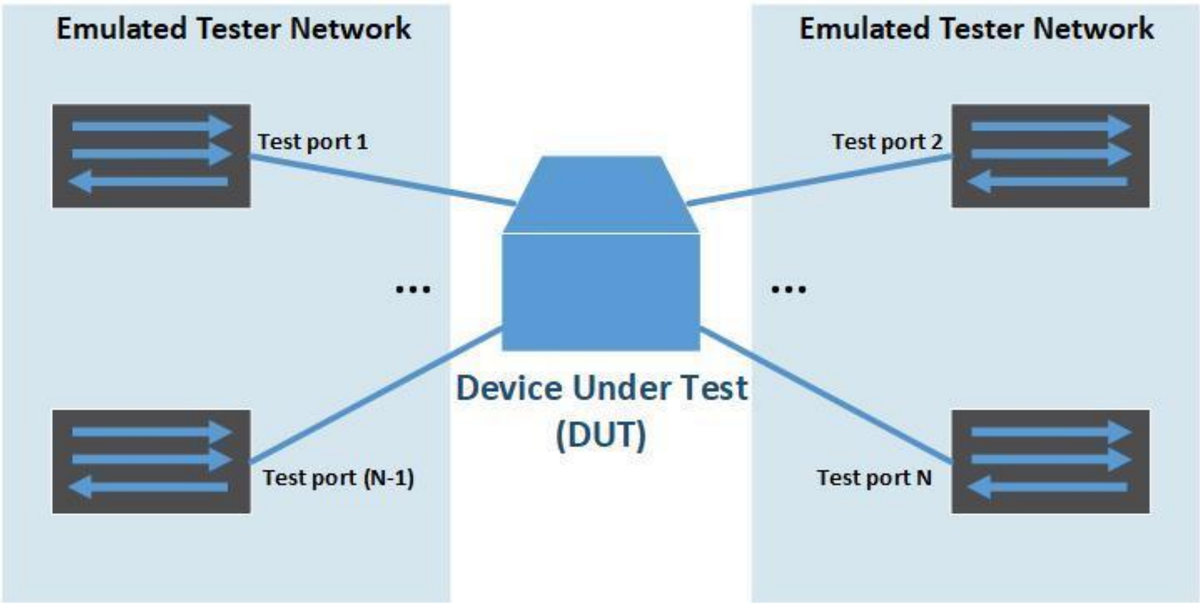


Figure 3.6: General test network topology – Errored Frames Filtering Test

Parameters and variables:

General RFC 2889 test parameters:

- *Trial Duration* – The recommended trial duration is 30 seconds. Trial duration should be adjustable at least between 1 and 300 seconds.
- *Intended Load (Iload)* – The intended load per port is expressed as a percentage of the medium's maximum theoretical load, regardless of traffic orientation or duplex mode. The test should be run multiple times with a different load per port in each case.

Specific Errored Frames Filtering Test parameters:

- *Encapsulation* – The frame encapsulation for existing endpoints (Ethernet II).
- *Burst Size* – Defines burst sizes and how they vary through successive test trials. Defines the number of test frames sent in one burst in the first iteration of the test.
- *Max Legal Frame Size* – Defines the length threshold of the jumbo frame counter (includes CRC). Configurable options are from 1 to 65,535 bytes. The default value is 1,518 bytes.
- *Errored Ethernet Frame*
    - CRC Errors – Enables generation of CRC errors in IPv4 packets. Configurable options are from 64 to 10,000 bytes. The default value is 64 bytes.
    - Undersize Frames – Enables generation of undersized frames in IPv4 packets. Configurable options are from 40 to 63 bytes.
    - Oversize Frames – Enables the generation of oversized frames. Configurable options are from 1,519 to 16,384 bytes.
    - Dribble Bit Errors (see RFC 2889 section 5.9.3) – Test not available on the Spirent platform.

General testbed setup (DUT and tester):

In an ideal situation the test network topology should include all available DUT ports in the testing procedure. Usually, due to resource restrictions, tests are done on a limited number of DUT and tester ports. For the example shown, a configuration of 2 DUT ports is used for the testing procedure. The tester network emulates 1 device per port. Traffic in the test is generated based on the configured end ports.

Measurements that the users should expect for the performance assessment (test result format):

Errored Frames Filtering by load

- Error Type
- Test Status – Passed/Error
- Intended Load
- Tx Signaling/Protocol Frame Count
- Rx Signaling/ProtocolFrame Count
- Tx Non Signaling/Protocol Frame Count
- Rx Non Signaling/Protocol Frame Count
- Oversize Frames
- Undersize Frames
- CRC Error Frames

3.2.7 Latency Test

Standard: RFC 2544 section 26.2.

Purpose: The test measures the latency of the forwarded packet. To be compatible with the Spirent tester, the forwarding delay as defined in [RFC2544] was used. Forwarding delay is also called last in, last out (LILO) latency. The LILO latency is estimated as the time interval from when the end of the frame is transmitted from the source test port to when the end of the frame is received at the destination test port.

Methodology description: Packets are sent from one or more of the tester's source ports, through the DUT, to the tester's destination ports. Forwarding delay can be measured at any intended load. The timestamp is inserted on the traffic generator and the delay on the cable (5.2 ns per metre at minimum) plus the time needed to place an entire frame on the medium are neglected or estimated and subtracted from the forwarding delay.

General test network topology:

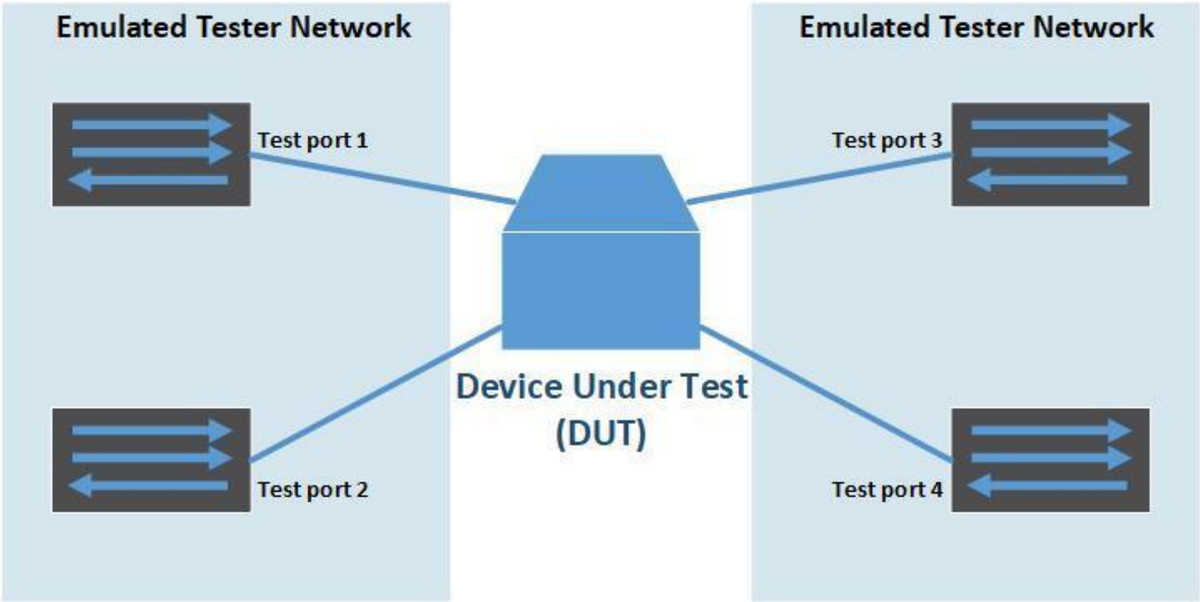


Figure 3.7: General test network topology – Latency Test

Parameters and variables:

General RFC 2544 test parameters:

- *Trial Duration* – The recommended trial duration is 60 seconds. Trial duration should be adjustable at least between 1 and 300 seconds.
- *Intended Load* (Iload) – The intended load per port is expressed as a percentage of the medium's maximum theoretical load, regardless of traffic orientation or duplex mode. The intended load can be increased incrementally (per 10% for instance).
- *Duplex Mode* – In this use case the traffic will be a full-duplex.

General testbed setup (DUT and tester):

The tester network emulates 1 device per port. Every port is in a different IPv4 network segment with its own default gateway. Traffic in the test is generated based on the configured end ports. Traffic flow is bi-directional with one-to-one mapping. Tester device 1 is paired with tester device 2 and tester device 3 is paired with tester device 4.

Measurements that the user should expect for the performance assessment (test result format):

Throughput by frame size (it is important to test several frame sizes)

- Min Latency per Frame Size and per Load
- Avg Latency per Frame Size and per Load
- Max Latency per Frame Size and per Load
- Min Jitter per Frame Size and per Load
- Avg Jitter per Frame Size and per Load
- Max Jitter per Frame Size and per Load

3.2.8 Broadcast Frame Forwarding Test

Standard: RFC 2889 section 5.10.

Purpose: This test determines the throughput of the DUT when forwarding broadcast traffic.

Methodology description: The test equipment emulates a single L2 MAC address per port. Learning frames are sent to the DUT and verified. Full mesh broadcast traffic is then sent from every test port in a round-robin fashion through the DUT to all other test ports. Various frame sizes and port loads are used across multiple test trials (iterations).

General test network topology:

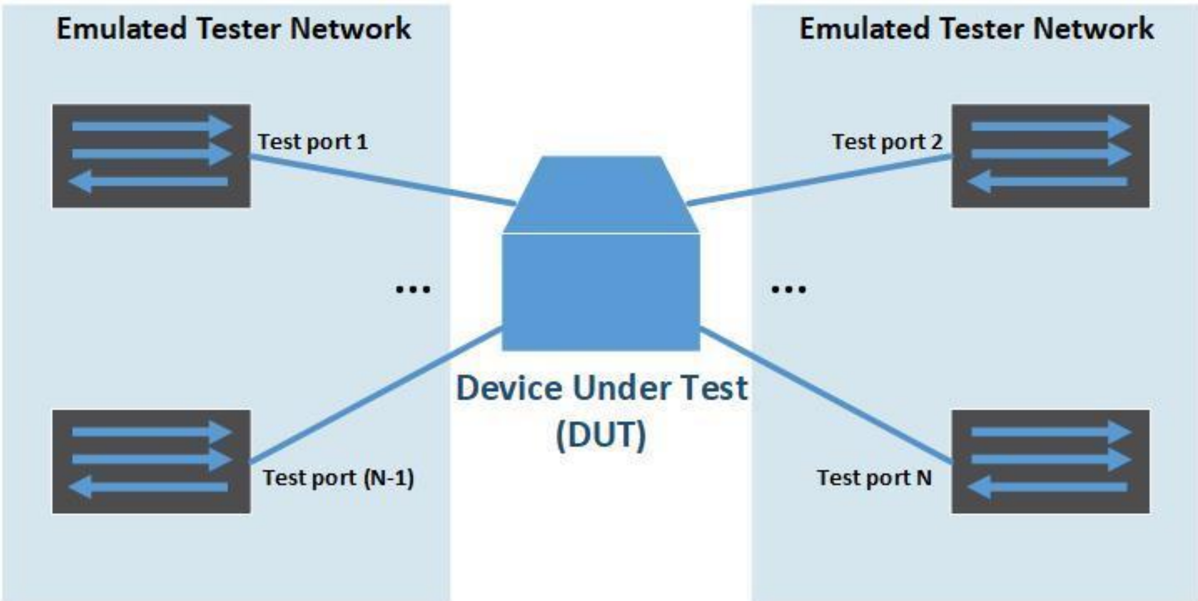


Figure 3.8: General test network topology – Broadcast Frame Forwarding Test

Parameters and variables:

General RFC 2889 test parameters:

- *Trial Duration* – The recommended trial duration is 30 seconds. The trial duration should be adjustable by at least between 1 and 300 seconds.
- *Intended Load (Iload)* – The intended load per port is expressed as a percentage of the medium's maximum theoretical load, regardless of traffic orientation or duplex mode. The intended load will not over-subscribe the DUT/SUT in this test.
- *Duplex Mode* – In this use case the traffic will be full-duplex.
- *Frame Size* – The frame size can vary between 64 and 16,383. Recommended frame sizes are 64, 128, 256, 512, 1,024, 1,280 and 1,518 bytes, per RFC 2544 section 9. It is also necessary to notify the user how the frame sizes will vary through successive test trials (note that the frame size includes the CRC).

Specific Broadcast Frame Forwarding Test parameters:

- *Encapsulation* – The frame encapsulation for existing endpoints (Ethernet II).

Measurements that the user should expect for the performance assessment (test result format):

Broadcast Frame Forwarding by frame size (it is important to test several frame sizes)

- Frame Size
- Intended Load
- Offered Load
- Forwarding Rate
- Tx Frame Count
- Rx Frame Count
- Frame Loss

3.3 Testbed Architecture and Test Tool

Spirent TestCenter [SpirentTC] is an advanced test solution delivering high performance with deterministic and detailed results. It provides software and hardware components used to test, measure and validate the network components and deploy services with predictable quality levels.

The equipment used during the tests consisted of:

- Spirent N4U chassis (SPT-N4U).
- Spirent MX3 2-Port 100 GbE QSFP28 (MX3-100GO-T2).
- Spirent MX 2-Port 100 GbE CFP2 (MX-100G-P2).
- Spirent TestCenter application v. 5.18.

The tester was connected to the DUT with 4 100GBase-LR4 interfaces.

The DUT was configured with 4 100 GbE interfaces in a single bridge domain.

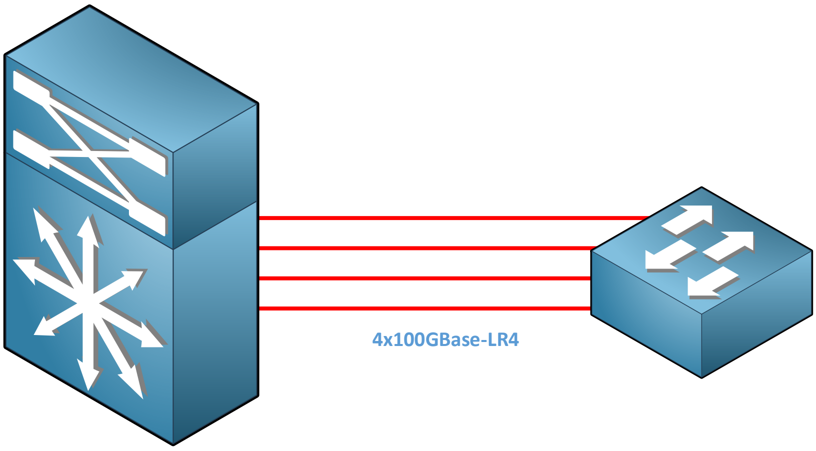


Figure 3.9: Spirent TestCenter configuration

3.4 DUT Router Configuration

As the configuration is the same for all tests, the relevant part of the DUT configuration in a bridge setup is given in Figure 3.10.

```
!
bridge 10
 description PPN-RFC-validation
 mac-learn
 exit
!
interface sdn4
 description POZ0001@31/0 -> SPIRENT@PSCN-#1
 mtu 1500
 macaddr 001a.2557.3a3e
 lldp enable
 bridge-group 10
 no shutdown
 no log-link-change
 exit
!
interface sdn6
 mtu 1500
 macaddr 003a.3249.7e0c
 lldp enable
 bridge-group 10
 no shutdown
 no log-link-change
 exit
!
interface sdn7
 mtu 1500
 macaddr 0028.491b.5a5f
```

```
 lldp enable
 bridge-group 10
 no shutdown
 no log-link-change
 exit
!
interface sdn8
 mtu 1500
 macaddr 0051.0600.0669
 lldp enable
 bridge-group 10
 no shutdown
 no log-link-change
 exit
```

Figure 3.10: Configuration of the DUT in a bridge setup

4 Results

This section provides a summary of the results and the conclusions of the different tests performed. The detailed results can be seen in Appendix A.

4.1 RFC 2889 Forwarding Test Results

The results of the measurements show the switching efficiency of the tested device for frames of various sizes.

It is clearly apparent that the switch is operating at full speed for frames of 256 B and larger. For frames with a length of 128 B, the switching efficiency is close to 100%.

The switching efficiency of 54% for 64 B frames is as expected and typical of today's switching platforms. It means that the device is able to handle up to 54% of the total interface capacity for traffic consisting of 64 B frames. For longer frames (such as 256 B and above), it offers line-rate switching.

From the obtained results it can be concluded that the tested device will work properly in the assumed conditions and configuration.

The detailed results are presented in Appendix A.1.

4.2 RFC 2889 Address Caching Capacity Test Results

As part of the test, the number of MAC addresses supported by the switch was tested. The result was 20,480 addresses.

The test results are consistent with the parameters of the device and confirm its proper functioning and that it meets the requirements for this platform.

The detailed results are presented in Appendix A.2.

4.3 RFC 2889 Address Learning Rate Test Results

As part of the test, the address learning rate of the new MAC addresses was tested. The test was performed for 1,518 B frames. The result was 14,880 addresses (frames with different addresses) per second.

The test results confirm the correct functioning of the device and meet the requirements for this platform.

The detailed results are presented in Appendix A.3.

4.4 RFC 2889 Congestion Control Test Results

The test results confirm the correct operation of the tested device (DUT) under overload conditions of one of the output interfaces. The obtained results are in line with the theoretical expectations and predictions.

For the shortest frame length of 64 B, no Head of Line Blocking (HOLB) was observed for burst values below 50,000 packets. For burst values greater than 50,000 packets, the HOLB effect was noticeable regardless of the average traffic.

On the other hand, for packets with a length of 1,500 B, the HOLB phenomenon was already visible in the case of a burst size equal to 10,000 packets.

From the tests, the estimation of the size of buffers available on the device is close to the actual size. It should be noted here that the purpose of the test is not to accurately estimate the size of buffers available on the device. An additional test should be carried out to investigate this parameter.

The conducted test allowed an objective result for the operation of the device under certain conditions to be obtained. An example of the use of the test results may be the device's resistance to the sudden appearance of a large number of small packets originating from a DDoS attack.

The detailed results are presented in Appendix A.4.

4.5 RFC 2889 Forward Pressure Test Results

The measurement obtained clearly shows that the Forward Pressure phenomenon was not observed on the tested device. The obtained results confirm the correct operation of the switch in this regard.

The detailed results are presented in Appendix A.5.

4.6 RFC 2889 Errored Frames Filtering Test Results

The test was carried out in order to test the possibility of automatically filtering out frames that are too short and too long or contain CRC errors.

The obtained results confirm the correct filtering of incorrect frames for the tested traffic load values (from 10% to 50%).

The detailed results are presented in Appendix A.6.

4.7 RFC 2544 Latency Test Results

In the traffic generator used (Spirent TestCenter device), the last in, last out (LILO) latency is estimated as the time interval from when the end of the frame is transmitted from the source test port to when the end of the frame is received at the destination test port.

The obtained measurements indicate almost no (slight) differences between the delays of switching frames of various lengths.

The average switching latency for the DUT is about 57 μs which is a normal and expected level. The differences between the maximum and minimum values of the delay are very small and are on the 2 μs level.

The measurement results confirm the stable operation of the tested device (DUT) in terms of switching delays.

The detailed results are presented in Appendix A.7.

4.8 RFC 2889 Broadcast Frame Forwarding Test Results

It was decided to measure Broadcast Frame Forwarding according to the RFC 2889 description instead of RFC 2544.

The obtained results allow the efficiency of switching broadcast frames at 13,081 fps to be estimated.

With regard to the obtained measurements, it should be noted that for the value of 14,880 fps of transmitted frames, the test result is classified as FAIL.

The result obtained is sufficient to handle broadcast traffic for the target use case. However, if the device were also to handle multicast traffic, then due to the mutual similarity from the point of view of switching in OSI layer 2, additional tests for multicast traffic or modification of the switch configuration would have to be performed.

The detailed results are presented in Appendix A.8.

5 Conclusions

This document has described a methodology for validating the performance of network devices. Recognising that it is now possible to have several network operating systems that are able to run on one hardware device, the proposed approach is to test the performance of the combination of the control plane, the data plane and the hardware chosen in the context of the selected use case. Some hardware devices or network operating systems are very versatile but others target only one segment of the market, for instance, data centre switches. This approach is not specific to white boxes; it can be used also for a traditional network device.

It is crucial to specify the list of tests that have to be conducted. Such a specification enables a fair comparison to be made between the network devices with their NOS. The RFCs outline the procedure and are a very good guideline for the test specification.

After the tests have been done, the analysis of results should take into consideration the internal architecture of the chipset (for instance, usage of external memory could degrade performance).

In this document, as an example, the “Private Peering Node (PPN) Level 2” use case (similar to a typical L2 switch use case) was tested on a combination of a Wedge 100BF-32X [Wedge] with the NOS freeRtr [freeRtr] running on the Router for Academia, Research and Education (RARE) [RARE] data plane. The tests were conducted with the Spirent TestCenter traffic generator [SpirentTC]. As freeRtr does not provide a broadcast storm control mechanism and MAC ACL, in this use case a workaround solution for MAC ACL is available. Taking this restriction into consideration, the conclusion is that this combination of the Wedge 100BF-32X with the NOS freeRtr running on the RARE data plane provides the appropriate performance to handle the Private Peering Node Level 2 use case in production.

The tests that were carried out allow the creation of a database or template of tests that could easily be reused by European NRENs for other use cases. As the number of use cases is limited, it would be very useful to take advantage of the test list, to adapt it to the particularity of the NREN use cases. It is also possible to have a test platform or a code framework that could be shared, especially as there are now open-source traffic generators such as the Realistic Traffic Generator (TRex) [TRex].

Appendix A Test-Results Reports

This appendix presents the detailed test-results reports generated by the Spirent TestCenter software.

A.1 RFC 2889 Forwarding Test Results Report

Spirent TestCenter Report

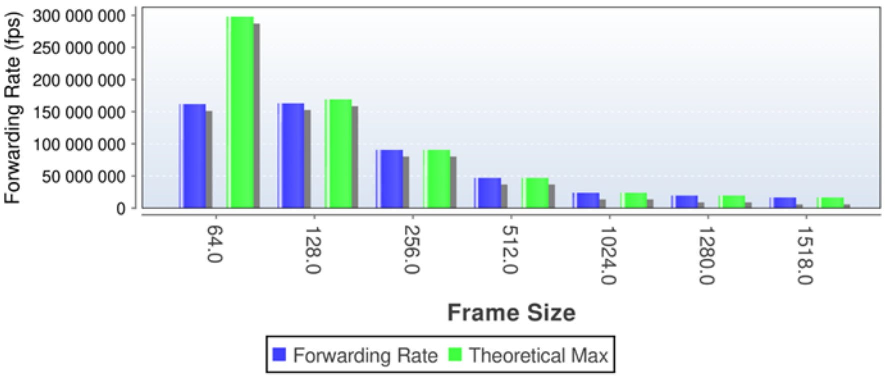
Test Type: RFC2889 Forwarding

Counter Mode: Interarrivaltime

Test Date: 2022-05-19 09:11:04 CEST

Page 1

Forwarding Rate by Frame Size Vs Theoretical Max



Summary Table

Trial	Frame Size (bytes)	Burst Size	Throughput (%)	Intended Load (%)	Offered Load (%)	Result	Forwarding Rate (fps)
1	64	1	54,297	54,297	54,297	Passed	161597841,38
1	128	1	96,484	96,484	96,484	Passed	162980362,55
1	256	1	100	100	100	Passed	90579709,58
1	512	1	100	100	100	Passed	46992481,06
1	1024	1	100	100	100	Passed	23946360,06
1	1280	1	100	100	100	Passed	19230769,18
1	1518	1	100	100	100	Passed	16254876,37

Page 2

Test Summary by Trial

Trials	Frame Size Bytes	Burst Size	Intended Load (%)	Offered Load (%)	Forwarding Rate (fps)	Tx Frame Count	Rx Frame Count	Frame Loss (%)	Frames Lost	Flood Count	Other Rx Frames
1	64	1	10	10	29761904,6	892857149	892857149	0	0	0	28
1	64	1	55	55	163690475,58	4910714311	4910714310	0,0000000203636362588	1	0	29
1	64	1	32,5	32,5	96726189,98	2901785731	2901785731	0	0	0	31
1	64	1	43,75	43,75	130208332,61	3906250025	3906250025	0	0	0	27
1	64	1	49,375	49,375	146949404,15	4408482173	4408482173	0	0	0	24
1	64	1	52,188	52,188	155319939,63	4659598238	4659598238	0	0	0	28
1	64	1	53,594	53,594	159505207,55	4785156292	4785156292	0	0	0	24
1	64	1	54,297	54,297	161597841,38	4847935318	4847935318	0	0	0	24
1	128	1	10	10	16891891,84	506756761	506756761	0	0	0	26
1	128	1	55	55	92905405,02	2787162184	2787162184	0	0	0	30
1	128	1	77,5	77,5	130912161,6	3927364895	3927364895	0	0	0	28
1	128	1	88,75	88,75	149915539,95	4497466235	4497466235	0	0	0	30
1	128	1	94,375	94,375	159417228,9	4782516925	4782516925	0	0	0	30
1	128	1	97,188	97,188	164168073,55	4925042261	4925042260	0,0000000203043942977	1	0	29
1	128	1	95,781	95,781	161792651,46	4853779597	4853779597	0	0	0	30
1	128	1	96,484	96,484	162980362,55	4889410932	4889410932	0	0	0	29
1	256	1	10	10	9057971,01	271739133	271739133	0	0	0	29
1	256	1	55	55	49818840,46	1494565228	1494565228	0	0	0	30
1	256	1	77,5	77,5	70199275,16	2105978271	2105978271	0	0	0	28
1	256	1	88,75	88,75	80389492,44	2411684801	2411684801	0	0	0	30
1	256	1	94,375	94,375	85484601,19	2564538060	2564538060	0	0	0	30
1	256	1	97,188	97,188	88032155,37	2640964691	2640964691	0	0	0	28
1	256	1	98,594	98,594	89305932,65	2679178011	2679178011	0	0	0	28
1	256	1	99,297	99,297	89942821,14	2698284660	2698284660	0	0	0	28
1	256	1	100	100	90579709,58	2717391320	2717391320	0	0	0	24
1	512	1	10	10	4699248,15	140977446	140977446	0	0	0	24
1	512	1	55	55	25845864,56	775375948	775375948	0	0	0	26
1	512	1	77,5	77,5	36419172,79	1092575195	1092575195	0	0	0	26
1	512	1	88,75	88,75	41705826,92	1251174819	1251174819	0	0	0	28
1	512	1	94,375	94,375	44349153,86	1330474633	1330474633	0	0	0	29
1	512	1	97,188	97,188	45670817,47	1370124539	1370124539	0	0	0	28
1	512	1	98,594	98,594	46331649,3	1389949495	1389949495	0	0	0	30
1	512	1	99,297	99,297	46662065,14	1399861971	1399861971	0	0	0	30
1	512	1	100	100	46992481,06	1409774445	1409774445	0	0	0	28
1	1024	1	10	10	2394636,03	71839082	71839082	0	0	0	28
1	1024	1	55	55	13170498,07	395114946	395114946	0	0	0	32
1	1024	1	77,5	77,5	18558429,02	556752878	556752878	0	0	0	28
1	1024	1	88,75	88,75	21252394,55	637571844	637571844	0	0	0	28
1	1024	1	94,375	94,375	22599377,33	677981327	677981327	0	0	0	30
1	1024	1	97,188	97,188	23272868,74	698186069	698186069	0	0	0	30
1	1024	1	98,594	98,594	23609614,38	708288439	708288439	0	0	0	28
1	1024	1	99,297	99,297	23777987,23	713339624	713339624	0	0	0	30
1	1024	1	100	100	23946360,06	718390810	718390810	0	0	0	29
1	1280	1	10	10	1923076,95	57692310	57692310	0	0	0	23
1	1280	1	55	55	10576923,05	317307696	317307696	0	0	0	24
1	1280	1	77,5	77,5	14903846,1	447115389	447115389	0	0	0	22
1	1280	1	88,75	88,75	17067307,64	512019235	512019235	0	0	0	23
1	1280	1	94,375	94,375	18149038,41	544471160	544471160	0	0	0	25

1	1280	1	97,188	97,188	18689903,79	560697120	560697120	0	0	0	22
1	1280	1	98,594	98,594	18960336,42	568810100	568810100	0	0	0	23
1	1280	1	99,297	99,297	19095552,85	572866591	572866591	0	0	0	31
1	1280	1	100	100	19230769,18	576923081	576923081	0	0	0	29
1	1518	1	10	10	1625487,67	48764630	48764630	0	0	0	28
1	1518	1	55	55	8940182,03	268205464	268205464	0	0	0	30
1	1518	1	77,5	77,5	12597529,24	377925880	377925880	0	0	0	29
1	1518	1	88,75	88,75	14426202,83	432786089	432786089	0	0	0	29
1	1518	1	94,375	94,375	15340539,63	460216194	460216194	0	0	0	30
1	1518	1	97,188	97,188	15797707,99	473931246	473931246	0	0	0	28
1	1518	1	98,594	98,594	16026292,21	480788772	480788772	0	0	0	25
1	1518	1	99,297	99,297	16140584,34	484217536	484217536	0	0	0	27
1	1518	1	100	100	16254876,37	487646298	487646298	0	0	0	24

Theoretical Maximum Frame Rates

Media Type	Line Speed (Mbps)	64 Byte	128 Byte	256 Byte	512 Byte	1024 Byte	1280 Byte	1518 Byte
Ethernet	10	14,880	8,445	4,528	2,349	1,197	961	812
Ethernet	100	148,809	84,459	45,289	23,496	11,973	9,615	8,127
Gigabit Ethernet	1,000	1,488,095	844,594	452,898	234,962	119,731	96,153	81,274
2.5 Gigabit Ethernet	2,500	3,720,238	2,111,486	1,132,246	587,406	299,329	240,384	202,922
5 Gigabit Ethernet	5,000	7,440,476	4,222,972	2,264,492	1,174,812	598,659	480,769	406,371
10 Gigabit Ethernet	10,000	14,880,952	8,445,945	4,528,985	2,349,624	1,197,318	961,538	812,743
25 Gigabit Ethernet	25,000	37,202,380	21,114,864	11,322,463	5,874,060	2,993,295	2,403,846	2,029,220
40 Gigabit Ethernet	40,000	59,523,809	33,783,783	18,115,942	9,398,496	4,789,272	3,846,153	3,250,975
50 Gigabit Ethernet	50,000	74,404,761	42,229,729	22,644,927	11,748,120	5,986,590	4,807,692	4,063,719
100 Gigabit Ethernet	100,000	148,809,523	84,459,459	45,289,855	23,496,240	11,973,180	9,615,384	8,127,438
POS (OC-3)	155	288,000	145,116	72,840	36,491	18,263	14,613	12,323
POS (OC-12)	622	1,152,000	580,465	291,361	145,964	73,053	58,622	49,413
POS (OC-48)	2,448	4,608,000	2,321,860	1,165,447	583,859	292,214	233,817	197,182
POS (OC-192)	9,953	18,432,000	9,287,441	4,661,789	2,335,438	1,168,858	935,269	788,729
ATM (OC-3)	155	176,603	117,735	58,867	32,109	16,054	13,082	11,037
ATM (OC-12)	622	706,412	470,940	235,468	122,810	64,216	52,578	44,148

Template Version: R2C

RunTime Start Data Set ID: 1

RunTime End Data Set ID: 2147483647

RR Template Saved Timestamp: Wed Aug 31 21:15:19.298 PDT 2011

A.2 RFC 2889 Address Caching Capacity Test Results Report

Spirent TestCenter Report

Test Type: RFC2889 Address Caching Capacity

Counter Mode: Basic

Test Date: 2022-08-01 13:45:04 CEST

Test Summary

Optimal Caching Capacity: 20480

Trial	Frame Size	Address Count	Test Status	Tx Sig Frames	Rx Sig Frames	Rx Frames	Expected Rx Frames	Flood Frames	Expected Frames	Lost Frames	Frame Loss (%)	Caching Capacity	Learned Percent(%)
1	1518	20480	Passed	20480	20480	20480	20480	0	20480	0	0	20480	100

Iteration Results

Trial	Frame Size	Address Count	Port	Port Type	Status	Tx Sig Frames	Rx Sig Frames	Rx Frames	Expected Rx Frames	Flood Frames	Expected Frames	Lost Frames	Frame Loss (%)	Learned (%)
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	20480	0	0	0	0	0	0	0	0
1	1518	20480	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Passed	0	20480	20480	20480	0	20480	0	0	100
1	1518	20480	Test	-	Passed	20480	20480	20480	20480	0	20480	0	0	100
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	43008	0	0	0	0	0	0	0	0
1	1518	43008	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	43007	43007	43007	0	43008	1	0,00232514880952381	99,9976748511905
1	1518	43008	Test	-	Failed	43008	43007	43007	43007	0	43008	1	0,00232514880952381	99,9976748511905
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	31744	0	0	0	0	0	0	0	0
1	1518	31744	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	31743	31743	31743	0	31744	1	0,00315020161290323	99,9968497983871
1	1518	31744	Test	-	Failed	31744	31743	31743	31743	0	31744	1	0,00315020161290323	99,9968497983871
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	26112	0	0	0	0	0	0	0	0
1	1518	26112	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	26111	26111	26111	0	26112	1	0,0038296568627451	99,9961703431373
1	1518	26112	Test	-	Failed	26112	26111	26111	26111	0	26112	1	0,0038296568627451	99,9961703431373
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	23296	0	0	0	0	0	0	0	0
1	1518	23296	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	23295	23295	23295	0	23296	1	0,00429258241758242	99,9957074175824
1	1518	23296	Test	-	Failed	23296	23295	23295	23295	0	23296	1	0,00429258241758242	99,9957074175824
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	21888	0	0	0	0	0	0	0	0
1	1518	21888	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	21887	21887	21887	0	21888	1	0,0045687134502924	99,9954312865497

1	1518	21888	Test	-	Failed	21888	21887	21887	21887	0	21888	1	0,0045687134502924	99,9954312865497
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	21184	0	0	0	0	0	0	0	0
1	1518	21184	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	21183	21183	21183	0	21184	1	0,00472054380664653	99,9952794561934
1	1518	21184	Test	-	Failed	21184	21183	21183	21183	0	21184	1	0,00472054380664653	99,9952794561934
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	20832	0	0	0	0	0	0	0	0
1	1518	20832	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	20831	20831	20831	0	20832	1	0,00480030721966206	99,9951996927803
1	1518	20832	Test	-	Failed	20832	20831	20831	20831	0	20832	1	0,00480030721966206	99,9951996927803
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	20656	0	0	0	0	0	0	0	0
1	1518	20656	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	20655	20655	20655	0	20656	1	0,00484120836560806	99,9951587916344
1	1518	20656	Test	-	Failed	20656	20655	20655	20655	0	20656	1	0,00484120836560806	99,9951587916344
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	20568	0	0	0	0	0	0	0	0
1	1518	20568	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	20567	20567	20567	0	20568	1	0,00486192143134967	99,9951380785686
1	1518	20568	Test	-	Failed	20568	20567	20567	20567	0	20568	1	0,00486192143134967	99,9951380785686
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	20524	0	0	0	0	0	0	0	0
1	1518	20524	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	20523	20523	20523	0	20524	1	0,00487234457220815	99,9951276554278
1	1518	20524	Test	-	Failed	20524	20523	20523	20523	0	20524	1	0,00487234457220815	99,9951276554278
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	20502	0	0	0	0	0	0	0	0
1	1518	20502	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	20501	20501	20501	0	20502	1	0,00487757291971515	99,9951224270803
1	1518	20502	Test	-	Failed	20502	20501	20501	20501	0	20502	1	0,00487757291971515	99,9951224270803
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	20491	0	0	0	0	0	0	0	0
1	1518	20491	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	20490	20490	20490	0	20491	1	0,0048801913034991	99,9951198086965
1	1518	20491	Test	-	Failed	20491	20490	20490	20490	0	20491	1	0,0048801913034991	99,9951198086965
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	20485	0	0	0	0	0	0	0	0
1	1518	20485	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	20484	20484	20484	0	20485	1	0,00488162069807176	99,9951183793019
1	1518	20485	Test	-	Failed	20485	20484	20484	20484	0	20485	1	0,00488162069807176	99,9951183793019
1	1518	0	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	Passed	20482	0	0	0	0	0	0	0	0
1	1518	20482	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	Failed	0	20481	20481	20481	0	20482	1	0,00488233570940338	99,9951176642906
1	1518	20482	Test	-	Failed	20482	20481	20481	20481	0	20482	1	0,00488233570940338	99,9951176642906

Theoretical Maximum Frame Rates

Media Type	Line Speed (Mbps)	64 Byte	128 Byte	256 Byte	512 Byte	1024 Byte	1280 Byte	1518 Byte
Ethernet	10	14,880	8,445	4,528	2,349	1,197	961	812
Ethernet	100	148,809	84,459	45,289	23,496	11,973	9,615	8,127
Gigabit Ethernet	1,000	1,488,095	844,594	452,898	234,962	119,731	96,153	81,274
2.5 Gigabit Ethernet	2,500	3,720,238	2,111,486	1,132,246	587,406	299,329	240,384	202,922
5 Gigabit Ethernet	5,000	7,440,476	4,222,972	2,264,492	1,174,812	598,659	480,769	406,371
10 Gigabit Ethernet	10,000	14,880,952	8,445,945	4,528,985	2,349,624	1,197,318	961,538	812,743
25 Gigabit Ethernet	25,000	37,202,380	21,114,864	11,322,463	5,874,060	2,993,295	2,403,846	2,029,220
40 Gigabit Ethernet	40,000	59,523,809	33,783,783	18,115,942	9,398,496	4,789,272	3,846,153	3,250,975
50 Gigabit Ethernet	50,000	74,404,761	42,229,729	22,644,927	11,748,120	5,986,590	4,807,692	4,063,719
100 Gigabit Ethernet	100,000	148,809,523	84,459,459	45,289,855	23,496,240	11,973,180	9,615,384	8,127,438
POS (OC-3)	155	288,000	145,116	72,840	36,491	18,263	14,613	12,323
POS (OC-12)	622	1,152,000	580,465	291,361	145,964	73,053	58,622	49,413
POS (OC-48)	2,448	4,608,000	2,321,860	1,165,447	583,859	292,214	233,817	197,182
POS (OC-192)	9,953	18,432,000	9,287,441	4,661,789	2,335,438	1,168,858	935,269	788,729
ATM (OC-3)	155	176,603	117,735	58,867	32,109	16,054	13,082	11,037
ATM (OC-12)	622	706,412	470,940	235,468	122,810	64,216	52,578	44,148

Template Version: R2C

RunTime Start Data Set ID: 1

RunTime End Data Set ID: 2147483647

RR Template Saved TimestampThu Jul 29 15:12:29.691 PDT 2010

A.3 RFC 2889 Address Learning Rate Test Results Report

SPIRENT

Spirent TestCenter Report

Test Type:	RFC2889 Address Learning Rate
Counter Mode:	Basic
Test Date:	2022-08-01 14:31:54 CEST

TESTED SPIRENT

Page 1

Test Summary

Optimal Learning Rate: 14880 fps

Trial	Frame Size	Addr Count	Test Status	Intended Load (%)	Tx Sig Frames	Rx Sig Frames	Rx Frames	Expected Rx Frames	Flood Frames	Expected Frames	Lost Frames	Frame Loss (%)	Learning Rate (fps)
1	1518	1	Passed	0,183	1	1	1	1	0	1	0	0	14880

Page 2

Iteration Results

Trial	Frame Size	Port	Port Type	Addr Count	Test Status	Intended Load (%)	Tx Sig Frames	Rx Sig Frames	Expected Rx Frames	Flood Frames	Expected Frames	Lost Frames	Frame Loss (%)	Learning Rate (fps)
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,018	1	0	0	0	0	0	0	1488
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0
1	1518	Test	-	1	Passed	0,018	1	1	1	0	1	0	0	1488
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,101	1	0	0	0	0	0	0	8184
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0
1	1518	Test	-	1	Passed	0,101	1	1	1	0	1	0	0	8184
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,142	1	0	0	0	0	0	0	11532
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0
1	1518	Test	-	1	Passed	0,142	1	1	1	0	1	0	0	11532
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,162	1	0	0	0	0	0	0	13206
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0
1	1518	Test	-	1	Passed	0,162	1	1	1	0	1	0	0	13206
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,173	1	0	0	0	0	0	0	14043
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0

1	1518	Test	-	1	Passed	0,173	1	1	1	0	1	0	0	14043
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,178	1	0	0	0	0	0	0	14461
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0
1	1518	Test	-	1	Passed	0,178	1	1	1	0	1	0	0	14461
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,18	1	0	0	0	0	0	0	14670
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0
1	1518	Test	-	1	Passed	0,18	1	1	1	0	1	0	0	14670
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,182	1	0	0	0	0	0	0	14775
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0
1	1518	Test	-	1	Passed	0,182	1	1	1	0	1	0	0	14775
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,182	1	0	0	0	0	0	0	14827
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0
1	1518	Test	-	1	Passed	0,182	1	1	1	0	1	0	0	14827
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,183	1	0	0	0	0	0	0	14853
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0
1	1518	Test	-	1	Passed	0,183	1	1	1	0	1	0	0	14853
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,183	1	0	0	0	0	0	0	14866
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0
1	1518	Test	-	1	Passed	0,183	1	1	1	0	1	0	0	14866
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,183	1	0	0	0	0	0	0	14873
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0

1	1518	Test	-	1	Passed	0,183	1	1	1	0	1	0	0	14873
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,183	1	0	0	0	0	0	0	14876
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0
1	1518	Test	-	1	Passed	0,183	1	1	1	0	1	0	0	14876
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,183	1	0	0	0	0	0	0	14878
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0
1	1518	Test	-	1	Passed	0,183	1	1	1	0	1	0	0	14878
1	1518	Port //1/1 [00:31:64:5A:1C:09/sdn4]	Transmit	1	Passed	0,183	1	0	0	0	0	0	0	14880
1	1518	Port //1/2 [00:31:64:5A:1C:09/sdn4]	Learning	0	Passed	0	0	1	1	0	1	0	0	0
1	1518	Port //2/2 [00:2B:22:27:0A:75/sdn7]	Monitor	0	Passed	0	0	0	0	0	0	0	0	0
1	1518	Test	-	1	Passed	0,183	1	1	1	0	1	0	0	14880

Theoretical Maximum Frame Rates

Media Type	Line Speed (Mbps)	64 Byte	128 Byte	256 Byte	512 Byte	1024 Byte	1280 Byte	1518 Byte
Ethernet	10	14,880	8,445	4,528	2,349	1,197	961	812
Ethernet	100	148,809	84,459	45,289	23,496	11,973	9,615	8,127
Gigabit Ethernet	1,000	1,488,095	844,594	452,898	234,962	119,731	96,153	81,274
2.5 Gigabit Ethernet	2,500	3,720,238	2,111,486	1,132,246	587,406	299,329	240,384	202,922
5 Gigabit Ethernet	5,000	7,440,476	4,222,972	2,264,492	1,174,812	598,659	480,769	406,371
10 Gigabit Ethernet	10,000	14,880,952	8,445,945	4,528,985	2,349,624	1,197,318	961,538	812,743
25 Gigabit Ethernet	25,000	37,202,380	21,114,864	11,322,463	5,874,060	2,993,295	2,403,846	2,029,220
40 Gigabit Ethernet	40,000	59,523,809	33,783,783	18,115,942	9,398,496	4,789,272	3,846,153	3,250,975
50 Gigabit Ethernet	50,000	74,404,761	42,229,729	22,644,927	11,748,120	5,986,590	4,807,692	4,063,719
100 Gigabit Ethernet	100,000	148,809,523	84,459,459	45,289,855	23,496,240	11,973,180	9,615,384	8,127,438
POS (OC-3)	155	288,000	145,116	72,840	36,491	18,263	14,613	12,323
POS (OC-12)	622	1,152,000	580,465	291,361	145,964	73,053	58,622	49,413
POS (OC-48)	2,448	4,608,000	2,321,860	1,165,447	583,859	292,214	233,817	197,182
POS (OC-192)	9,953	18,432,000	9,287,441	4,661,789	2,335,438	1,168,858	935,269	788,729
ATM (OC-3)	155	176,603	117,735	58,867	32,109	16,054	13,082	11,037
ATM (OC-12)	622	706,412	470,940	235,468	122,810	64,216	52,578	44,148

Template Version: R2C

RunTime Start Data Set ID: 1

RunTime End Data Set ID: 2147483647

RR Template Saved Timestamp: Wed Aug 31 21:14:05.710 PDT 2011

A.4 RFC 2889 Congestion Control Test Results Report

Spirent TestCenter Report

Test Type:	RFC2889 Congestion Control
Counter Mode:	Basic
Test Date:	2022-09-13 18:27:28 CEST

Page 1

Test Summary

Trial	Frame Size	Burst Size	Intended Load (%)	Head of Line Blocking	Back-Pressure
1	64	10000	40	No	No
1	64	10000	50	No	No
1	64	10000	60	No	No
1	64	10000	70	No	No
1	64	20000	40	No	No
1	64	20000	50	No	No
1	64	20000	60	No	No
1	64	20000	70	No	No
1	64	30000	40	No	No
1	64	30000	50	No	No
1	64	30000	60	No	No
1	64	30000	70	No	No
1	64	40000	40	No	No
1	64	40000	50	No	No
1	64	40000	60	No	No
1	64	40000	70	No	No
1	64	50000	40	No	No
1	64	50000	50	Yes	No
1	64	50000	60	Yes	No
1	64	50000	70	No	No
1	64	60000	40	Yes	No
1	64	60000	50	Yes	No
1	64	60000	60	Yes	No
1	64	60000	70	No	No
1	64	70000	40	Yes	No
1	64	70000	50	Yes	No
1	64	70000	60	Yes	No
1	64	70000	70	No	No
1	64	80000	40	Yes	No
1	64	80000	50	Yes	No
1	64	80000	60	Yes	No
1	64	80000	70	No	No
1	64	90000	40	Yes	No
1	64	90000	50	Yes	No
1	64	90000	60	Yes	No
1	64	90000	70	No	No
1	64	100000	40	Yes	No
1	64	100000	50	Yes	No
1	64	100000	60	Yes	No
1	64	100000	70	No	No
1	64	110000	40	Yes	No
1	64	110000	50	Yes	No
1	64	110000	60	Yes	No
1	64	110000	70	Yes	No
1	64	120000	40	Yes	No
1	64	120000	50	Yes	No
1	64	120000	60	Yes	No

1	64	120000	70	No	No
1	64	130000	40	Yes	No
1	64	130000	50	Yes	No
1	64	130000	60	Yes	No
1	64	130000	70	No	No
1	64	140000	40	Yes	No
1	64	140000	50	Yes	No
1	64	140000	60	Yes	No
1	64	140000	70	No	No
1	64	150000	40	Yes	No
1	64	150000	50	Yes	No
1	64	150000	60	Yes	No
1	64	150000	70	No	No
1	64	160000	40	Yes	No
1	64	160000	50	Yes	No
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1	1280	110000	60	Yes	No
1	1280	110000	70	No	No
1	1280	120000	40	Yes	No
1	1280	120000	50	Yes	No
1	1280	120000	60	Yes	No
1	1280	120000	70	No	No
1	1280	130000	40	Yes	No
1	1280	130000	50	Yes	No
1	1280	130000	60	Yes	No
1	1280	130000	70	No	No
1	1280	140000	40	Yes	No
1	1280	140000	50	Yes	No
1	1280	140000	60	Yes	No
1	1280	140000	70	No	No
1	1280	150000	40	Yes	No
1	1280	150000	50	Yes	No
1	1280	150000	60	Yes	No
1	1280	150000	70	No	No
1	1280	160000	40	Yes	No
1	1280	160000	50	Yes	No
1	1280	160000	60	Yes	No

1	1280	160000	70	No	No
1	1280	170000	40	Yes	No
1	1280	170000	50	Yes	No
1	1280	170000	60	Yes	No
1	1280	170000	70	No	No
1	1280	180000	40	Yes	No
1	1280	180000	50	Yes	No
1	1280	180000	60	Yes	No
1	1280	180000	70	No	No
1	1280	190000	40	Yes	No
1	1280	190000	50	Yes	No
1	1280	190000	60	Yes	No
1	1280	190000	70	No	No
1	1280	200000	40	Yes	No
1	1280	200000	50	Yes	No
1	1280	200000	60	Yes	No
1	1280	200000	70	No	No
1	1280	210000	40	Yes	No
1	1280	210000	50	Yes	No
1	1280	210000	60	Yes	No
1	1280	210000	70	No	No
1	1280	220000	40	Yes	No
1	1280	220000	50	Yes	No
1	1280	220000	60	Yes	No
1	1280	220000	70	No	No
1	1280	230000	40	Yes	No
1	1280	230000	50	Yes	No
1	1280	230000	60	Yes	No
1	1280	230000	70	No	No
1	1280	240000	40	Yes	No
1	1280	240000	50	Yes	No
1	1280	240000	60	Yes	No
1	1280	240000	70	No	No
1	1280	250000	40	Yes	No
1	1280	250000	50	Yes	No
1	1280	250000	60	Yes	No
1	1280	250000	70	No	No
1	1280	260000	40	Yes	No
1	1280	260000	50	Yes	No
1	1280	260000	60	Yes	No
1	1280	260000	70	No	No
1	1280	270000	40	Yes	No
1	1280	270000	50	Yes	No
1	1280	270000	60	Yes	No
1	1280	270000	70	No	No
1	1280	280000	40	Yes	No
1	1280	280000	50	Yes	No
1	1280	280000	60	Yes	No
1	1280	280000	70	No	No
1	1280	290000	40	Yes	No
1	1280	290000	50	Yes	No
1	1280	290000	60	Yes	No
1	1280	290000	70	No	No
1	1280	300000	40	Yes	No
1	1280	300000	50	Yes	No
1	1280	300000	60	Yes	No

1	1280	300000	70	No	No
1	1518	10000	40	Yes	No
1	1518	10000	50	Yes	No
1	1518	10000	60	Yes	No
1	1518	10000	70	No	No
1	1518	20000	40	Yes	No
1	1518	20000	50	Yes	No
1	1518	20000	60	Yes	No
1	1518	20000	70	No	No
1	1518	30000	40	Yes	No
1	1518	30000	50	Yes	No
1	1518	30000	60	Yes	No
1	1518	30000	70	No	No
1	1518	40000	40	Yes	No
1	1518	40000	50	Yes	No
1	1518	40000	60	Yes	No
1	1518	40000	70	No	No
1	1518	50000	40	Yes	No
1	1518	50000	50	Yes	No
1	1518	50000	60	Yes	No
1	1518	50000	70	No	No
1	1518	60000	40	Yes	No
1	1518	60000	50	Yes	No
1	1518	60000	60	Yes	No
1	1518	60000	70	No	No
1	1518	70000	40	Yes	No
1	1518	70000	50	Yes	No
1	1518	70000	60	Yes	No

1	1518	70000	70	No	No
1	1518	80000	40	Yes	No
1	1518	80000	50	Yes	No
1	1518	80000	60	Yes	No
1	1518	80000	70	No	No
1	1518	90000	40	Yes	No
1	1518	90000	50	Yes	No
1	1518	90000	60	Yes	No
1	1518	90000	70	No	No
1	1518	100000	40	Yes	No
1	1518	100000	50	Yes	No
1	1518	100000	60	Yes	No
1	1518	100000	70	No	No
1	1518	110000	40	Yes	No
1	1518	110000	50	Yes	No
1	1518	110000	60	Yes	No
1	1518	110000	70	No	No
1	1518	120000	40	Yes	No
1	1518	120000	50	Yes	No
1	1518	120000	60	Yes	No
1	1518	120000	70	No	No
1	1518	130000	40	Yes	No
1	1518	130000	50	Yes	No
1	1518	130000	60	Yes	No
1	1518	130000	70	No	No
1	1518	140000	40	Yes	No
1	1518	140000	50	Yes	No
1	1518	140000	60	Yes	No

1	1518	140000	70	No	No
1	1518	150000	40	Yes	No
1	1518	150000	50	Yes	No
1	1518	150000	60	Yes	No
1	1518	150000	70	No	No
1	1518	160000	40	Yes	No
1	1518	160000	50	Yes	No
1	1518	160000	60	Yes	No
1	1518	160000	70	No	No
1	1518	170000	40	Yes	No
1	1518	170000	50	Yes	No
1	1518	170000	60	Yes	No
1	1518	170000	70	No	No
1	1518	180000	40	Yes	No
1	1518	180000	50	Yes	No
1	1518	180000	60	Yes	No
1	1518	180000	70	No	No
1	1518	190000	40	Yes	No
1	1518	190000	50	Yes	No
1	1518	190000	60	Yes	No
1	1518	190000	70	No	No
1	1518	200000	40	Yes	No
1	1518	200000	50	Yes	No
1	1518	200000	60	Yes	No
1	1518	200000	70	No	No
1	1518	210000	40	Yes	No
1	1518	210000	50	Yes	No
1	1518	210000	60	Yes	No
1	1518	210000	70	No	No
1	1518	220000	40	Yes	No
1	1518	220000	50	Yes	No
1	1518	220000	60	Yes	No
1	1518	220000	70	No	No
1	1518	230000	40	Yes	No
1	1518	230000	50	Yes	No
1	1518	230000	60	Yes	No
1	1518	230000	70	No	No
1	1518	240000	40	Yes	No
1	1518	240000	50	Yes	No
1	1518	240000	60	Yes	No
1	1518	240000	70	No	No
1	1518	250000	40	Yes	No
1	1518	250000	50	Yes	No
1	1518	250000	60	Yes	No
1	1518	250000	70	No	No
1	1518	260000	40	Yes	No
1	1518	260000	50	Yes	No
1	1518	260000	60	Yes	No
1	1518	260000	70	No	No
1	1518	270000	40	Yes	No
1	1518	270000	50	Yes	No
1	1518	270000	60	Yes	No
1	1518	270000	70	No	No
1	1518	280000	40	Yes	No
1	1518	280000	50	Yes	No
1	1518	280000	60	Yes	No

1	1518	280000	70	No	No
1	1518	290000	40	Yes	No
1	1518	290000	50	Yes	No
1	1518	290000	60	Yes	No
1	1518	290000	70	No	No
1	1518	300000	40	Yes	No
1	1518	300000	50	Yes	No
1	1518	300000	60	Yes	No
1	1518	300000	70	No	No

Theoretical Maximum Frame Rates

Media Type	Line Speed (Mbps)	64 Byte	128 Byte	256 Byte	512 Byte	1024 Byte	1280 Byte	1518 Byte
Ethernet	10	14,880	8,445	4,528	2,349	1,197	961	812
Ethernet	100	148,809	84,459	45,289	23,496	11,973	9,615	8,127
Gigabit Ethernet	1,000	1,488,095	844,594	452,898	234,962	119,731	96,153	81,274
2.5 Gigabit Ethernet	2,500	3,720,238	2,111,486	1,132,246	587,406	299,329	240,384	202,922
5 Gigabit Ethernet	5,000	7,440,476	4,222,972	2,264,492	1,174,812	598,659	480,769	406,371
10 Gigabit Ethernet	10,000	14,880,952	8,445,945	4,528,985	2,349,624	1,197,318	961,538	812,743
25 Gigabit Ethernet	25,000	37,202,380	21,114,864	11,322,463	5,874,060	2,993,295	2,403,846	2,029,220
40 Gigabit Ethernet	40,000	59,523,809	33,783,783	18,115,942	9,398,496	4,789,272	3,846,153	3,250,975
50 Gigabit Ethernet	50,000	74,404,761	42,229,729	22,644,927	11,748,120	5,986,590	4,807,692	4,063,719
100 Gigabit Ethernet	100,000	148,809,523	84,459,459	45,289,855	23,496,240	11,973,180	9,615,384	8,127,438
POS (OC-3)	155	288,000	145,116	72,840	36,491	18,263	14,613	12,323
POS (OC-12)	622	1,152,000	580,465	291,361	145,964	73,053	58,622	49,413
POS (OC-48)	2,448	4,608,000	2,321,860	1,165,447	583,859	292,214	233,817	197,182
POS (OC-192)	9,953	18,432,000	9,287,441	4,661,789	2,335,438	1,168,858	935,269	788,729
ATM (OC-3)	155	176,603	117,735	58,867	32,109	16,054	13,082	11,037
ATM (OC-12)	622	706,412	470,940	235,468	122,810	64,216	52,578	44,148

Template Version: R2B

RunTime Start Data Set ID: 1

RunTime End Data Set ID: 2147483647

RR Template Saved Timestamp: Thu Sep 01 14:37:05.565 PDT 2011

A.5 RFC 2889 Forward Pressure Test Results Report

Spirent TestCenter Report

Test Type:	RFC2889 Forward Pressure
Counter Mode:	Interarrivaltime
Test Date:	2022-08-02 14:06:55 CEST

Page 1

Test Summary by Trial and Frame Size

Trial	Frame Size	Forward Pressure	Intended Load (%)	Offered Load (%)	Offered Load (fps)	Forwarding Rate (fps)	Frame Loss (%)	Frames Lost	Tx Frame Count	Rx Frame Count	Other Frames	Expected Frames	Flood Count
1	64	FALSE	101,205	101,205	150602409,667	72637	99,952	4515887523	4518072290	2184767	0	4518072290	0
1	128	FALSE	100,68	100,68	85034013,6330001	73881	99,913	2548801760	2551020409	2218649	0	2551020409	0
1	256	FALSE	100,364	100,364	45454545,467	72714	99,84	1361453870	1363636364	2182494	0	1363636364	0
1	512	FALSE	100,188	100,188	23540489,667	71790	99,695	704059024	706214690	2155666	0	706214690	0
1	1024	FALSE	100,096	100,096	11984659,667	68974	99,424	357469700	359539790	2070090	0	359539790	0
1	1280	FALSE	100,077	100,077	9622786,767	68378	99,289	286631568	288683603	2052035	0	288683603	0
1	1518	FALSE	100,065	100,065	8132726,1	67654	99,168	241951346	243981783	2030437	0	243981783	0

Page 2

SPIRENT.

Theoretical Maximum Frame Rates

Media Type	Line Speed (Mbps)	64 Byte	128 Byte	256 Byte	512 Byte	1024 Byte	1280 Byte	1518 Byte
Ethernet	10	14,880	8,445	4,528	2,349	1,197	961	812
Ethernet	100	148,809	84,459	45,289	23,496	11,973	9,615	8,127
Gigabit Ethernet	1,000	1,488,095	844,594	452,898	234,962	119,731	96,153	81,274
2.5 Gigabit Ethernet	2,500	3,720,238	2,111,486	1,132,246	587,406	299,329	240,384	202,922
5 Gigabit Ethernet	5,000	7,440,476	4,222,972	2,264,492	1,174,812	598,659	480,769	406,371
10 Gigabit Ethernet	10,000	14,880,952	8,445,945	4,528,985	2,349,624	1,197,318	961,538	812,743
25 Gigabit Ethernet	25,000	37,202,380	21,114,864	11,322,463	5,874,060	2,993,295	2,403,846	2,029,220
40 Gigabit Ethernet	40,000	59,523,809	33,783,783	18,115,942	9,398,496	4,789,272	3,846,153	3,250,975
50 Gigabit Ethernet	50,000	74,404,761	42,229,729	22,644,927	11,748,120	5,986,590	4,807,692	4,063,719
100 Gigabit Ethernet	100,000	148,809,523	84,459,459	45,289,855	23,496,240	11,973,180	9,615,384	8,127,438
POS (OC-3)	155	288,000	145,116	72,840	36,491	18,263	14,613	12,323
POS (OC-12)	622	1,152,000	580,465	291,361	145,964	73,053	58,622	49,413
POS (OC-48)	2,448	4,608,000	2,321,860	1,165,447	583,859	292,214	233,817	197,182
POS (OC-192)	9,953	18,432,000	9,287,441	4,661,789	2,335,438	1,168,858	935,269	788,729
ATM (OC-3)	155	176,603	117,735	58,867	32,109	16,054	13,082	11,037
ATM (OC-12)	622	706,412	470,940	235,468	122,810	64,216	52,578	44,148

Template Version: R1D

RunTime Start Data Set ID: 1

RunTime End Data Set ID: 2147483647

RR Template Saved Timestamp: Thu Jan 12 18:42:34.672 PST 2012

TESTED SPIRENT

A.6 RFC 2889 Errored Frames Filtering Test Results Report

Spirent TestCenter Report

Test Type: RFC2889 Errored Frames Filtering

Counter Mode: Basic

Test Date: 2022-08-01 11:06:56 CEST

Page 1

Test Summary by Load

Trial	Error Type	Test Status	Intended Load (%)	Tx Sig FrameCount	Rx Sig Frame Count	Tx Non Sig Frame Count	Rx Non Sig Frame Count	Oversize Frames	Undersize Frames	CRC Error Frames
1	CRC	Passed	10	446428574	0	0	2	0	0	0
1	CRC	Passed	20	892857149	0	0	2	0	0	0
1	CRC	Passed	30	1339285725	0	0	2	0	0	0
1	CRC	Passed	40	1785714293	0	0	2	0	0	0
1	CRC	Passed	50	2232142869	0	0	2	0	0	0
1	Oversize	Passed	10	24303306	0	0	2	0	0	0
1	Oversize	Passed	20	48606611	0	0	2	0	0	0
1	Oversize	Passed	30	72909917	0	0	2	0	0	0
1	Oversize	Passed	40	97213222	0	0	2	0	0	0
1	Oversize	Passed	50	121516528	0	0	2	0	0	0
1	Undersize	Passed	10	451807231	0	0	2	0	0	0
1	Undersize	Passed	20	903614467	0	0	2	0	0	0
1	Undersize	Passed	30	1355421694	0	0	2	0	0	0
1	Undersize	Passed	40	1807228930	0	0	1	0	0	0
1	Undersize	Passed	50	2259036162	0	0	1	0	0	0

Theoretical Maximum Frame Rates

Media Type	Line Speed (Mbps)	64 Byte	128 Byte	256 Byte	512 Byte	1024 Byte	1280 Byte	1518 Byte
Ethernet	10	14,880	8,445	4,528	2,349	1,197	961	812
Ethernet	100	148,809	84,459	45,289	23,496	11,973	9,615	8,127
Gigabit Ethernet	1,000	1,488,095	844,594	452,898	234,962	119,731	96,153	81,274
2.5 Gigabit Ethernet	2,500	3,720,238	2,111,486	1,132,246	587,406	299,329	240,384	202,922
5 Gigabit Ethernet	5,000	7,440,476	4,222,972	2,264,492	1,174,812	598,659	480,769	406,371
10 Gigabit Ethernet	10,000	14,880,952	8,445,945	4,528,985	2,349,624	1,197,318	961,538	812,743
25 Gigabit Ethernet	25,000	37,202,380	21,114,864	11,322,463	5,874,060	2,993,295	2,403,846	2,029,220
40 Gigabit Ethernet	40,000	59,523,809	33,783,783	18,115,942	9,398,496	4,789,272	3,846,153	3,250,975
50 Gigabit Ethernet	50,000	74,404,761	42,229,729	22,644,927	11,748,120	5,986,590	4,807,692	4,063,719
100 Gigabit Ethernet	100,000	148,809,523	84,459,459	45,289,855	23,496,240	11,973,180	9,615,384	8,127,438
POS (OC-3)	155	288,000	145,116	72,840	36,491	18,263	14,613	12,323
POS (OC-12)	622	1,152,000	580,465	291,361	145,964	73,053	58,622	49,413
POS (OC-48)	2,448	4,608,000	2,321,860	1,165,447	583,859	292,214	233,817	197,182
POS (OC-192)	9,953	18,432,000	9,287,441	4,661,789	2,335,438	1,168,858	935,269	788,729
ATM (OC-3)	155	176,603	117,735	58,867	32,109	16,054	13,082	11,037
ATM (OC-12)	622	706,412	470,940	235,468	122,810	64,216	52,578	44,148

Test Configuration

Template Version: R1A

RunTime Start Data Set ID: 1

RunTime End Data Set ID: 2147483647

Test Error Type	Enabled/ Disabled	Frame Size
CRC	Enabled	64
Undersized	Enabled	63
Oversized	Enabled	1523

RR Template Saved Timestamp: Thu Sep 01 19:21:11.175 PDT 2011

A.7 RFC 2544 Latency Test Results Report

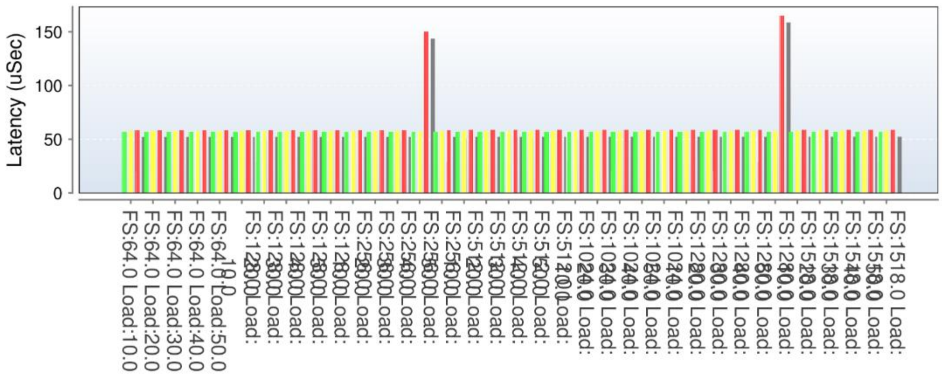
SPIRENT

Spirent TestCenter Report

Test Type:	RFC2544 Latency Test
Counter Mode:	Histogram
Test Date:	2022-09-15 15:53:24 CEST

Page 1

Latency by Frame Size and Load

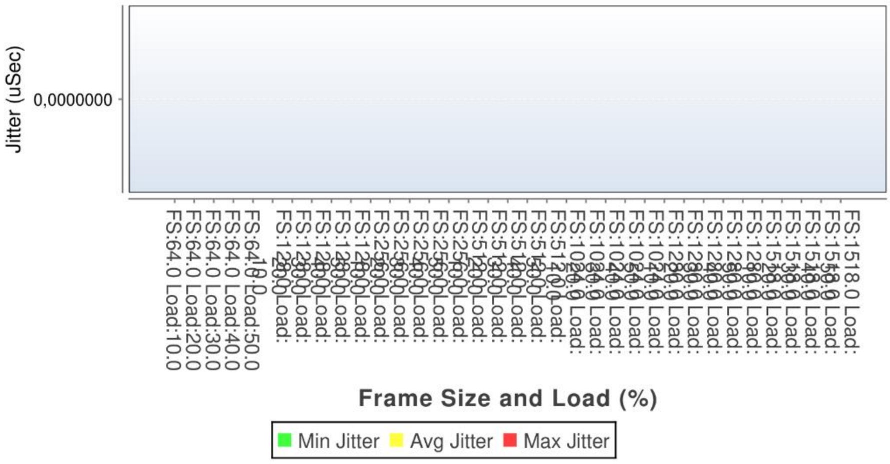


Frame Size (bytes)	Load (%)	Min Latency (uSec)	Avg Latency (uSec)	Max Latency (uSec)	Latency Type
64	10	56,84	57,633	58,433	LILO
64	20	56,84	57,633	58,433	LILO
64	30	56,84	57,633	58,433	LILO
64	40	56,84	57,633	58,435	LILO
64	50	56,84	57,633	58,433	LILO
128	10	56,84	57,634	58,433	LILO
128	20	56,84	57,634	58,435	LILO
128	30	56,84	57,635	58,445	LILO
128	40	56,84	57,634	58,443	LILO
128	50	56,845	57,635	58,44	LILO
256	10	56,868	57,661	58,46	LILO
256	20	56,868	57,661	58,46	LILO
256	30	56,868	57,661	58,46	LILO
256	40	56,868	57,661	149,898	LILO
256	50	56,868	57,662	58,46	LILO
512	10	56,883	57,674	58,473	LILO
512	20	56,883	57,674	58,473	LILO
512	30	56,883	57,674	58,473	LILO
512	40	56,883	57,675	58,473	LILO
512	50	56,883	57,675	58,475	LILO
1024	10	56,908	57,698	58,498	LILO
1024	20	56,905	57,699	58,498	LILO
1024	30	56,908	57,699	58,498	LILO
1024	40	56,908	57,7	58,5	LILO
1024	50	56,908	57,699	58,498	LILO
1280	10	56,92	57,711	58,51	LILO
1280	20	56,918	57,711	58,51	LILO
1280	30	56,918	57,711	58,51	LILO
1280	40	56,918	57,712	58,51	LILO
1280	50	56,918	57,712	164,975	LILO
1518	10	56,933	57,724	58,523	LILO
1518	20	56,933	57,724	58,523	LILO
1518	30	56,933	57,724	58,523	LILO
1518	40	56,933	57,725	58,525	LILO
1518	50	56,933	57,725	58,525	LILO

Page 2

Note: Jitter measurements are only available when the test is run in the 'Jitter' mode.

Jitter by Frame Size and Load



Frame Size (bytes)	Load (%)	Frame Loss (%)	Min Jitter (uSec)	Avg Jitter (uSec)	Max Jitter (uSec)
64	10	0	0	0	0
64	20	0	0	0	0
64	30	0	0	0	0
64	40	0	0	0	0
64	50	0	0	0	0
128	10	0	0	0	0
128	20	0	0	0	0
128	30	0	0	0	0
128	40	0	0	0	0
128	50	0	0	0	0
256	10	0	0	0	0
256	20	0	0	0	0
256	30	0	0	0	0
256	40	0	0	0	0
256	50	0	0	0	0
512	10	0	0	0	0
512	20	0	0	0	0
512	30	0	0	0	0
512	40	0	0	0	0
512	50	0	0	0	0
1024	10	0	0	0	0
1024	20	0	0	0	0
1024	30	0	0	0	0
1024	40	0	0	0	0
1024	50	0	0	0	0
1280	10	0	0	0	0
1280	20	0	0	0	0
1280	30	0	0	0	0
1280	40	0	0	0	0
1280	50	0	0	0	0
1518	10	0	0	0	0
1518	20	0	0	0	0
1518	30	0	0	0	0
1518	40	0	0	0	0
1518	50	0	0	0	0

Latency by Load

Trial	Frame Size (bytes)	Load (%)	Min Latency (uSec)	Avg Latency (uSec)	Max Latency (uSec)	Min Jitter (uSec)	Avg Jitter (uSec)	Max Jitter (uSec)	Tx Frames	Rx Frames
1	64	10	56,84	57,633	58,433	0	0	0	3571428578	3571428578
1	64	20	56,84	57,633	58,433	0	0	0	7142857157	7142857155
1	64	30	56,84	57,633	58,433	0	0	0	10714285738	10714285738
1	64	40	56,84	57,633	58,435	0	0	0	14285714304	14285714300
1	64	50	56,84	57,633	58,433	0	0	0	17857142895	17857142892
1	128	10	56,84	57,634	58,433	0	0	0	2027027032	2027027032
1	128	20	56,84	57,634	58,435	0	0	0	4054054064	4054054064
1	128	30	56,84	57,635	58,445	0	0	0	6081081094	6081081093
1	128	40	56,84	57,634	58,443	0	0	0	8108108123	8108108122
1	128	50	56,845	57,635	58,44	0	0	0	10135135150	10135135138
1	256	10	56,868	57,661	58,46	0	0	0	1086956526	1086956526
1	256	20	56,868	57,661	58,46	0	0	0	2173913048	2173913048
1	256	30	56,868	57,661	58,46	0	0	0	3260869573	3260869573
1	256	40	56,868	57,661	149,898	0	0	0	4347826096	4347824947
1	256	50	56,868	57,662	58,46	0	0	0	5434782619	5434782611
1	512	10	56,883	57,674	58,473	0	0	0	563909777	563909777
1	512	20	56,883	57,674	58,473	0	0	0	1127819553	1127819553
1	512	30	56,883	57,674	58,473	0	0	0	1691729328	1691729328
1	512	40	56,883	57,675	58,473	0	0	0	2255639103	2255639101
1	512	50	56,883	57,675	58,475	0	0	0	2819548880	2819548872
1	1024	10	56,908	57,698	58,498	0	0	0	287356324	287356324
1	1024	20	56,905	57,699	58,498	0	0	0	574712646	574712646
1	1024	30	56,908	57,699	58,498	0	0	0	862068970	862068969
1	1024	40	56,908	57,7	58,5	0	0	0	1149425291	1149425290
1	1024	50	56,908	57,699	58,498	0	0	0	1436781613	1436781604
1	1280	10	56,92	57,711	58,51	0	0	0	230769232	230769232
1	1280	20	56,918	57,711	58,51	0	0	0	461538464	461538464
1	1280	30	56,918	57,711	58,51	0	0	0	692307696	692307695
1	1280	40	56,918	57,712	58,51	0	0	0	923076926	923076922
1	1280	50	56,918	57,712	164,975	0	0	0	1153846158	1153846153
1	1518	10	56,933	57,724	58,523	0	0	0	195058520	195058520
1	1518	20	56,933	57,724	58,523	0	0	0	390117038	390117038
1	1518	30	56,933	57,724	58,523	0	0	0	585175556	585175556
1	1518	40	56,933	57,725	58,525	0	0	0	780234074	780234073
1	1518	50	56,933	57,725	58,525	0	0	0	975292591	975292587

Frame sizes for iMIX Distributions

Note: Imix Distributions are only available for the 'iMIX' Frame Size Type

iMIX Distribution	Frame Length Mode	IP Total Length	Default Ethernet	POS Length	Weight	Percentage (%)

Theoretical Maximum Frame Rates

Media Type	Line Speed (Mbps)	64 Byte	128 Byte	256 Byte	512 Byte	1024 Byte	1280 Byte	1518 Byte
Ethernet	10	14,880	8,445	4,528	2,349	1,197	961	812
Ethernet	100	148,809	84,459	45,289	23,496	11,973	9,615	8,127
Gigabit Ethernet	1,000	1,488,095	844,594	452,898	234,962	119,731	96,153	81,274
2.5 Gigabit Ethernet	2,500	3,720,238	2,111,486	1,132,246	587,406	299,329	240,384	202,922
5 Gigabit Ethernet	5,000	7,440,476	4,222,972	2,264,492	1,174,812	598,659	480,769	406,371
10 Gigabit Ethernet	10,000	14,880,952	8,445,945	4,528,985	2,349,624	1,197,318	961,538	812,743
25 Gigabit Ethernet	25,000	37,202,380	21,114,864	11,322,463	5,874,060	2,993,295	2,403,846	2,029,220
40 Gigabit Ethernet	40,000	59,523,809	33,783,783	18,115,942	9,398,496	4,789,272	3,846,153	3,250,975
50 Gigabit Ethernet	50,000	74,404,761	42,229,729	22,644,927	11,748,120	5,986,590	4,807,692	4,063,719
100 Gigabit Ethernet	100,000	148,809,523	84,459,459	45,289,855	23,496,240	11,973,180	9,615,384	8,127,438
POS (OC-3)	155	288,000	145,116	72,840	36,491	18,263	14,613	12,323
POS (OC-12)	622	1,152,000	580,465	291,361	145,964	73,053	58,622	49,413
POS (OC-48)	2,448	4,608,000	2,321,860	1,165,447	583,859	292,214	233,817	197,182
POS (OC-192)	9,953	18,432,000	9,287,441	4,661,789	2,335,438	1,168,858	935,269	788,729
ATM (OC-3)	155	176,603	117,735	58,867	32,109	16,054	13,082	11,037
ATM (OC-12)	622	706,412	470,940	235,468	122,810	64,216	52,578	44,148

Template Version: R2C

RunTime Start Data Set ID: 1

RunTime End Data Set ID: 2147483647

RR Template Saved Timestamp: Wed Aug 31 18:26:30.263 PDT 2011

A.8 RFC 2889 Broadcast Frame Forwarding Test Results Report

SPIRENT

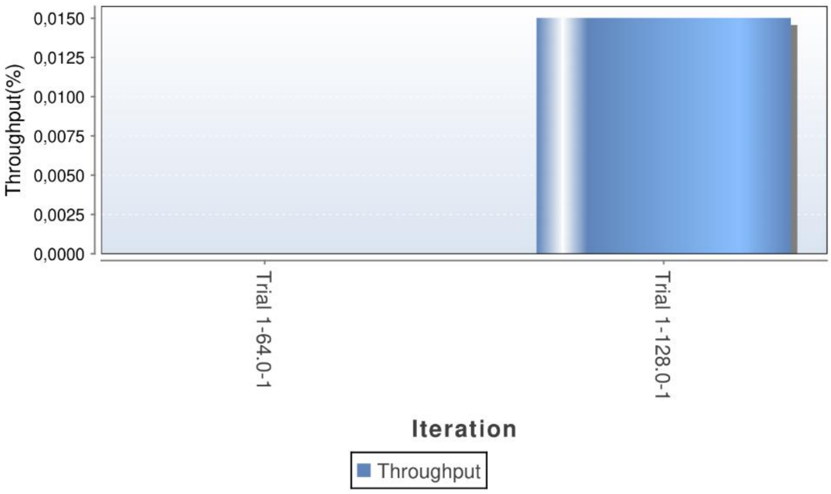
Spirent TestCenter Report

Test Type:	RFC2889 Broadcast Frame Forwarding
Counter Mode:	Interarrivaltime
Test Date:	2022-09-15 09:46:15 CEST

TESTED SPIRENT

Page 1

Broadcast Frame Forwarding Summary Results



Trial	Frame Size (bytes)	Burst Size	Throughput (%)	Intended Load (%)	Offered Load (%)	Result	Forwarding Rate (fps)
1	64	1	0	0,01	0,01	Failed	14812
1	128	1	0,015	0,015	0,015	Passed	13081

Page 2

Test Summary by Trial

Trial	Frame Size (bytes)	Burst Size	Intended Load (%)	Offered Load (%)	Offered Load (fps)	Forwarding Rate (fps)	Tx Frame Count	Rx Frame Count	Frame Loss	Other Frames	Frame Loss (%)
1	64	1	0,01	0,01	14880,967	14812,53	446429	444372	2057	0	0,460767557663145
1	128	1	0,01	0,01	8445,967	8445,35	253379	253379	0	0	0
1	128	1	5,005	5,005	4227195,967	17616,65	126815879	529331	126286548	0	99,5825988005808
1	128	1	2,508	2,508	2117820,967	17867,4	63534629	536988	62997641	0	99,1548105207319
1	128	1	1,259	1,259	1063133,467	17681,58	31894004	531294	31362710	0	98,3341884574919
1	128	1	0,634	0,634	535789,7	17631,03	16073691	530058	15543633	0	96,7023255579568
1	128	1	0,322	0,322	272118,267	16995,56	8163548	510332	7653216	0	93,7486494842684
1	128	1	0,166	0,166	140282,1	16998,24	4208463	510443	3698020	0	87,871035102364
1	128	1	0,088	0,088	74364,033	16767,04	2230921	503581	1727340	0	77,4272150380941
1	128	1	0,049	0,049	41404,567	17181,36	1242137	515908	726229	0	58,4660951247729
1	128	1	0,03	0,03	24925,7	17819,25	747771	535034	212737	0	28,4494852033577
1	128	1	0,02	0,02	16685,833	16185,8	500575	485646	14929	0	2,98237027418469
1	128	1	0,015	0,015	12565,9	12564,17	376977	376977	0	0	0
1	128	1	0,017	0,017	14625,867	14573,03	438776	437188	1588	0	0,361915875070651
1	128	1	0,016	0,016	13596,3	13595,82	407889	407871	18	0	0,00441296529202798
1	128	1	0,015	0,015	13081,1	13081,21	392433	392433	0	0	0
1	256	1	0,01	0,01	4529	4529,01	135870	135870	0	0	0

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[RFC2285]	RFC 2285 “Benchmarking Terminology for LAN Switching Devices” https://www.rfc-editor.org/rfc/rfc2285.html
[RFC2544]	RFC 2544 “Benchmarking Methodology for Network Interconnect Devices” https://www.rfc-editor.org/rfc/rfc2544.html
[RFC2889]	RFC 2889 “Benchmarking Methodology for LAN Switching Devices” https://www.rfc-editor.org/rfc/rfc2889.html
[SpirentTC]	https://www.spirent.com/products/testcenter-ethernet-ip-cloud-test
[TRex]	TRex Realistic Traffic Generator https://trex-tgn.cisco.com/
[Wedge]	https://www.edge-core.com/productsInfo.php?id=335

Glossary

ACL	Access Control List
B	Byte
BGP	Border Gateway Protocol
CFP	C Form-factor Pluggable
CPE	Customer Premise Equipment
CRC	Cyclic Redundancy Check
DC	Data Centre
DDoS	Distributed Denial of Service
DUT	Device Under Test
EBGP	External Border Gateway Protocol
FIFO	First In, First Out
FPS	Frames Per Second
HOLB	Head of Line Blocking
IEEE	Institute of Electrical and Electronics Engineers
IFG	Interframe Gap
Iload	Intended load
IP	Internet Protocol
ISP	Internet Service Provider
IX	Internet Exchange
L*n*	Layer *n*
LACP	Link Aggregation Control Protocol
LAG	Link Aggregation Group
LILO	Last In, Last Out
MAC	Media Access Control
MOL	Maximum offered load
NOS	Network Operating System
NREN	National Research and Education Network
Oload	Offered load
OS	Operating System
OSI	Open Systems Interconnection
PPN	Private Peering Node
QSFP	Quad Small Form-factor Pluggable
RARE	Router for Academia, Research and Education
RFC	Request for Comments
Rx	Recevied
SUT	System Under Test
TRex	Realistic Traffic Generator
Tx	Transmitted
VLAN	Virtual Local Area Network
WB	White Box