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Considerations for Benchmarking Network Virtualization Platforms  
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## Abstract

Current network benchmarking methodologies are focused on physical networking components and do not consider the actual application layer traffic patterns and hence do not reflect the traffic that virtual networking components work with. The purpose of this document is to distinguish and highlight benchmarking considerations when testing and evaluating virtual networking components in the data center.

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## 1. Introduction

Datacenter virtualization that includes both compute and network virtualization is growing rapidly as the industry continues to look for ways to improve productivity, flexibility and at the same time cut costs. Network virtualization, is comparatively new and expected to grow tremendously similar to compute virtualization. There are multiple vendors and solutions out in the market, each with their own benchmarks to showcase why a particular solution is better than another. Hence, the need for a vendor and product agnostic way to benchmark multivendor solutions to help with comparison and make informed decisions when it comes to selecting the right network virtualization solution.

Applications traditionally have been segmented using VLANs and ACLs between the VLANs. This model does not scale because of the 4K scale limitations of VLANs. Overlays such as VXLAN were designed to address the limitations of VLANs

With VXLAN, applications are segmented based on VXLAN encapsulation (specifically the VNI field in the VXLAN header), which is similar to VLAN ID in the 802.1Q VLAN tag, however without the 4K scale limitations of VLANs. For a more detailed discussion on this subject please refer RFC 7364 "Problem Statement: Overlays for Network Virtualization".

VXLAN is just one of several Network Virtualization Overlays(NVO). Some of the others include STT, Geneve and NVGRE. . STT and Geneve have expanded on the capabilities of VXLAN. Please refer IETF's nvo3 working group <<https://datatracker.ietf.org/wg/nvo3/documents/>> for more information.

Modern application architectures, such as Micro-services, are going beyond the three tier app models such as web, app and db. Benchmarks MUST consider whether the proposed solution is able to scale up to the demands of such applications and not just a three-tier architecture.

## 2. Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

In this document, these words will appear with that interpretation only when in ALL CAPS. Lower case uses of these words are not to be interpreted as carrying significance described in RFC 2119.

## 3. Definitions

### 3.1. System Under Test (SUT)

Traditional hardware based networking devices generally use the device under test (DUT) model of testing. In this model, apart from any allowed configuration, the DUT is a black box from a testing perspective. This method works for hardware based networking devices since the device itself is not influenced by any other components outside the DUT.

Virtual networking components cannot leverage DUT model of testing as the DUT is not just the virtual device but includes the hardware components that were used to host the virtual device

Hence SUT model MUST be used instead of the traditional device under test

With SUT model, the virtual networking component along with all software and hardware components that host the virtual networking component MUST be considered as part of the SUT.

Virtual networking components may also work with higher level TCP segments such as TSO. In contrast, all physical switches and routers, including the ones that act as initiators for NVOs, work with L2/L3 packets.

Please refer to section 5 Figure 1 for a visual representation of System Under Test in the case of Intra-Host testing and section 5 Figure 2 for System Under Test in the case of Inter-Host testing

### 3.2. Network Virtualization Platform

This document does not focus on Network Function Virtualization.

Network Function Virtualization focuses on being independent of networking hardware while providing the same functionality. In the case of NFV, traditional benchmarking methodologies recommended by IETF may be used. Considerations for Benchmarking Virtual Network Functions and Their Infrastructure IETF document addresses benchmarking NFVs.

Network Virtualization Platforms, apart from providing hardware agnostic network functions, also leverage performance optimizations provided by the TCP stacks of hypervisors.

Network Virtualization Platforms are architected differently when compared to NFV and are not limited by packet size constraints via MTU that exist for both NFV and Hardware based network platforms.

NVPs leverage TCP stack optimizations such as TSO that enables NVPs to work with much larger payloads of 64K unlike their counterparts such as NFVs.

Because of the difference in the payload and thus the overall segment sizes, normal benchmarking methods are not relevant to the NVPs.

Instead, newer methods that take into account the built in advantages of TCP provided optimizations MUST be used for testing Network Virtualization Platforms.

### 3.3. Micro-services

Traditional monolithic application architectures such as the three tier web, app and db architectures are hitting scale and deployment limits for the modern use cases.

Micro-services make use of classic unix style of small app with single responsibility.

These small apps are designed with the following characteristics:

- . Each application only does one thing - like unix tools
- . Small enough that you could rewrite instead of maintain
- . Embedded with a simple web container
- . Packaged as a single executable
- . Installed as daemons
- . Each of these applications are completely separate
- . Interact via uniform interface
  - . REST (over HTTP/HTTPS) being the most common

With Micro-services architecture, a single web app of the three tier application model could now have 100s of smaller apps dedicated to do just one job.

These 100s of small one responsibility only services will MUST be secured into their own segment - hence pushing the scale boundaries of the overlay from both simple segmentation perspective and also from a security perspective

## 4. Scope

This document does not address Network Function Virtualization has been covered already by previous IETF documents ([https://datatracker.ietf.org/doc/draft-ietf-bmwg-virtual-net/?include\\_text=1](https://datatracker.ietf.org/doc/draft-ietf-bmwg-virtual-net/?include_text=1)) the focus of this document is Network Virtualization Platform where the network functions are an intrinsic part of the hypervisor's TCP stack, working closer to the application layer and leveraging performance optimizations such TSO/RSS provided by the TCP stack and the underlying hardware.

#### 4.1. Virtual Networking for Datacenter Applications

While virtualization is growing beyond the datacenter, this document focuses on the virtual networking for east-west traffic within the datacenter applications only. For example, in a three tier app such web, app and db, this document focuses on the east-west traffic between web and app. It does not address north-south web traffic accessed from outside the datacenter. A future document would address north-south traffic flows.

This document addresses scale requirements for modern application architectures such as Micro-services to consider whether the proposed solution is able to scale up to the demands of micro-services application models that basically have 100s of small services communicating on some standard ports such as http/https using protocols such as REST

#### 4.2. Interaction with Physical Devices

Virtual network components cannot be tested independent of other components within the system. Example, unlike a physical router or a firewall, where the tests can be focused directly solely on the device, when testing a virtual router or firewall, multiple other devices may become part of the system under test. Hence the characteristics of these other traditional networking switches and routers, LB, FW etc. MUST be considered.

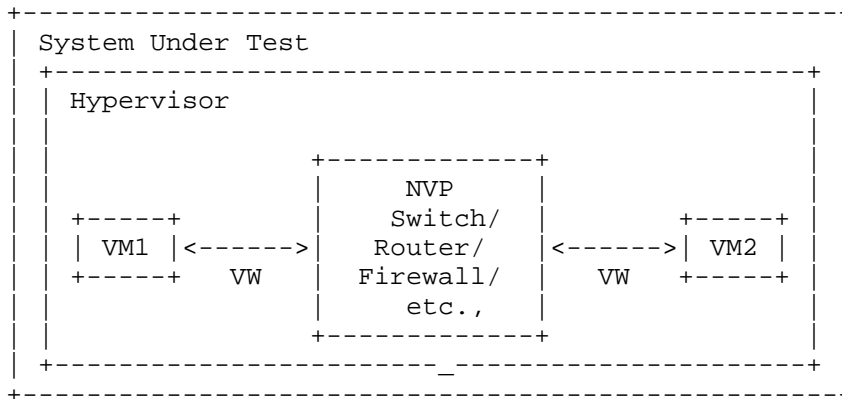
- . Hashing method used
- . Over-subscription rate
- . Throughput available
- . Latency characteristics

#### 5. Interaction with Physical Devices

In virtual environments, System Under Test (SUT) may often share resources and reside on the same Physical hardware with other components involved in the tests. Hence SUT MUST be clearly defined. In this tests, a single hypervisor may host multiple servers, switches, routers, firewalls etc.,

Intra host testing: Intra host testing helps in reducing the number of components involved in a test. For example, intra host testing would help focus on the System Under Test, logical switch and the hardware that is running the hypervisor that hosts the logical switch, and eliminate other components. Because of the nature of virtual infrastructures and multiple elements being hosted on the

same physical infrastructure, influence from other components cannot be completely ruled out. For example, unlike in physical infrastructures, logical routing or distributed firewall MUST NOT be benchmarked independent of logical switching. System Under Test definition MUST include all components involved with that particular test.



Legend

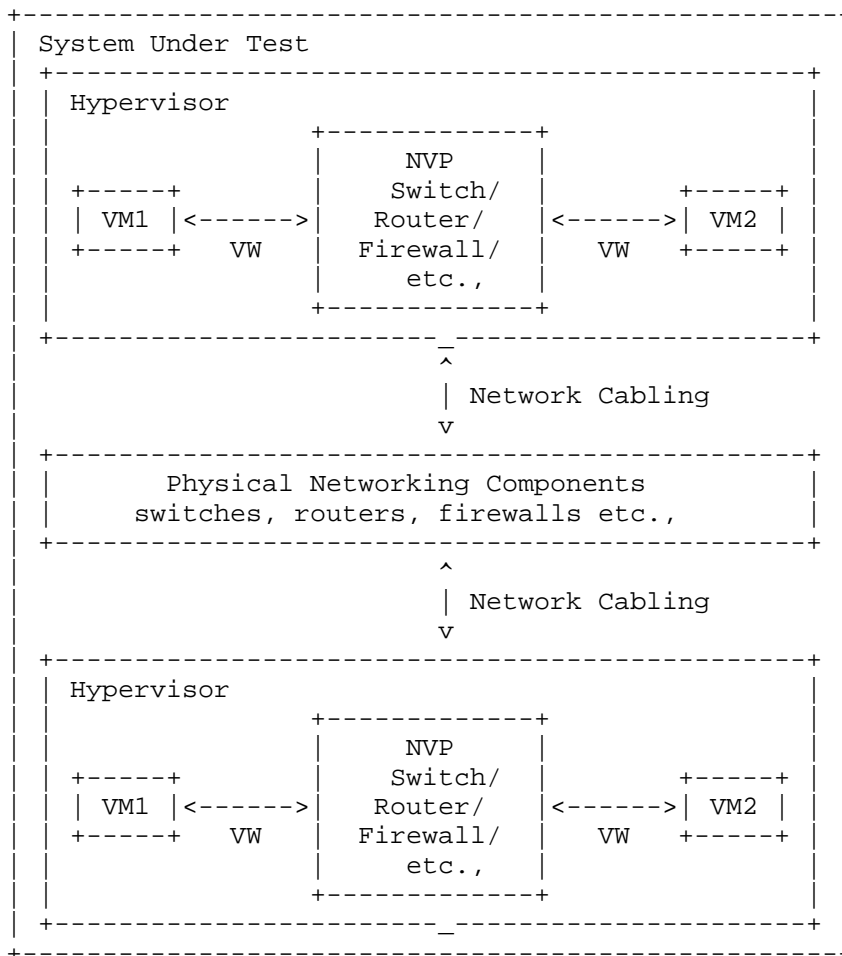
VM: Virtual Machine

VW: Virtual Wire

Figure 1 Intra-Host System Under Test

Inter host testing: Inter host testing helps in profiling the underlying network interconnect performance. For example, when testing Logical Switching, inter host testing would not only test the logical switch component but also any other devices that are part of the physical data center fabric that connects the two hypervisors. System Under Test MUST be well defined to help with repeatability of tests. System Under Test definition in the case of inter host testing, MUST include all components, including the underlying network fabric.

Figure 2 is a visual representation of system under test for inter-host testing



Legend

VM: Virtual Machine

VW: Virtual Wire

Figure 2 Inter-Host System Under Test

Virtual components have a direct dependency on the physical infrastructure that is hosting these resources. Hardware characteristics of the physical host impact the performance of the virtual components. The components that are being tested and the impact of the other hardware components within the hypervisor on the performance of the SUT MUST be documented. Virtual component performance is influenced by the physical hardware components within

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the hypervisor. Access to various offloads such as TCP segmentation offload, may have significant impact on performance. Firmware and driver differences may also significantly impact results based on whether the specific driver leverages any hardware level offloads offered. Hence, all physical components of the physical server running the hypervisor that hosts the virtual components MUST be documented along with the firmware and driver versions of all the components used to help ensure repeatability of test results. For example, BIOS configuration of the server MUST be documented as some of those changes are designed to improve performance. Please refer to Appendix A for a partial list of parameters to document.

### 5.1. Server Architecture Considerations

When testing physical networking components, the approach taken is to consider the device as a black-box. With virtual infrastructure, this approach would no longer help as the virtual networking components are an intrinsic part of the hypervisor they are running on and are directly impacted by the server architecture used. Server hardware components define the capabilities of the virtual networking components. Hence, server architecture MUST be documented in detail to help with repeatability of tests. And the entire hardware and software components become the SUT.

#### 5.1.1. Frame format/sizes within the Hypervisor

Maximum Transmission Unit (MTU) limits physical network component's frame sizes. The most common max supported MTU for physical devices is 9000. However, 1500 MTU is the standard. Physical network testing and NFV uses these MTU sizes for testing. However, the virtual networking components that live inside a hypervisor, may work with much larger segments because of the availability of hardware and software based offloads. Hence, the normal smaller packets based testing is not relevant for performance testing of virtual networking components. All the TCP related configuration such as TSO size, number of RSS queues MUST be documented along with any other physical NIC related configuration.

Virtual network components work closer to the application layer than the physical networking components. Hence virtual network components work with type and size of segments that are often not the same type and size that the physical network works with. Hence, testing virtual network components MUST be done with application layer segments instead of the physical network layer packets.

#### 5.1.2. Baseline testing with Logical Switch

Logical switch is often an intrinsic component of the test system along with any other hardware and software components used for

testing. Also, other logical components cannot be tested independent of the Logical Switch.

#### 5.1.3. Tunnel encap/decap outside the hypervisor

Logical network components may also have performance impact based on the functionality available within the physical fabric. Physical fabric that supports NVO encap/decap is one such case that has considerable impact on the performance. Any such functionality that exists on the physical fabric MUST be part of the test result documentation to ensure repeatability of tests. In this case SUT MUST include the physical fabric

#### 5.1.4. SUT Hypervisor Profile

Physical networking equipment has well defined physical resource characteristics such as type and number of ASICs/SoCs used, amount of memory, type and number of processors etc., Virtual networking components' performance is dependent on the physical hardware that hosts the hypervisor. Hence the physical hardware usage, which is part of SUT, for a given test MUST be documented. Example, CPU usage when running logical router.

CPU usage changes based on the type of hardware available within the physical server. For example, TCP Segmentation Offload greatly reduces CPU usage by offloading the segmentation process to the NIC card on the sender side. Receive side scaling offers similar benefit on the receive side. Hence, availability and status of such hardware MUST be documented along with actual CPU/Memory usage when the virtual networking components have access to such offload capable hardware.

Following is a partial list of components that MUST be documented - both in terms of what's available and also what's used by the SUT -

- . CPU - type, speed, available instruction sets (e.g. AES-NI)
- . Memory - type, amount
- . Storage - type, amount
- . NIC Cards - type, number of ports, offloads available/used, drivers, firmware (if applicable), HW revision
- . Libraries such as DPDK if available and used
- . Number and type of VMs used for testing and

- o vCPUs

- o RAM
- o Storage
- o Network Driver
- o Any prioritization of VM resources
- o Operating System type, version and kernel if applicable
- o TCP Configuration Changes - if any
- o MTU
- . Test tool
  - o Workload type
  - o Protocol being tested
  - o Number of threads
  - o Version of tool
- . For inter-hypervisor tests,
  - o Physical network devices that are part of the test
    - . Note: For inter-hypervisor tests, system under test is no longer only the virtual component that is being tested but the entire fabric that connects the virtual components become part of the system under test.

## 6. Security Considerations

Benchmarking activities as described in this memo are limited to technology characterization of a Device Under Test/System Under Test (DUT/SUT) using controlled stimuli in a laboratory environment, with dedicated address space and the constraints specified in the sections above.

The benchmarking network topology will be an independent test setup and MUST NOT be connected to devices that may forward the test traffic into a production network, or misroute traffic to the test management network.

Further, benchmarking is performed on a "black-box" basis, relying solely on measurements observable external to the DUT/SUT.

Special capabilities SHOULD NOT exist in the DUT/SUT specifically for benchmarking purposes. Any implications for network security arising from the DUT/SUT SHOULD be identical in the lab and in production networks.

## 7. IANA Considerations

No IANA Action is requested at this time.

## 8. Conclusions

Network Virtualization Platforms, because of their proximity to the application layer and since they can take advantage of TCP stack optimizations, do not function on packets/sec basis. Hence, traditional benchmarking methods, while still relevant for Network Function Virtualization, are not designed to test Network Virtualization Platforms. Also, advances in application architectures such as micro-services, bring new challenges and need benchmarking not just around throughput and latency but also around scale. New benchmarking methods that are designed to take advantage of the TCP optimizations or needed to accurately benchmark performance of the Network Virtualization Platforms

## 9. References

### 9.1. Normative References

[RFC7364] T. Narten, E. Gray, D. Black, L. Fang, L. Kreeger, M. Napierala, "Problem Statement: Overlays for Network Virtualization", RFC 7364, October 2014, <https://datatracker.ietf.org/doc/rfc7364/>

[nv03] IETF, WG, Network Virtualization Overlays, <  
<https://datatracker.ietf.org/wg/nv03/documents/>>

### 9.2. Informative References

[1] A. Morton " Considerations for Benchmarking Virtual Network Functions and Their Infrastructure", draft-ietf-bmwg-virtual-net-03, < [https://datatracker.ietf.org/doc/draft-ietf-bmwg-virtual-net/?include\\_text=1](https://datatracker.ietf.org/doc/draft-ietf-bmwg-virtual-net/?include_text=1)>

Appendix A.

Partial List of Parameters to Document

A.1. CPU

CPU Vendor

CPU Number

CPU Architecture

# of Sockets (CPUs)

# of Cores

Clock Speed (GHz)

Max Turbo Freq. (GHz)

Cache per CPU (MB)

# of Memory Channels

Chipset

Hyperthreading (BIOS Setting)

Power Management (BIOS Setting)

VT-d

A.2. Memory

Memory Speed (MHz)

DIMM Capacity (GB)

# of DIMMs

DIMM configuration

Total DRAM (GB)

A.3. NIC

Vendor

Model

Port Speed (Gbps)

Ports

PCIe Version

PCIe Lanes

Bonded

Bonding Driver

Kernel Module Name

Driver Version

VXLAN TSO Capable

VXLAN RSS Capable

Ring Buffer Size RX

Ring Buffer Size TX

#### A.4. Hypervisor

Hypervisor Name

Version/Build

Based on

Hotfixes/Patches

OVS Version/Build

IRQ balancing

vCPUs per VM

Modifications to HV

Modifications to HV TCP stack

Number of VMs

IP MTU

Flow control TX (send pause)

Flow control RX (honor pause)

Encapsulation Type

A.5. Guest VM

Guest OS & Version

Modifications to VM

IP MTU Guest VM (Bytes)

Test tool used

Number of NetPerf Instances

Total Number of Streams

Guest RAM (GB)

A.6. Overlay Network Physical Fabric

Vendor

Model

# and Type of Ports

Software Release

Interface Configuration

Interface/Ethernet MTU (Bytes)

Flow control TX (send pause)

Flow control RX (honor pause)

A.7. Gateway Network Physical Fabric

Vendor

Model

# and Type of Ports

Software Release

Interface Configuration

Interface/Ethernet MTU (Bytes)

Flow control TX (send pause)

Flow control RX (honor pause)



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Benchmarking Methodology for Virtualization Network Performance  
draft-huang-bmwg-virtual-network-performance-02

Abstract

As the virtual network has been widely established in IDC, the performance of virtual network has become a valuable consideration to the IDC managers. This draft introduces a benchmarking methodology for virtualization network performance based on virtual switch.

Status of This Memo

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## 1. Introduction

As the virtual network has been widely established in IDC, the performance of virtual network has become a valuable consideration to the IDC managers. This draft introduces a benchmarking methodology

for virtualization network performance based on virtual switch as the DUT.

## 2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

## 3. Test Considerations

In a conventional test setup with Non-Virtual test ports, it is quite legitimate to assume that test ports provide the golden standard in measuring the performance metrics. If test results are sub optimal, it is automatically assumed that the Device-Under-Test (DUT) is at fault. For example, when testing throughput at a given frame size, if the test result shows less than 100% throughput, we can safely conclude that it's the DUT that can not deliver line rate forwarding at that frame size(s). We never doubt that the tester can be an issue.

While in a virtual test environment where both the DUT as well as the test tool itself are software based, it's quite a different story. Just like the DUT, tester running as software will have its own performance peak under various conditions.

There are two types of vSwitch according to different installation location. One is VM based vSwitch which is installed on a virtual machine, another is vSwitch directly installed on the host OS (similar to hypervisor).The latter is much more popular currently.

Tester's calibration is essential in benchmarking testing in a virtual environment. Furthermore, to reduce the enormous combination of various conditions, tester must be calibrated with the exact same combination and parameter settings the user wants to measure against the DUT. A slight variation of conditions and parameter values will cause inaccurate measurements of the DUT.

While it is difficult to list the exact combination and parameter settings, the following table attempts to give the most common example how to calibrate a tester before testing a DUT (VSWITCH).

Sample calibration permutation:

Hypervisor Type	VM VNIC Speed	VM Memory CPU Allocation	Frame Size	Throughput
ESXi	1G/10G	512M/1Core	64	
			128	
			256	
			512	
			1024	
			1518	

Figure 1: Sample Calibration Permutation

Key points are as following:

- a) The hypervisor type is of ultimate importance to the test results. VM tester(s) MUST be installed on the same hypervisor type as the DUT (VSWITCH). Different hypervisor type has an influence on the test result.
- b) The VNIC speed will have an impact on testing results. Testers MUST calibrate against all VNIC speeds.
- c) VM allocations of CPU resources and memory have an influence on test results.
- d) Frame sizes will affect the test results dramatically due to the nature of virtual machines.
- e) Other possible extensions of above table: The number of VMs to be created, latency reading, one VNIC per VM vs. multiple VM sharing one VNIC, and uni-directional traffic vs. bi-directional traffic.

Besides, the compute environment including the hardware should be also recorded.

Compute environment componenets	Model
CPU	
Memory	
Hard Disk	
10G Adaptors	
Blade/Motherboard	

Figure 2: Compute Environment

It's important to confirm test environment for tester's calibration as close to the environment a virtual DUT (VSWITCH) involved in for the benchmark test. Key points which SHOULD be noticed in test setup are listed as follows.

1. One or more VM tester(s) need to be created for both traffic generation and analysis.
2. vSwitch has an influence on performance penalty due to extra resource occupation.
3. VNIC and its type is needed in the test setup to once again accommodate performance penalty when DUT (VSWITCH) is created.

In summary, calibration should be done in such an environment that all possible factors which may negatively impact test results should be taken into consideration.

#### 4. Key Performance Indicators

We listed numbers of key performance indicators for virtual network below:

- a) Throughput under various frame sizes: forwarding performance under various frame sizes is a key performance indicator of interest.
- b) DUT consumption of CPU: when adding one or more VM(s), DUT (VSWITCH) will consume more CPU. Vendors can allocate appropriate CPU to reach the line rate performance.

c) DUT consumption of MEM: when adding one or more VM(s), DUT (VSWITCH) will consume more memory. Vendors can allocate appropriate MEM to reach the line rate performance.

d) Latency readings: Some applications are highly sensitive on latency. It's important to get the latency reading with respective to various conditions.

Other indicators such as VxLAN maximum supported by the virtual switch and so on can be added in the scene when VxLAN is needed.

5. Test Setup

The test setup is classified into two traffic models: Model A and Model B.

In traffic model A: A physical tester connects to the server which bears the DUT (VSWITCH) and Virtual tester to verify the benchmark of server.

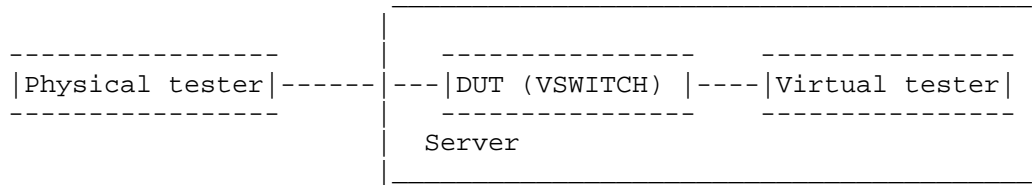


Figure 3: test model A

In traffic model B: Two virtual testers are used to verify the benchmark. In this model, two testers are installed in one server.

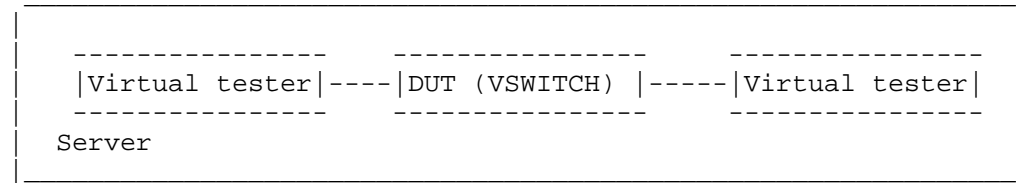


Figure 4: test model B

In our test, the test bed is constituted by physical servers of the Dell with a pair of 10GE NIC and physical tester. Virtual tester which occupies 2 vCPU and 8G MEM and DUT (VSWITCH) are installed in the server. 10GE switch and 1GE switch are used for test traffic and management respectively.



This test setup is also available in the VxLAN measurement.

## 6. Benchmarking Tests

### 6.1. Throughput

Unlike traditional test cases where the DUT and the tester are separated, virtual network test has been brought in unparalleled challenges. In virtual network test, the virtual tester and the DUT (VSWITCH) are in one server which means they are physically converged, so the test and DUT (VSWITCH) are sharing the same CPU and MEM resources of one server. Theoretically, the virtual tester's operation may have influence on the DUT (VSWITCH)'s performance. However, for the specialty of virtualization, this method is the only way to test the performance of a virtual DUT.

Under the background of existing technology, when we test the virtual switch's throughput, the concept of traditional physical switch CANNOT be applicable. The traditional throughput indicates the switches' largest forwarding capability, for certain bytes selected and under zero-packet-lose conditions. But in virtual environments, virtual variations on virtual network will be much greater than that of dedicated physical devices. As the DUT and the tester cannot be separated, it proves that the DUT (VSWITCH) realize such network performances under certain circumstances.

Therefore, we change the bytes in virtual environment to test the maximum value which we think of the indicator of throughput. It's conceivable that the throughput should be tested on both the test model A and B. The tested throughput has certain referential meanings to value the performance of the virtual DUT.

#### 6.1.1. Objectives

The objective of the test is to determine the throughput of the DUT (VSWITCH), which the DUT can support.

#### 6.1.2. Configuration parameters

Network parameters should be defined as follows:

- a) the number of virtual tester (VMs)
- b) the number of vNIC of virtual tester
- c) the CPU type of the server
- d) vCPU allocated for virtual tester (VMs)

e) memory allocated for virtual tester (VMs)

f) the number and rate of server NIC

#### 6.1.3. Test parameters

a) test repeated times

b) test frame length

#### 6.1.4. Test process

1. Configure the VM tester to offer traffic to the V-Switch.
2. Increase the number of vCPU in the tester until the traffic has no packet loss.
3. Record the max throughput on VSwitch.
4. Change the frame length and repeat from step1 to step4.

#### 6.1.5. Test result format

Byte	Throughput (Gbps)
64	
128	
256	
512	
1024	
1518	

Figure 5: test result format

#### 6.2. Frame loss rate

Frame loss rate is also an important indicator in evaluating the performance of virtual switch. As is defined in RFC 1242, percentage of frames that should have been forwarded which actually fails to be forwarded due to lack of resources needs to be tested. Both model A

and model B are tested. Frame loss rate is an important indicator in evaluating the performance of virtual switches.

#### 6.2.1. Objectives

The objective of the test is to determine the frame loss rate under different data rates and frame sizes..

#### 6.2.2. Configuration parameters

Network parameters should be defined as follows:

- a) the number of virtual tester (VMs)
- b) the number of vNIC of virtual tester
- c) the CPU type of the server
- d) vCPU allocated for virtual tester (VMs)
- e) memory allocated for virtual tester (VMs)
- f) the number and rate of server NIC

#### 6.2.3. Test parameters

- a) test repeated times
- b) test frame length
- c) test frame rate

#### 6.2.4. Test process

1. Configure the VM tester to offer traffic to the V-Switch with the input frame changing from the maximum rate to the rate with no frame loss at reducing 10% intervals according to RFC 2544.
2. Record the input frame count and output count on VSwitch.
3. Calculate the frame loss percentage under different frame rate.
4. Change the frame length and repeat from step1 to step4.

## 6.2.5. Test result format

Byte	Maximum rate (Gbps)	90% Maximum rate (Gbps)	80% Maximum rate (Gbps)	...	rate with no loss (Gbps)
64					
128					
256					
512					
1024					
1518					

Figure 6: test result format

## 6.3. CPU consumption

The objective of the test is to determine the CPU load of DUT(VSWITCH). The operation of DUT (VSWITCH) can increase the CPU load of host server. Different V-Switches have different CPU occupation. This can be an important indicator in benchmarking the virtual network performance.

## 6.3.1. Objectives

The objective of this test is to verify the CPU consumption caused by the DUT (VSWITCH).

## 6.3.2. Configuration parameters

Network parameters should be defined as follows:

- a) the number of virtual tester (VMs)
- b) the number of vNIC of virtual tester
- c) the CPU type of the server
- d) vCPU allocated for virtual tester (VMs)
- e) memory allocated for virtual tester (VMs)

f) the number and rate of server NIC

6.3.3. Test parameters

a) test repeated times

b) test frame length

c) traffic rate

6.3.4. Test process

1. Configure the VM tester to offer traffic to the V-Switch with certain traffic rate. The traffic rate could be different ratio of NIC's speed.

2. Record vSwitch's CPU usage on the host OS if no packets loss happens.

3. Change the traffic rate and repeat from step1 to step2.

4. Change the frame length and repeat from step1 to step3.

6.3.5. Test result format

Byte	Traffic Rate(Gbps)	CPU usage of vSwitch
64	50% of NIC speed	
	75%	
	90%	
128	50% of NIC speed	
	75%	
	90%	
~	~	~
1500	50% of NIC speed	
	75%	
	90%	

Figure 7: test result format

#### 6.4. MEM consumption

The objective of the test is to determine the Memory load of DUT(VSWITCH). The operation of DUT (VSWITCH) can increase the Memory load of host server. Different V-Switches have different memory occupation. This can be an important indicator in benchmarking the virtual network performance.

##### 6.4.1. Objectives

The objective of this test is to verify the memory consumption by the DUT (VSWITCH) on the Host server.

##### 6.4.2. Configuration parameters

Network parameters should be defined as follows:

- a) the number of virtual tester (VMs)
- b) the number of vNIC of virtual tester
- c) the CPU type of the server

- d) vCPU allocated for virtual tester (VMs)
- e) memory allocated for virtual tester (VMs)
- f) the number and rate of server NIC

#### 6.4.3. Test parameters

- a) test repeated times
- b) test frame length

#### 6.4.4. Test process

1. Configure the VM tester to offer traffic to the V-Switch with certain traffic rate. The traffic rate could be different ratio of NIC's speed.
2. Record vSwitch's MEM usage on the host OS if no packets loss happens.
3. Change the traffic rate and repeat from step1 to step2.
4. Change the frame length and repeat from step1 to step3.

#### 6.4.5. Test result format

Byte	Traffic Rate(Gbps)	MEM usage of vSwitch
64	50% of NIC speed	
	75%	
	90%	
128	50% of NIC speed	
	75%	
	90%	
~	~	~
1500	50% of NIC speed	
	75%	
	90%	

Figure 8: test result format

### 6.5. Latency

Physical tester's time refers from its own clock or other time source, such as GPS, which can achieve the accuracy of 10ns. While in virtual network circumstances, the virtual tester gets its reference time from the clock of Linux systems. However, due to current methods, the clock of different servers or VMs can't synchronize accuracy. Although VMs of some higher versions of CentOS or Fedora can achieve the accuracy of 1ms, we can get better results if the network can provide better NTP connections.

Instead of finding a better synchronization of clock to improve the accuracy of the test, we consider to use an echo server in order to forward the traffic back to the virtual switch.

We use the traffic model A as the latency test model by substituting the virtual tester with the echo server, which is used to echo the traffic. Thus the one-way delay equals to half of the round-trip time.



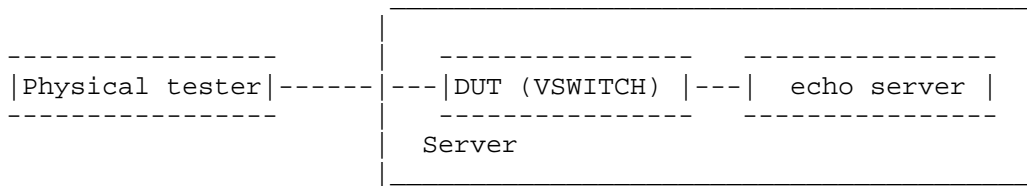


Figure 9: time delay test model

#### 6.5.1. Objectives

The objective of this test is to verify the DUT (VSWITCH) for latency of the flow. This can be an important indicator in benchmarking the virtual network performance.

#### 6.5.2. Configuration parameters

Network parameters should be defined as follows:

- a) the number of virtual tester (VMs)
- b) the number of vNIC of virtual tester
- c) the CPU type of the server
- d) vCPU allocated for virtual tester (VMs)
- e) memory allocated for virtual tester (VMs)
- f) the number and rate of server NIC

#### 6.5.3. Test parameters

- a) test repeated times
- b) test frame length

#### 6.5.4. Test process

1. Configure the physical tester to offer traffic to the V-Switch with the traffic value of throughput tested in 6.1.
2. Under the same throughput, record the time of transmitting the traffic and receiving the traffic by the physical tester with and without the DUT.

3. Calculate the time difference value between receiving and transmitting the traffic..
4. Calculate the time delay with time difference value with and without the DUT.
5. Change the frame length and repeat from step1 to step4.

#### 6.5.5. Test result format

Byte	Latency
64	
128	
256	
512	
1024	
1518	

Figure 10: test result format

#### 7. Security Considerations

None.

#### 8. IANA Considerations

None.

#### 9. Normative References

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Benchmarking Methodology for SDN Controller Performance  
draft-ietf-bmwg-sdn-controller-benchmark-meth-03

Abstract

This document defines the methodologies for benchmarking control plane performance of SDN controllers. Terminology related to benchmarking SDN controllers is described in the companion terminology document. SDN controllers have been implemented with many varying designs in order to achieve their intended network functionality. Hence, the authors have taken the approach of considering an SDN controller as a black box, defining the methodology in a manner that is agnostic to protocols and network services supported by controllers. The intent of this document is to provide a standard mechanism to measure the performance of all controller implementations.

Status of this Memo

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## 1. Introduction

This document provides generic methodologies for benchmarking SDN controller performance. An SDN controller may support many northbound and southbound protocols, implement a wide range of applications, and work solely, or as a group to achieve the desired functionality. This document considers an SDN controller as a black box, regardless of design and implementation. The tests defined in the document can be used to benchmark SDN controller for performance, scalability, reliability and security independent of northbound and southbound protocols. These tests can be performed on an SDN controller running as a virtual machine (VM) instance or on a bare metal server. This document is intended for those who want to measure the SDN controller performance as well as compare various SDN controllers performance.

Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119.

## 2. Scope

3. This document defines methodology to measure the networking metrics of SDN controllers. For the purpose of this memo, the SDN controller is a function that manages and controls Network Devices. Any SDN controller without a control capability is out of scope for this memo. The tests defined in this document enable benchmarking of SDN Controllers in two ways; as a standalone controller and as a cluster of homogeneous controllers. These tests are recommended for execution in lab environments rather than in live network deployments. Performance benchmarking of a federation of controllers is beyond the scope of this document. Test Setup

The tests defined in this document enable measurement of an SDN controllers performance in standalone mode and cluster mode. This section defines common reference topologies that are later referred to in individual tests (Additional forwarding Plane topologies are provided in Appendix A).

3.1. Test setup - Controller working in Standalone Mode

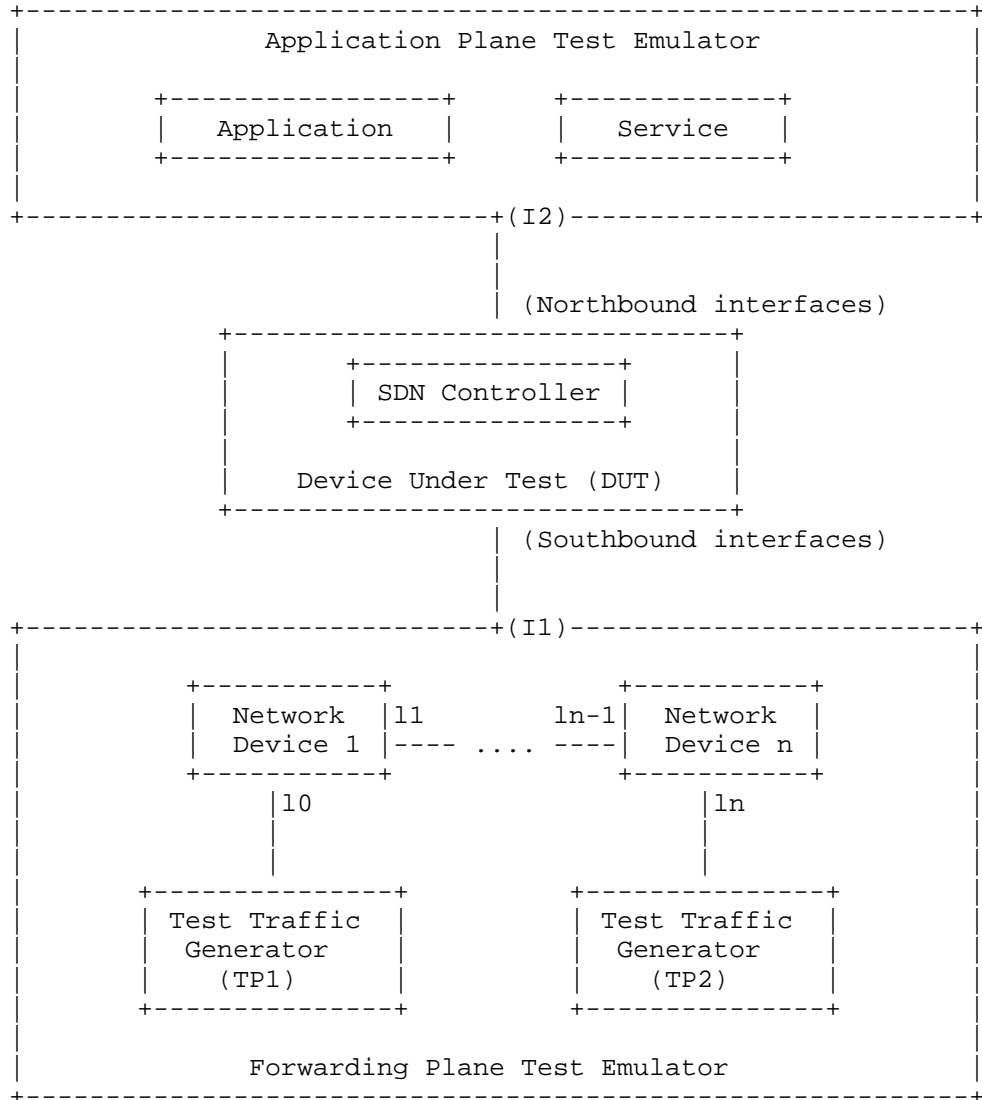


Figure 1



3.2. Test setup - Controller working in Cluster Mode

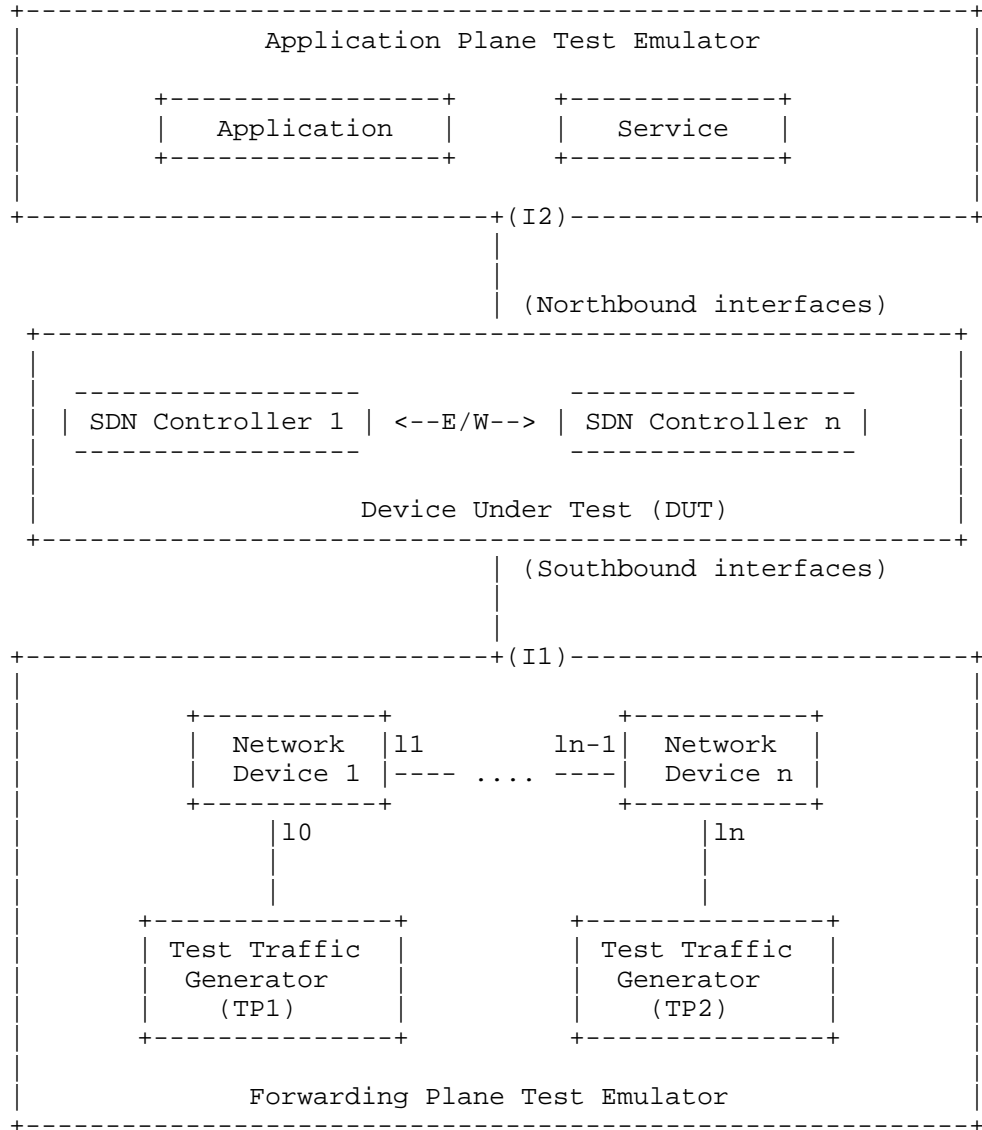


Figure 2

## 4. Test Considerations

### 4.1. Network Topology

The test cases SHOULD use Leaf-Spine topology with at least 1 Network Device in the topology for benchmarking. The test traffic generators TP1 and TP2 SHOULD be connected to the first and the last leaf Network Device. If a test case uses test topology with 1 Network Device, the test traffic generators TP1 and TP2 SHOULD be connected to the same node. However to achieve a complete performance characterization of the SDN controller, it is recommended that the controller be benchmarked for many network topologies and a varying number of Network Devices. This document includes two sample test topologies, defined in Section 10 - Appendix A for reference. Further, care should be taken to make sure that a loop prevention mechanism is enabled either in the SDN controller, or in the network when the topology contains redundant network paths.

### 4.2. Test Traffic

Test traffic is used to notify the controller about the asynchronous arrival of new flows. The test cases SHOULD use frame sizes of 128, 512 and 1508 bytes for benchmarking. Testing using jumbo frames are optional.

### 4.3. Test Emulator Requirements

The Test Emulator SHOULD time stamp the transmitted and received control messages to/from the controller on the established network connections. The test cases use these values to compute the controller processing time.

### 4.4. Connection Setup

There may be controller implementations that support unencrypted and encrypted network connections with Network Devices. Further, the controller may have backward compatibility with Network Devices running older versions of southbound protocols. It may be useful to measure the controller performance be measured with one or more applicable connection setup methods defined below.

1. Unencrypted connection with Network Devices, running same protocol version.
2. Unencrypted connection with Network Devices, running different protocol versions.

Example:

- a. Controller running current protocol version and switch running older protocol version
- b. Controller running older protocol version and switch running current protocol version
3. Encrypted connection with Network Devices, running same protocol version
4. Encrypted connection with Network Devices, running different protocol versions.

Example:

- a. Controller running current protocol version and switch running older protocol version
- b. Controller running older protocol version and switch running current protocol version

#### 4.5. Measurement Point Specification and Recommendation

The measurement accuracy depends on several factors including the point of observation where the indications are captured. For example, the notification can be observed at the controller or test emulator. The test operator SHOULD make the observations/measurements at the interfaces of test emulator unless it is explicitly mentioned otherwise in the individual test. In any case, the locations of measurement points MUST be reported.

#### 4.6. Connectivity Recommendation

The SDN controller in the test setup SHOULD be connected directly with the forwarding and the management plane test emulators to avoid any delays or failure introduced by the intermediate devices during benchmarking tests. When the controller is implemented as a virtual machine, details of the physical and logical connectivity MUST be reported.

#### 4.7. Test Repeatability

To increase the confidence in measured result, it is recommended that each test SHOULD be repeated a minimum of 10 times.

##### Test Reporting

Each test has a reporting format that contains some global and identical reporting components, and some individual components that are specific to individual tests. The following test configuration parameters and controller settings parameters MUST be reflected in the test report.

##### Test Configuration Parameters:

1. Controller name and version
2. Northbound protocols and versions
3. Southbound protocols and versions
4. Controller redundancy mode (Standalone or Cluster Mode)
5. Connection setup (Unencrypted or Encrypted)
6. Network Topology (Mesh or Tree or Linear)
7. Network Device Type (Physical or Virtual or Emulated)
8. Number of Nodes
9. Number of Links
10. Dataplane Test Traffic Type
11. Controller System Configuration (e.g., Physical or Virtual Machine, CPU, Memory, Caches, Operating System, Interface Speed, Storage)
12. Reference Test Setup (e.g., Section 3.1 etc.,)

Controller Settings Parameters:

1. Topology re-discovery timeout
2. Controller redundancy mode (e.g., active-standby etc.,)
3. Controller state persistence enabled/disabled

To ensure the repeatability of test, the following capabilities of test emulator SHOULD be reported

1. Maximum number of Network Devices that the forwarding plane emulates
2. Control message processing time (e.g., Topology Discovery Messages)

One way to determine the above two values are to simulate the required control sessions and messages from the control plane.

## 5. Benchmarking Tests

### 5.1. Performance

#### 5.1.1. Network Topology Discovery Time

Objective:

The time taken by controller(s) to determine the complete network topology, defined as the interval starting with the first discovery message from the controller(s) at its Southbound interface, ending with all features of the static topology determined.

## Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

## Prerequisite:

1. The controller MUST support network discovery.
2. Tester should be able to retrieve the discovered topology information either through the controller's management interface, or northbound interface to determine if the discovery was successful and complete.
3. Ensure that the controller's topology re-discovery timeout has been set to the maximum value to avoid initiation of re-discovery process in the middle of the test.

## Procedure:

1. Ensure that the controller is operational, its network applications, northbound and southbound interfaces are up and running.
2. Establish the network connections between controller and Network Devices.
3. Record the time for the first discovery message (Tm1) received from the controller at forwarding plane test emulator interface I1.
4. Query the controller every 3 seconds to obtain the discovered network topology information through the northbound interface or the management interface and compare it with the deployed network topology information.
5. Stop the test when the discovered topology information matches the deployed network topology, or when the discovered topology information for 3 consecutive queries return the same details.
6. Record the time last discovery message (Tmn) sent to controller from the forwarding plane test emulator interface (I1) when the test completed successfully. (e.g., the topology matches).

## Measurement:

Topology Discovery Time  $Tr1 = Tmn - Tm1$ .

$$\text{Average Topology Discovery Time} = \frac{Tr1 + Tr2 + Tr3 \dots Trn}{\text{Total Test Iterations}}$$

#### Reporting Format:

The Topology Discovery Time results MUST be reported in the format of a table, with a row for each successful iteration. The last row of the table indicates the average Topology Discovery Time.

If this test is repeated with varying number of nodes over the same topology, the results SHOULD be reported in the form of a graph. The X coordinate SHOULD be the Number of nodes (N), the Y coordinate SHOULD be the average Topology Discovery Time.

If this test is repeated with same number of nodes over different topologies, the results SHOULD be reported in the form of a graph. The X coordinate SHOULD be the Topology Type, the Y coordinate SHOULD be the average Topology Discovery Time.

#### 5.1.2. Asynchronous Message Processing Time

##### Objective:

The time taken by controller(s) to process an asynchronous message, defined as the interval starting with an asynchronous message from a network device after the discovery of all the devices by the controller(s), ending with a response message from the controller(s) at its Southbound interface.

##### Reference Test Setup:

This test SHOULD use one of the test setup described in section 3.1 or section 3.2 of this document in combination with Appendix A.

##### Prerequisite:

1. The controller MUST have successfully completed the network topology discovery for the connected Network Devices.

##### Procedure:

1. Generate asynchronous messages from every connected Network Device, to the SDN controller, one at a time in series from the forwarding plane test emulator for the test duration.
2. Record every request transmit (T1) timestamp and the corresponding response (R1) received timestamp at the forwarding plane test emulator interface (I1) for every successful message exchange.

Measurement:

$$\text{Asynchronous Message Processing Time } Tr1 = \frac{(R1-T1) + (R2-T2) \dots (Rn-Tn)}{Nrx}$$

Where Nrx is the total number of successful messages exchanged

$$\text{Average Asynchronous Message Processing Time} = \frac{Tr1 + Tr2 + Tr3 \dots Trn}{\text{Total Test Iterations}}$$

Reporting Format:

The Asynchronous Message Processing Time results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the average Asynchronous Message Processing Time.

The report should capture the following information in addition to the configuration parameters captured in section 5. - Successful messages exchanged (Nrx)

If this test is repeated with varying number of nodes with same topology, the results SHOULD be reported in the form of a graph. The X coordinate SHOULD be the Number of nodes (N), the Y coordinate SHOULD be the average Asynchronous Message Processing Time.

If this test is repeated with same number of nodes using different topologies, the results SHOULD be reported in the form of a graph. The X coordinate SHOULD be the Topology Type, the Y coordinate SHOULD be the average Asynchronous Message Processing Time.

### 5.1.3. Asynchronous Message Processing Rate

Objective:

The maximum number of asynchronous messages (session aliveness check message, new flow arrival notification message etc.) that the controller(s) can process, defined as the iteration starting with sending asynchronous messages to the controller (s) at the maximum possible rate and ending with an iteration that the controller(s) processes the received asynchronous messages without dropping.

## Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

## Prerequisite:

1. The controller MUST have successfully completed the network topology discovery for the connected Network Devices.

## Procedure:

1. Generate asynchronous messages continuously at the maximum possible rate on the established connections from all the emulated/simulated Network Devices for the given Test Duration (Td).
2. Record the total number of responses received from the controller (Nrx1) as well as the number of messages sent (Ntx1) to the controller within the test duration(Td).
3. Repeat the test by generating the asynchronous messages equal to the number of responses received from the controller in last iteration for the given test duration (Td).
4. Test MUST be repeated until the generated asynchronous messages and the responses received from the controller are equal for two consecutive iterations.
5. Record the number of responses received from the controller (Nrxn) as well as the number of messages sent(Ntxn) to the controller in the last test iteration.

## Measurement:

$$\text{Asynchronous Message Processing Rate Tr1} = \frac{\text{Nrxn}}{\text{Td}}$$

$$\text{Average Asynchronous Message Processing Rate} = \frac{\text{Tr1} + \text{Tr2} + \text{Tr3}.. \text{Trn}}{\text{Total Test Iterations}}$$

## Reporting Format:

The Asynchronous Message Processing Rate results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the average Asynchronous Message Processing Rate.



The report should capture the following information in addition to the configuration parameters captured in section 5.

- Offered rate (Ntx)
- Loss Ratio

If this test is repeated with varying number of nodes over same topology, the results SHOULD be reported in the form of a graph. The X coordinate SHOULD be the Number of nodes (N), the Y coordinate SHOULD be the average Asynchronous Message Processing Rate.

If this test is repeated with same number of nodes over different topologies, the results SHOULD be reported in the form of a graph. The X coordinate SHOULD be the Topology Type, the Y coordinate SHOULD be the average Asynchronous Message Processing Rate.

#### 5.1.4. Reactive Path Provisioning Time

Objective:

The time taken by the controller to setup a path reactively between source and destination node, defined as the interval starting with the first flow provisioning request message received by the controller(s) at its Southbound interface, ending with the last flow provisioning response message sent from the controller(s) at its Southbound interface.

Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A. The number of Network Devices in the path is a parameter of the test that may be varied from 2 to maximum discovery size in repetitions of this test.

Prerequisite:

1. The controller MUST contain the network topology information for the deployed network topology.
2. The controller should have the knowledge about the location of destination endpoint for which the path has to be provisioned. This can be achieved through dynamic learning or static provisioning.

3. Ensure that the default action for 'flow miss' in Network Device is configured to 'send to controller'.
4. Ensure that each Network Device in a path requires the controller to make the forwarding decision while paving the entire path.

Procedure:

1. Send a single traffic stream from the test traffic generator TP1 to test traffic generator TP2.
2. Record the time of the first flow provisioning request message sent to the controller (Tsf1) from the Network Device at the forwarding plane test emulator interface (I1).
3. Wait for the arrival of first traffic frame at the Traffic Endpoint TP2 or the expiry of test duration (Td).
4. Record the time of the last flow provisioning response message received from the controller (Tdf1) to the Network Device at the forwarding plane test emulator interface (I1).

Measurement:

Reactive Path Provisioning Time  $Tr1 = Tdf1 - Tsf1$ .

$$\text{Average Reactive Path Provisioning Time} = \frac{Tr1 + Tr2 + Tr3 \dots Trn}{\text{Total Test Iterations}}$$

Reporting Format:

The Reactive Path Provisioning Time results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the Average Reactive Path Provisioning Time

The report should capture the following information in addition to the configuration parameters captured in section 5.

- Number of Network Devices in the path

#### 5.1.5. Proactive Path Provisioning Time

Objective:

The time taken by the controller to setup a path proactively between source and destination node, defined as the interval starting with

the first proactive flow provisioned in the controller(s) at its Northbound interface, ending with the last flow provisioning response message sent from the controller(s) at its Southbound interface.

#### Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

#### Prerequisite:

1. The controller MUST contain the network topology information for the deployed network topology.
2. The controller should have the knowledge about the location of destination endpoint for which the path has to be provisioned. This can be achieved through dynamic learning or static provisioning.
3. Ensure that the default action for flow miss in Network Device is 'drop'.

#### Procedure:

1. Send a single traffic stream from test traffic generator TP1 to TP2.
2. Install the flow entries to reach from test traffic generator TP1 to the test traffic generator TP2 through controller's northbound or management interface.
3. Wait for the arrival of first traffic frame at the test traffic generator TP2 or the expiry of test duration (Td).
4. Record the time when the proactive flow is provisioned in the Controller (Tsf1) at the management plane test emulator interface I2.
5. Record the time of the last flow provisioning message received from the controller (Tdf1) at the forwarding plane test emulator interface I1.

#### Measurement:

Proactive Flow Provisioning Time  $Tr_1 = Tdf_1 - Tsf_1$ .

$$\text{Average Proactive Path Provisioning Time} = \frac{Tr_1 + Tr_2 + Tr_3 \dots Tr_n}{\text{Total Test Iterations}}$$

#### Reporting Format:

The Proactive Path Provisioning Time results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the Average Proactive Path Provisioning Time.

The report should capture the following information in addition to the configuration parameters captured in section 5.

- Number of Network Devices in the path

#### 5.1.6. Reactive Path Provisioning Rate

##### Objective:

The maximum number of independent paths a controller can concurrently establish between source and destination nodes reactively, defined as the number of paths provisioned by the controller(s) at its Southbound interface for the flow provisioning requests received for path provisioning at its Southbound interface between the start of the test and the expiry of given test duration.

##### Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

##### Prerequisite:

1. The controller MUST contain the network topology information for the deployed network topology.
2. The controller should have the knowledge about the location of destination addresses for which the paths have to be provisioned. This can be achieved through dynamic learning or static provisioning.
3. Ensure that the default action for 'flow miss' in Network Device is configured to 'send to controller'.
4. Ensure that each Network Device in a path requires the controller to make the forwarding decision while provisioning the entire path.

##### Procedure:

1. Send traffic with unique source and destination addresses from test traffic generator TP1.
2. Record total number of unique traffic frames (Ndf) received at the test traffic generator TP2 within the test duration (Td).

Measurement:

$$\text{Reactive Path Provisioning Rate Tr1} = \frac{\text{Ndf}}{\text{Td}}$$

$$\text{Average Reactive Path Provisioning Rate} = \frac{\text{Tr1} + \text{Tr2} + \text{Tr3} \dots \text{Trn}}{\text{Total Test Iterations}}$$

Reporting Format:

The Reactive Path Provisioning Rate results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the Average Reactive Path Provisioning Rate.

The report should capture the following information in addition to the configuration parameters captured in section 5.

- Number of Network Devices in the path
- Offered rate

#### 5.1.7. Proactive Path Provisioning Rate

Objective:

Measure the maximum rate of independent paths a controller can concurrently establish between source and destination nodes proactively, defined as the number of paths provisioned by the controller(s) at its Southbound interface for the paths requested in its Northbound interface between the start of the test and the expiry of given test duration . The measurement is based on dataplane observations of successful path activation

Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

Prerequisite:

1. The controller MUST contain the network topology information for the deployed network topology.

2. The controller should have the knowledge about the location of destination addresses for which the paths have to be provisioned. This can be achieved through dynamic learning or static provisioning.

3. Ensure that the default action for flow miss in Network Device is 'drop'.

#### Procedure:

1. Send traffic continuously with unique source and destination addresses from test traffic generator TP1.

2. Install corresponding flow entries to reach from simulated sources at the test traffic generator TP1 to the simulated destinations at test traffic generator TP2 through controller's northbound or management interface.

3. Record total number of unique traffic frames received (Ndf) at the test traffic generator TP2 within the test duration (Td).

#### Measurement:

$$\text{Proactive Path Provisioning Rate } Tr1 = \frac{Ndf}{Td}$$

$$\text{Average Proactive Path Provisioning Rate} = \frac{Tr1 + Tr2 + Tr3 \dots Trn}{\text{Total Test Iterations}}$$

#### Reporting Format:

The Proactive Path Provisioning Rate results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the Average Proactive Path Provisioning Rate.

The report should capture the following information in addition to the configuration parameters captured in section 5.

- Number of Network Devices in the path
- Offered rate

## 5.1.8. Network Topology Change Detection Time

## Objective:

The amount of time required for the controller to detect any changes in the network topology, defined as the interval starting with the notification message received by the controller(s) at its Southbound interface, ending with the first topology rediscovery messages sent from the controller(s) at its Southbound interface.

## Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

## Prerequisite:

1. The controller MUST have successfully discovered the network topology information for the deployed network topology.
2. The periodic network discovery operation should be configured to twice the Test duration (Td) value.

## Procedure:

1. Trigger a topology change event by bringing down an active Network Device in the topology.
2. Record the time when the first topology change notification is sent to the controller (Tcn) at the forwarding plane test emulator interface (I1).
3. Stop the test when the controller sends the first topology re-discovery message to the Network Device or the expiry of test interval (Td).
4. Record the time when the first topology re-discovery message is received from the controller (Tcd) at the forwarding plane test emulator interface (I1)

## Measurement:

Network Topology Change Detection Time  $Tr1 = Tcd - Tcn$ .

$$\text{Average Network Topology Change Detection Time} = \frac{Tr1 + Tr2 + Tr3 \dots Trn}{\text{Total Test Iterations}}$$

**Reporting Format:**

The Network Topology Change Detection Time results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the average Network Topology Change Time.

**5.2. Scalability****5.2.1. Control Session Capacity****Objective:**

Measure the maximum number of control sessions the controller can maintain, defined as the number of sessions that the controller can accept from network devices, starting with the first control session, ending with the last control session that the controller(s) accepts at its Southbound interface.

**Reference Test Setup:**

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

**Procedure:**

1. Establish control connection with controller from every Network Device emulated in the forwarding plane test emulator.
2. Stop the test when the controller starts dropping the control connections.
3. Record the number of successful connections established with the controller (CCn) at the forwarding plane test emulator.

**Measurement:**

Control Sessions Capacity = CCn.

**Reporting Format:**

The Control Session Capacity results MUST be reported in addition to the configuration parameters captured in section 5.



### 5.2.2. Network Discovery Size

#### Objective:

Measure the network size (number of nodes, links and hosts) that a controller can discover, defined as the size of a network that the controller(s) can discover, starting from a network topology given by the user for discovery, ending with the topology that the controller(s) could successfully discover.

#### Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

#### Prerequisite:

1. The controller MUST support automatic network discovery.
2. Tester should be able to retrieve the discovered topology information either through controller's management interface or northbound interface.

#### Procedure:

1. Establish the network connections between controller and network nodes.
2. Query the controller for the discovered network topology information and compare it with the deployed network topology information.
3. 3a. Increase the number of nodes by 1 when the comparison is successful and repeat the test.
4. 3b. Decrease the number of nodes by 1 when the comparison fails and repeat the test.
5. Continue the test until the comparison of step 3b is successful.
6. Record the number of nodes for the last iteration (Ns) where the topology comparison was successful.

#### Measurement:

Network Discovery Size = Ns.

#### Reporting Format:

The Network Discovery Size results MUST be reported in addition to the configuration parameters captured in section 5.

### 5.2.3. Forwarding Table Capacity

#### Objective:

Measure the maximum number of flow entries a controller can manage in its Forwarding table.

#### Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

#### Prerequisite:

1. The controller Forwarding table should be empty.
2. Flow Idle time MUST be set to higher or infinite value.
3. The controller MUST have successfully completed network topology discovery.
4. Tester should be able to retrieve the forwarding table information either through controller's management interface or northbound interface.

#### Procedure:

##### Reactive Flow Provisioning Mode:

1. Send bi-directional traffic continuously with unique source and/or destination addresses from test traffic generators TP1 and TP2 at the asynchronous message processing rate of controller.
2. Query the controller at a regular interval (e.g., 5 seconds) for the number of learnt flow entries from its northbound interface.
3. Stop the test when the retrieved value is constant for three consecutive iterations and record the value received from the last query (Nrp).

##### Proactive Flow Provisioning Mode:

1. Install unique flows continuously through controller's northbound or management interface until a failure response is received from the controller.
2. Record the total number of successful responses (Nrp).

#### Note:

Some controller designs for proactive flow provisioning mode may require the switch to send flow setup requests in order to generate

flow setup responses. In such cases, it is recommended to generate bi-directional traffic for the provisioned flows.

Measurement:

Proactive Flow Provisioning Mode:

Max Flow Entries = Total number of flows provisioned (Nrp)

Reactive Flow Provisioning Mode:

Max Flow Entries = Total number of learnt flow entries (Nrp)

Forwarding Table Capacity = Max Flow Entries.

Reporting Format:

The Forwarding Table Capacity results MUST be tabulated with the following information in addition to the configuration parameters captured in section 5.

- Provisioning Type (Proactive/Reactive)

### 5.3. Security

#### 5.3.1. Exception Handling

Objective:

Determine the effect of handling error packets and notifications on performance tests. The impact MUST be measured for the following performance tests

- a. Path Provisioning Rate
- b. Path Provisioning Time
- c. Network Topology Change Detection Time

Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

## Prerequisite:

1. This test MUST be performed after obtaining the baseline measurement results for the above performance tests.
2. Ensure that the invalid messages are not dropped by the intermediate devices connecting the controller and Network Devices.

## Procedure:

1. Perform the above listed performance tests and send 1% of messages from the Asynchronous Message Processing Rate as invalid messages from the connected Network Devices emulated at the forwarding plane test emulator.
2. Perform the above listed performance tests and send 2% of messages from the Asynchronous Message Processing Rate as invalid messages from the connected Network Devices emulated at the forwarding plane test emulator.

## Note:

Invalid messages can be frames with incorrect protocol fields or any form of failure notifications sent towards controller.

## Measurement:

Measurement MUST be done as per the equation defined in the corresponding performance test measurement section.

## Reporting Format:

The Exception Handling results MUST be reported in the format of table with a column for each of the below parameters and row for each of the listed performance tests.

- Without Exceptions
- With 1% Exceptions
- With 2% Exceptions

### 5.3.2. Denial of Service Handling

#### Objective:

Determine the effect of handling DoS attacks on performance and scalability tests the impact MUST be measured for the following tests:

- a. Path Provisioning Rate
- b. Path Provisioning Time
- c. Network Topology Change Detection Time
- d. Network Discovery Size

#### Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

#### Prerequisite:

This test MUST be performed after obtaining the baseline measurement results for the above tests.

#### Procedure:

1. Perform the listed tests and launch a DoS attack towards controller while the test is running.

#### Note:

DoS attacks can be launched on one of the following interfaces.

- a. Northbound (e.g., Sending a huge number of requests on northbound interface)
- b. Management (e.g., Ping requests to controller's management interface)
- c. Southbound (e.g., TCP SYNC messages on southbound interface)

#### Measurement:

Measurement MUST be done as per the equation defined in the corresponding test's measurement section.

#### Reporting Format:

The DoS Attacks Handling results MUST be reported in the format of table with a column for each of the below parameters and row for each of the listed tests.

- Without any attacks
- With attacks

The report should also specify the nature of attack and the interface.

### 5.4. Reliability

#### 5.4.1. Controller Failover Time

##### Objective:

The time taken to switch from an active controller to the backup controller, when the controllers work in redundancy mode and the active controller fails, defined as the interval starting with the active controller bringing down, ending with the first re-discovery message received from the new controller at its Southbound interface.

##### Reference Test Setup:

The test SHOULD use the test setup described in section 3.2 of this document in combination with Appendix A.

##### Prerequisite:

1. Master controller election MUST be completed.
2. Nodes are connected to the controller cluster as per the Redundancy Mode (RM).
3. The controller cluster should have successfully completed the network topology discovery.
4. The Network Device MUST send all new flows to the controller when it receives from the test traffic generator.
5. Controller should have learnt the location of destination (D1) at test traffic generator TP2.

## Procedure:

1. Send uni-directional traffic continuously with incremental sequence number and source addresses from test traffic generator TP1 at the rate that the controller processes without any drops.
2. Ensure that there are no packet drops observed at the test traffic generator TP2.
3. Bring down the active controller.
4. Stop the test when a first frame received on TP2 after failover operation.
5. Record the time at which the last valid frame received (T1) at test traffic generator TP2 before sequence error and the first valid frame received (T2) after the sequence error at TP2

## Measurement:

Controller Failover Time = (T2 - T1)

Packet Loss = Number of missing packet sequences.

## Reporting Format:

The Controller Failover Time results MUST be tabulated with the following information.

- Number of cluster nodes
- Redundancy mode
- Controller Failover Time
- Packet Loss
- Cluster keep-alive interval

## 5.4.2. Network Re-Provisioning Time

## Objective:

The time taken to re-route the traffic by the Controller, when there is a failure in existing traffic paths, defined as the interval starting from the first failure notification message received by the controller, ending with the last flow re-provisioning message sent by the controller at its Southbound interface.

## Reference Test Setup:

This test SHOULD use one of the test setup described in section 3.1 or section 3.2 of this document in combination with Appendix A.

## Prerequisite:

1. Network with the given number of nodes and redundant paths MUST be deployed.
2. Ensure that the controller MUST have knowledge about the location of test traffic generators TP1 and TP2.
3. Ensure that the controller does not pre-provision the alternate path in the emulated Network Devices at the forwarding plane test emulator.

## Procedure:

1. Send bi-directional traffic continuously with unique sequence number from TP1 and TP2.
2. Bring down a link or switch in the traffic path.
3. Stop the test after receiving first frame after network re-convergence.
4. Record the time of last received frame prior to the frame loss at TP2 (TP2-Tlfr) and the time of first frame received after the frame loss at TP2 (TP2-Tffr). There must be a gap in sequence numbers of these frames
5. Record the time of last received frame prior to the frame loss at TP1 (TP1-Tlfr) and the time of first frame received after the frame loss at TP1 (TP1-Tffr).

## Measurement:

Forward Direction Path Re-Provisioning Time (FDRT)  
= (TP2-Tffr - TP2-Tlfr)

Reverse Direction Path Re-Provisioning Time (RDRT)  
= (TP1-Tffr - TP1-Tlfr)

Network Re-Provisioning Time = (FDRT+RDRT)/2

Forward Direction Packet Loss = Number of missing sequence frames at TP1

Reverse Direction Packet Loss = Number of missing sequence frames at TP2



## Reporting Format:

The Network Re-Provisioning Time results MUST be tabulated with the following information.

- Number of nodes in the primary path
- Number of nodes in the alternate path
- Network Re-Provisioning Time
- Forward Direction Packet Loss
- Reverse Direction Packet Loss

## 6. References

## 6.1. Normative References

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- [RFC6241] R. Enns, M. Bjorklund, J. Schoenwaelder, A. Bierman, "Network Configuration Protocol (NETCONF)", RFC 6241, July 2011.
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## 6.2. Informative References

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[OpenContrail] Ankur Singla, Bruno Rijsman, "OpenContrail Architecture Documentation", <http://opencontrail.org/opencontrail-architecture-documentation>

[OpenDaylight] OpenDaylight Controller:Architectural Framework, [https://wiki.opendaylight.org/view/OpenDaylight\\_Controller](https://wiki.opendaylight.org/view/OpenDaylight_Controller)

## 7. IANA Considerations

This document does not have any IANA requests.

## 8. Security Considerations

Benchmarking tests described in this document are limited to the performance characterization of controller in lab environment with isolated network.

The benchmarking network topology will be an independent test setup and MUST NOT be connected to devices that may forward the test traffic into a production network, or misroute traffic to the test management network.

Further, benchmarking is performed on a "black-box" basis, relying solely on measurements observable external to the controller.

Special capabilities SHOULD NOT exist in the controller specifically for benchmarking purposes. Any implications for network security arising from the controller SHOULD be identical in the lab and in production networks

## 9. Acknowledgments

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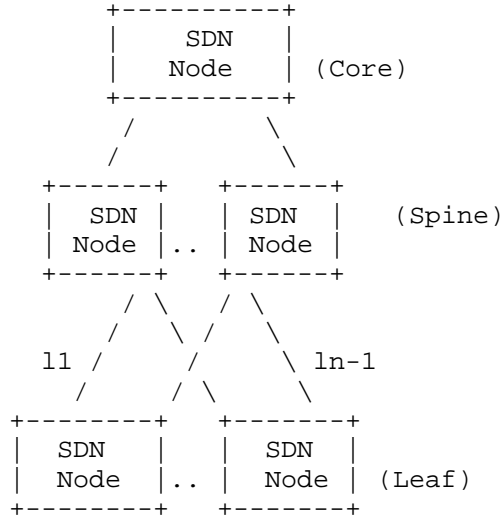
(NAIST), Andrew McGregor (Google), Scott Bradner (Harvard University), Jay Karthik (Cisco), Ramakrishnan (Dell), Khasanov Boris (Huawei), Brian Castelli (Spirent)

This document was prepared using 2-Word-v2.0.template.dot.

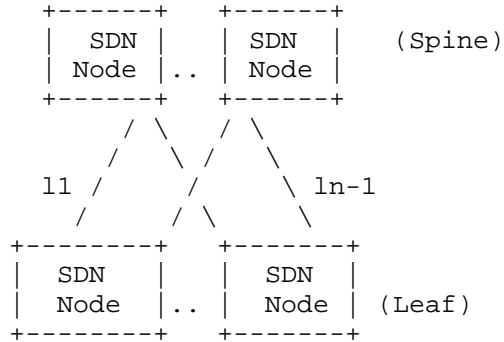
Appendix A.

Example Test Topologies

A.1. Leaf-Spine Topology - Three Tier Network Architecture



A.2. Leaf-Spine Topology - Two Tier Network Architecture



## Appendix B. Benchmarking Methodology using OpenFlow Controllers

This section gives an overview of OpenFlow protocol and provides test methodology to benchmark SDN controllers supporting OpenFlow southbound protocol.

### B.1. Protocol Overview

OpenFlow is an open standard protocol defined by Open Networking Foundation (ONF), used for programming the forwarding plane of network switches or routers via a centralized controller.

### B.2. Messages Overview

OpenFlow protocol supports three messages types namely controller-to-switch, asynchronous and symmetric.

Controller-to-switch messages are initiated by the controller and used to directly manage or inspect the state of the switch. These messages allow controllers to query/configure the switch (Features, Configuration messages), collect information from switch (Read-State message), send packets on specified port of switch (Packet-out message), and modify switch forwarding plane and state (Modify-State, Role-Request messages etc.).

Asynchronous messages are generated by the switch without a controller soliciting them. These messages allow switches to update controllers to denote an arrival of new flow (Packet-in), switch state change (Flow-Removed, Port-status) and error (Error).

Symmetric messages are generated in either direction without solicitation. These messages allow switches and controllers to set up connection (Hello), verify for liveness (Echo) and offer additional functionalities (Experimenter).

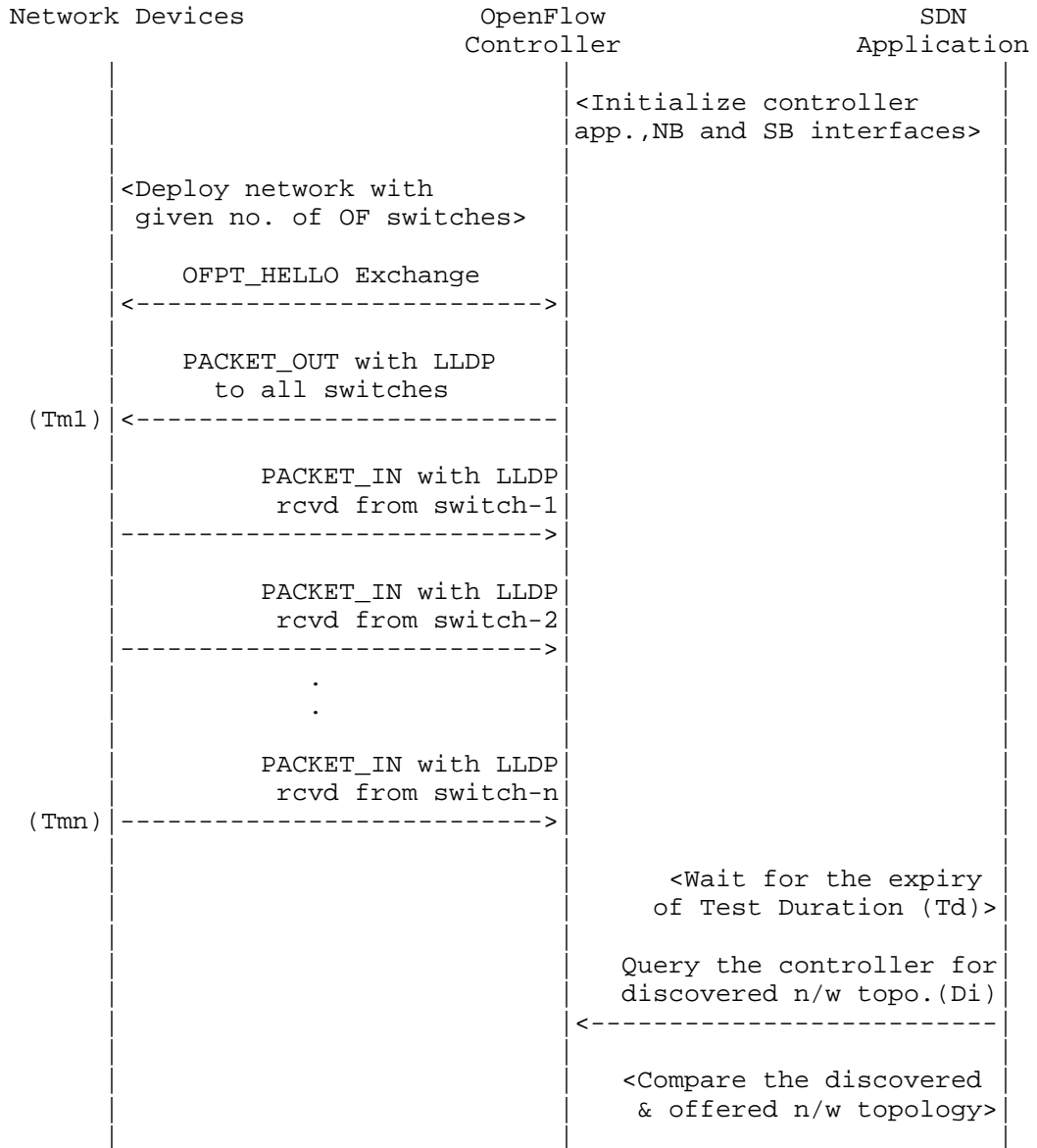
### B.3. Connection Overview

OpenFlow channel is used to exchange OpenFlow message between an OpenFlow switch and an OpenFlow controller. The OpenFlow channel connection can be setup using plain TCP or TLS. By default, a switch establishes single connection with SDN controller. A switch may establish multiple parallel connections to single controller (auxiliary connection) or multiple controllers to handle controller failures and load balancing.

B.4. Performance Benchmarking Tests

B.4.1. Network Topology Discovery Time

Procedure:



Legend:

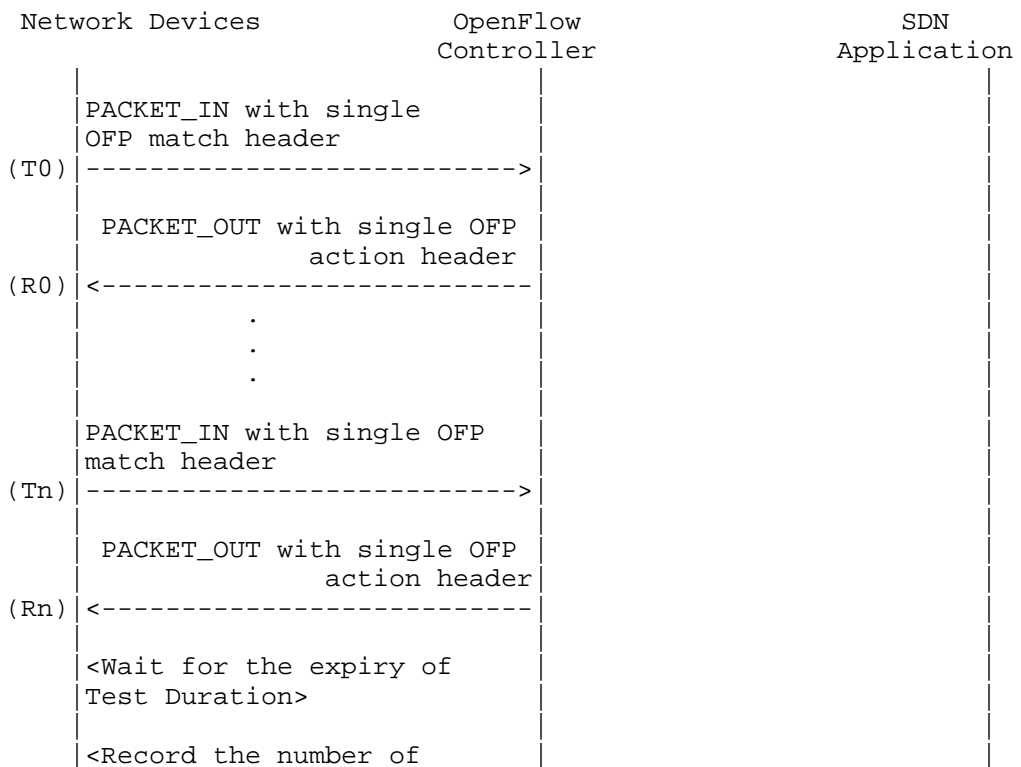
- NB: Northbound
- SB: Southbound
- OF: OpenFlow
- Tm1: Time of reception of first LLDP message from controller
- Tmn: Time of last LLDP message sent to controller

Discussion:

The Network Topology Discovery Time can be obtained by calculating the time difference between the first PACKET\_OUT with LLDP message received from the controller (Tm1) and the last PACKET\_IN with LLDP message sent to the controller (Tmn) when the comparison is successful.

B.4.2. Asynchronous Message Processing Time

Procedure:



PACKET_INs/PACKET_OUTs Exchanged (Nrx)>	
--	--

Legend:

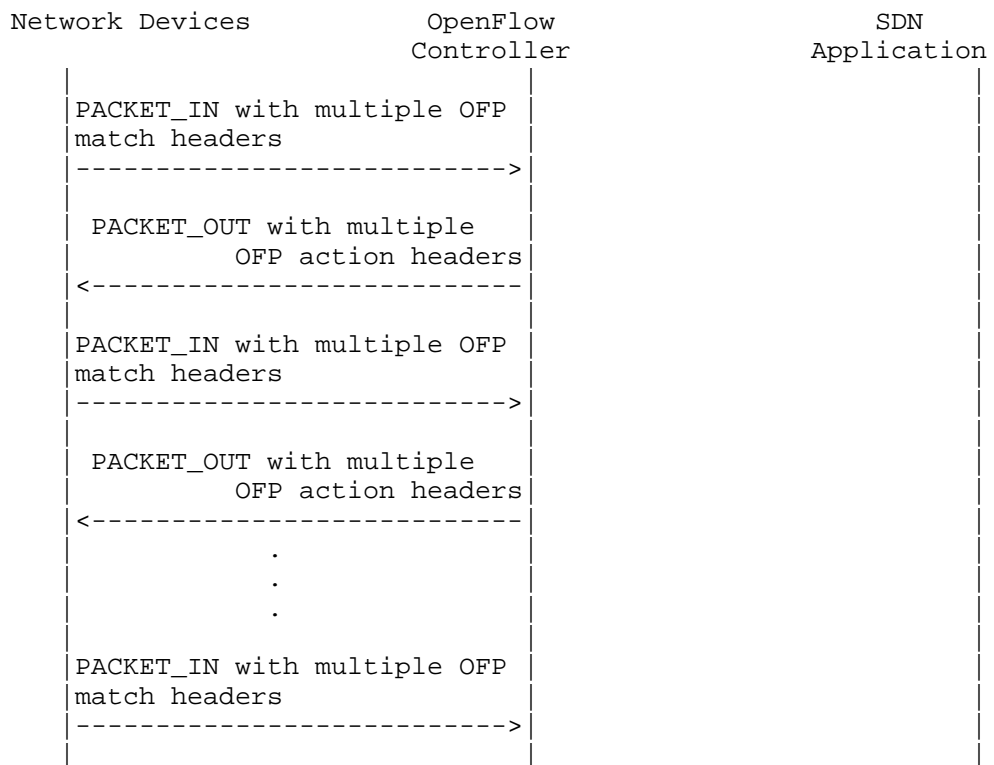
T0,T1, ..Tn are PACKET\_IN messages transmit timestamps.  
 R0,R1, ..Rn are PACKET\_OUT messages receive timestamps.  
 Nrx : Number of successful PACKET\_IN/PACKET\_OUT message exchanges

Discussion:

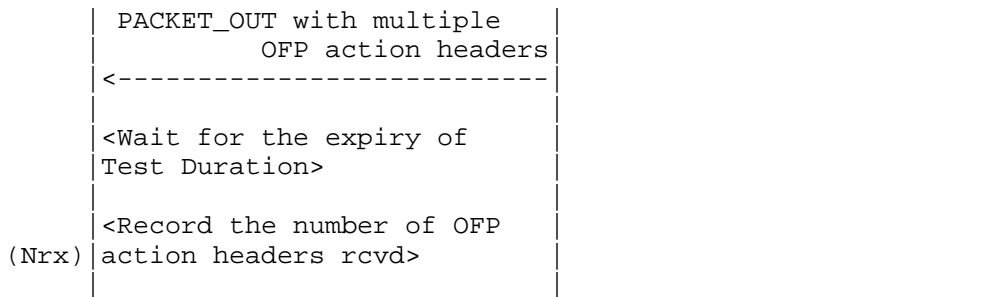
The Asynchronous Message Processing Time will be obtained by sum of  $((R0-T0), (R1-T1)..(Rn - Tn)) / Nrx$ .

B.4.3. Asynchronous Message Processing Rate

Procedure:





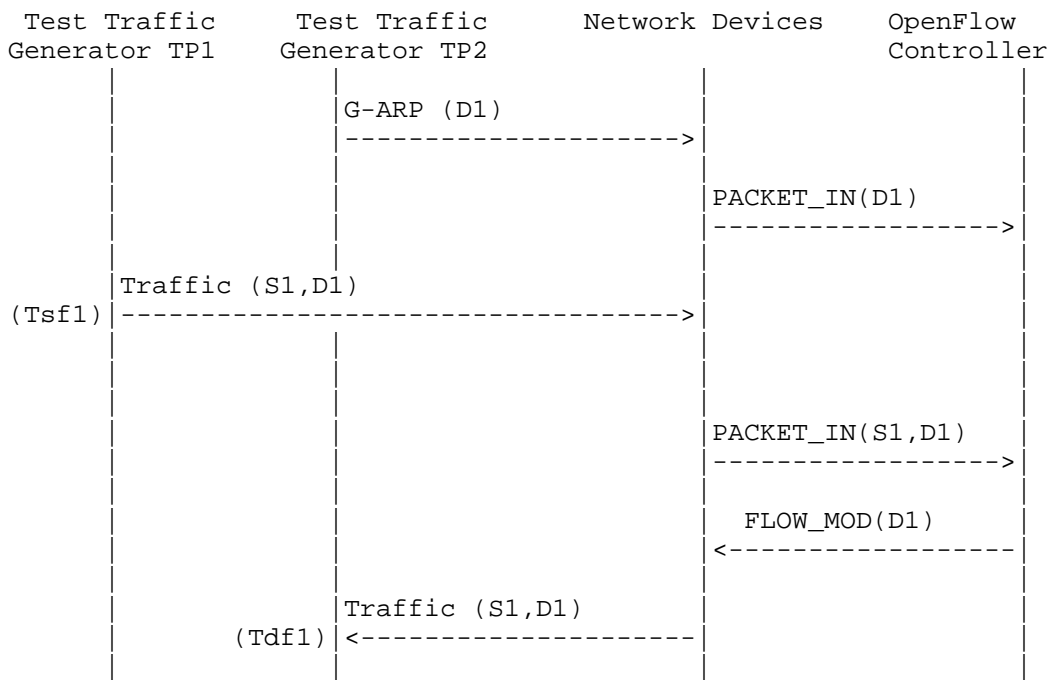


Discussion:

The Asynchronous Message Processing Rate will be obtained by calculating the number of OFP action headers received in all PACKET\_OUT messages during the test duration.

B.4.4. Reactive Path Provisioning Time

Procedure:



Legend:

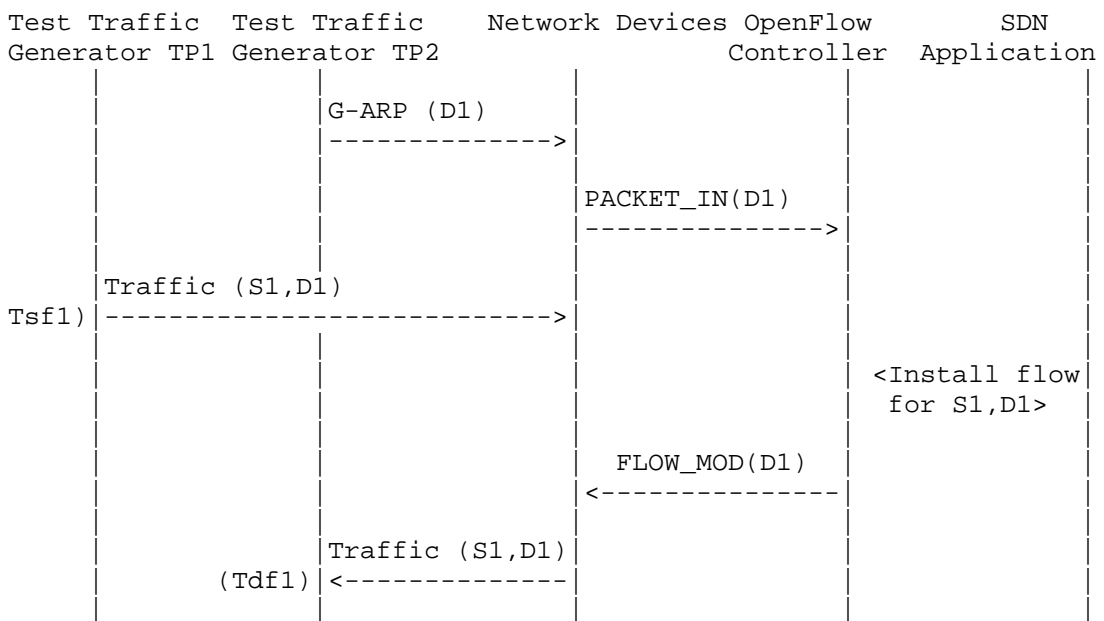
- G-ARP: Gratuitous ARP message.
- Tsfl: Time of first frame sent from TP1
- Tdf1: Time of first frame received from TP2

Discussion:

The Reactive Path Provisioning Time can be obtained by finding the time difference between the transmit and receive time of the traffic (Tsfl-Tdf1).

B.4.5. Proactive Path Provisioning Time

Procedure:



Legend:

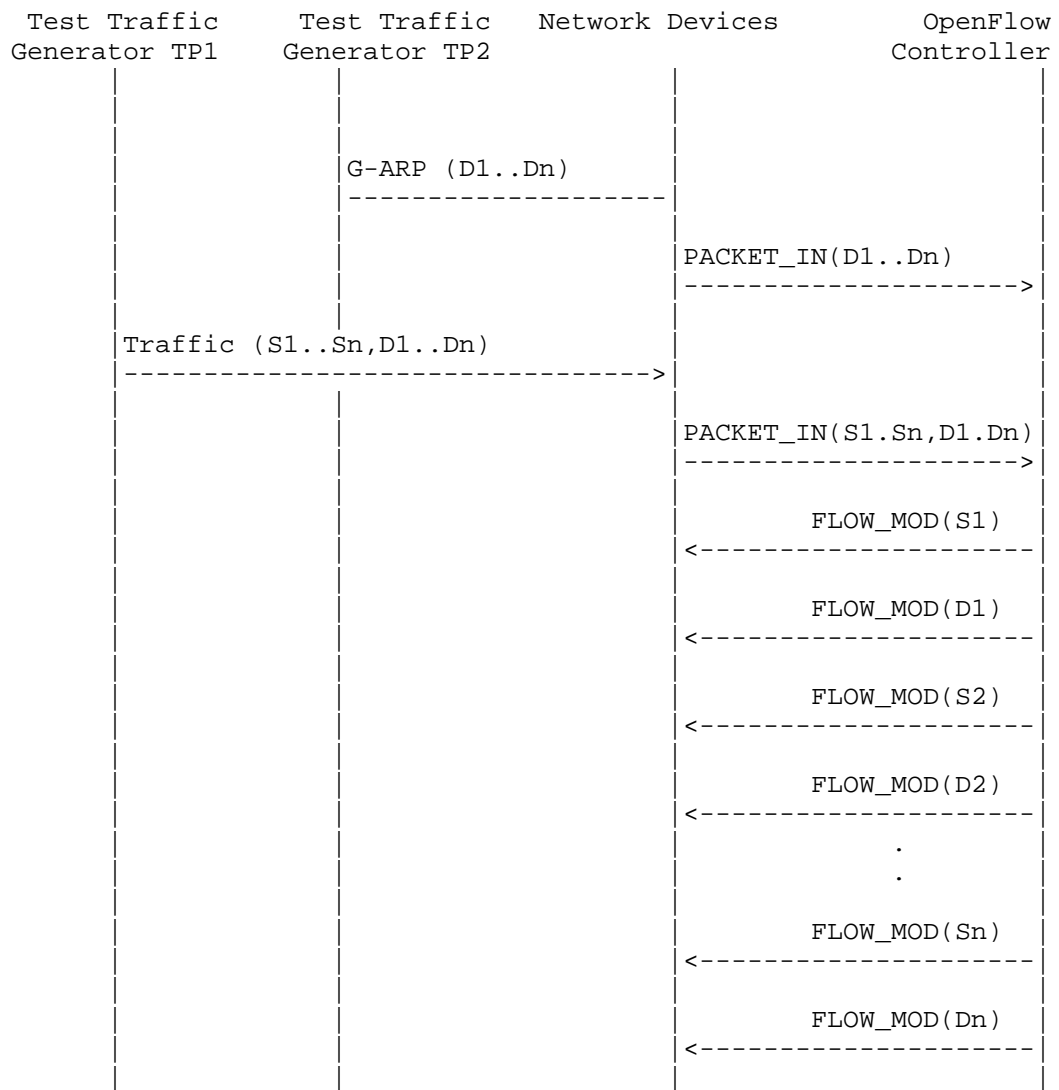
- G-ARP: Gratuitous ARP message.
- Tsfl: Time of first frame sent from TP1
- Tdf1: Time of first frame received from TP2

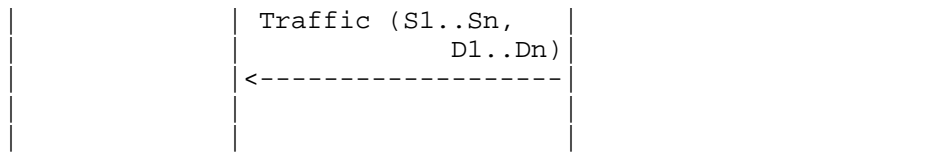
Discussion:

The Proactive Path Provisioning Time can be obtained by finding the time difference between the transmit and receive time of the traffic (Tsf1-Tdf1).

B.4.6. Reactive Path Provisioning Rate

Procedure:





Legend:

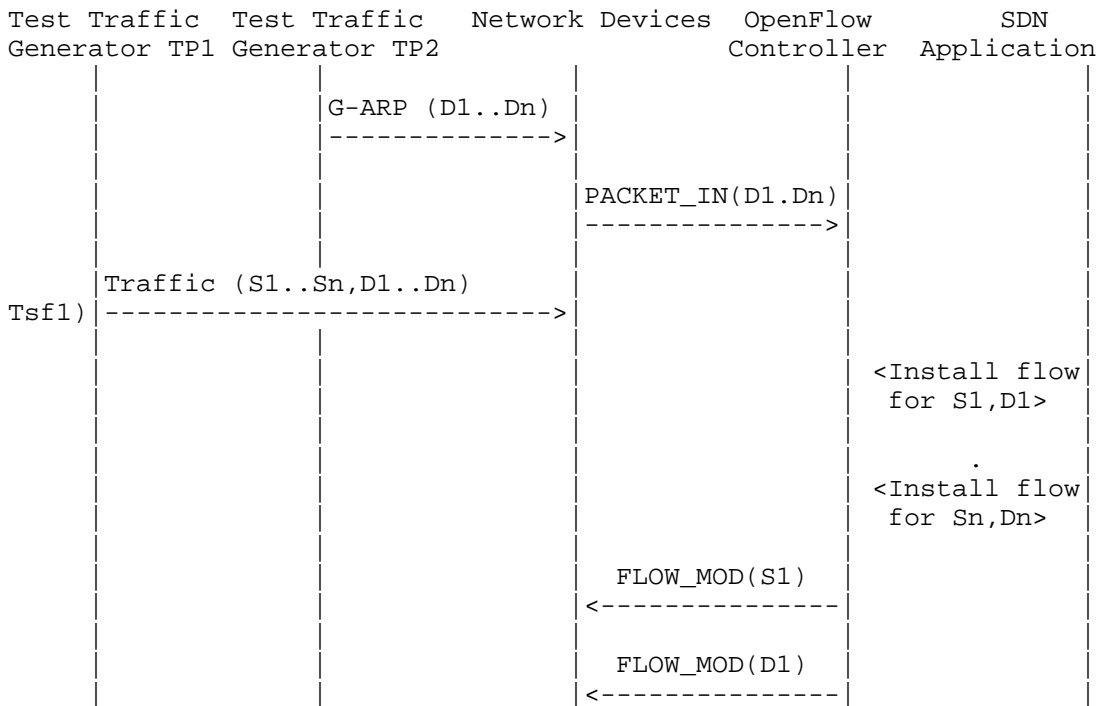
- G-ARP: Gratuitous ARP
- D1..Dn: Destination Endpoint 1, Destination Endpoint 2 .... Destination Endpoint n
- S1..Sn: Source Endpoint 1, Source Endpoint 2 .., Source Endpoint n

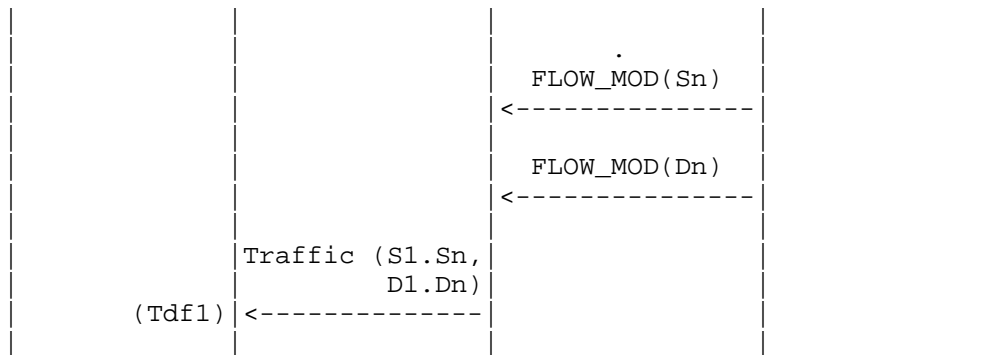
Discussion:

The Reactive Path Provisioning Rate can be obtained by finding the total number of frames received at TP2 after the test duration.

B.4.7. Proactive Path Provisioning Rate

Procedure:





Legend:

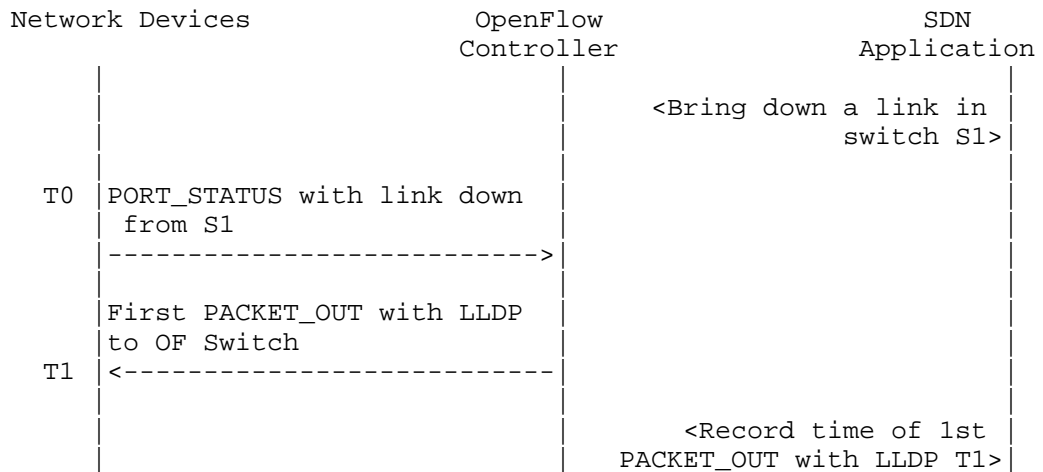
- G-ARP: Gratuitous ARP
- D1..Dn: Destination Endpoint 1, Destination Endpoint 2 .... Destination Endpoint n
- S1..Sn: Source Endpoint 1, Source Endpoint 2 .., Source Endpoint n

Discussion:

The Proactive Path Provisioning Rate can be obtained by finding the total number of frames received at TP2 after the test duration

B.4.8. Network Topology Change Detection Time

Procedure:



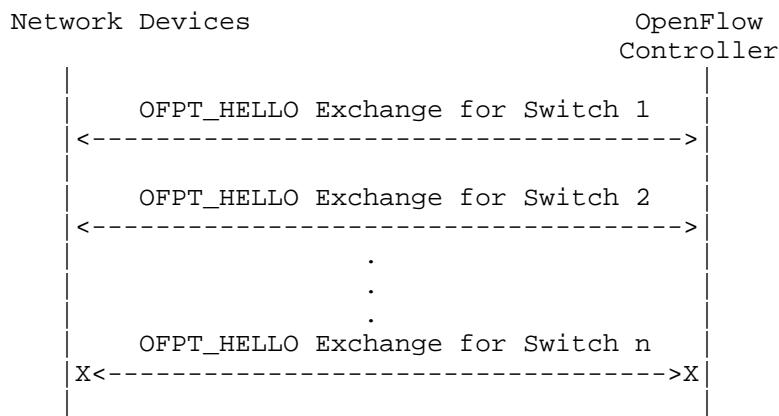
Discussion:

The Network Topology Change Detection Time can be obtained by finding the difference between the time the OpenFlow switch S1 sends the PORT\_STATUS message (T0) and the time that the OpenFlow controller sends the first topology re-discovery message (T1) to OpenFlow switches.

B.5. Scalability

B.5.1. Control Sessions Capacity

Procedure:

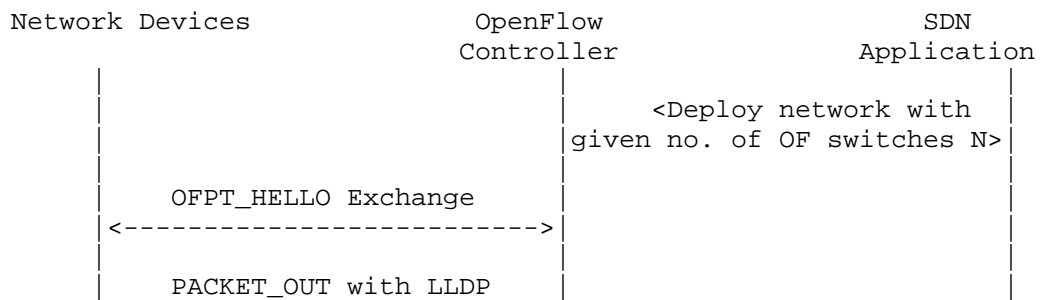


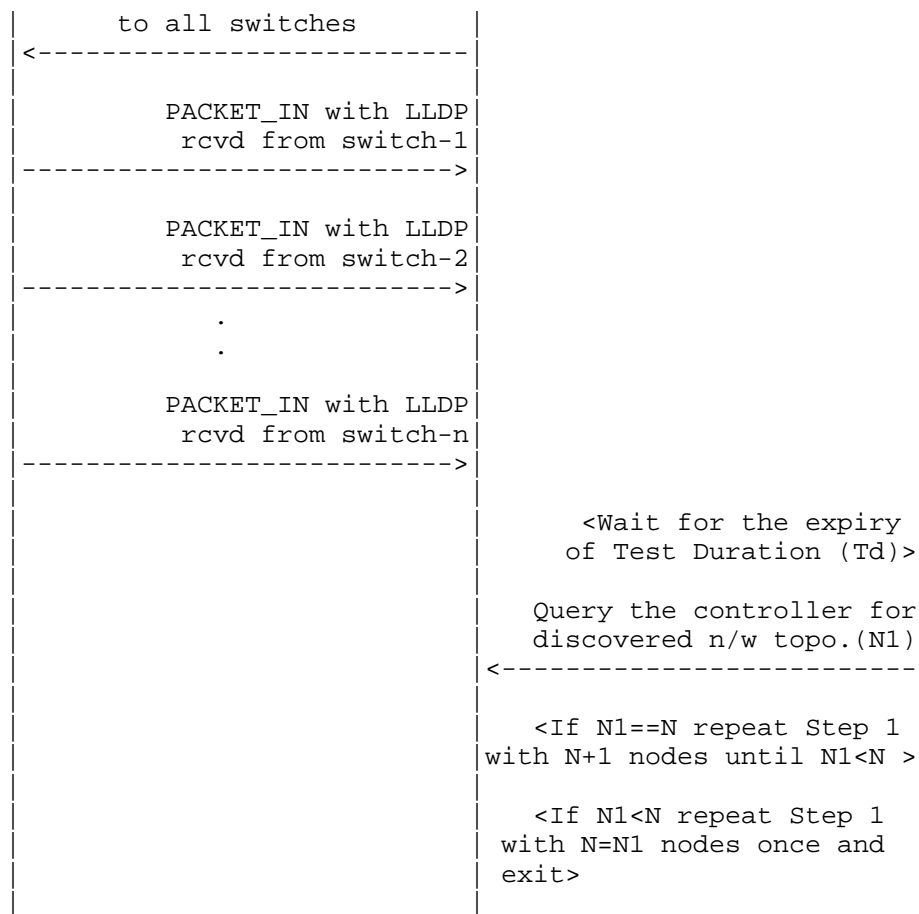
Discussion:

The value of Switch n-1 will provide Control Sessions Capacity.

B.5.2. Network Discovery Size

Procedure:





Legend:

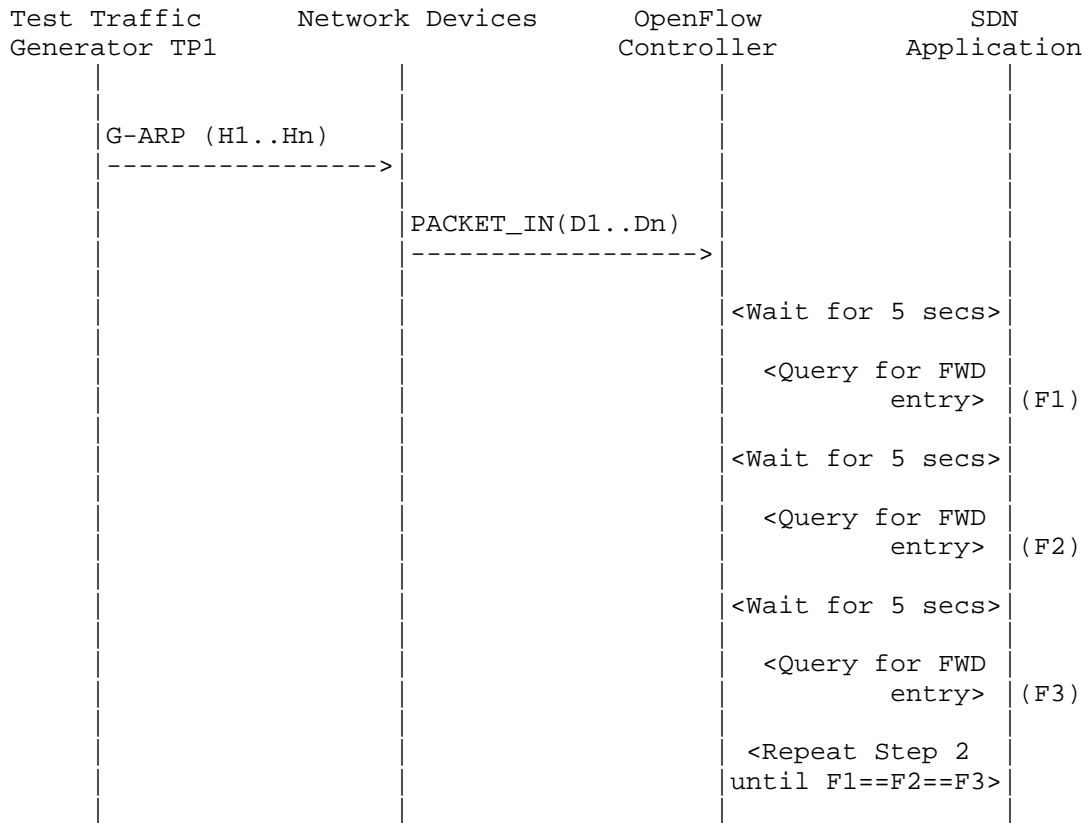
n/w topo: Network Topology  
 OF: OpenFlow

Discussion:

The value of N1 provides the Network Discovery Size value. The test duration can be set to the stipulated time within which the user expects the controller to complete the discovery process.

B.5.3. Forwarding Table Capacity

Procedure:



Legend:

- G-ARP: Gratuitous ARP
- H1..Hn: Host 1 .. Host n
- FWD: Forwarding Table

Discussion:

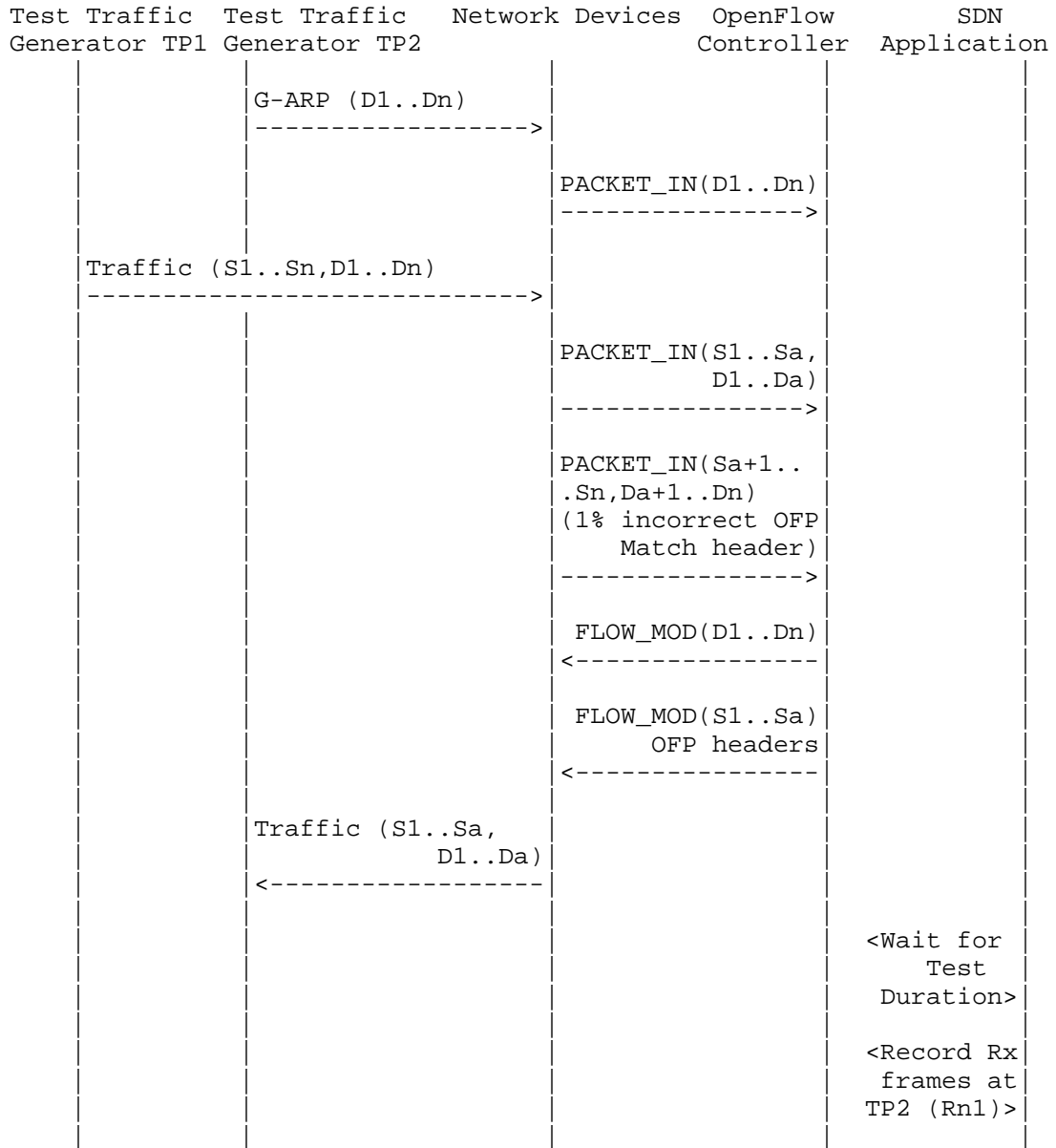
Query the controller forwarding table entries for multiple times until the three consecutive queries return the same value. The last value retrieved from the controller will provide the Forwarding Table Capacity value. The query interval is user configurable. The 5 seconds shown in this example is for representational purpose.

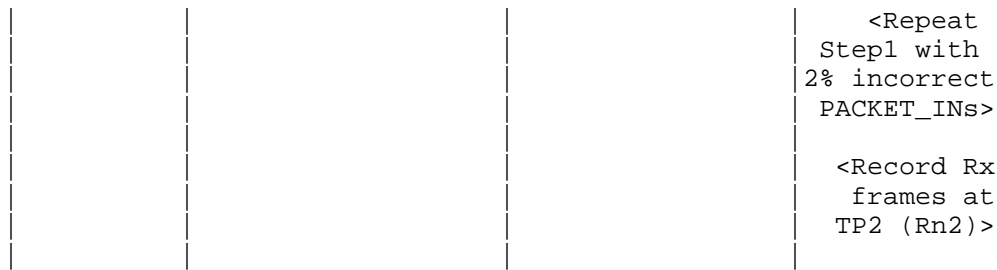


B.6. Security

B.6.1. Exception Handling

Procedure:





Legend:

- G-ARP: Gratuitous ARP
- PACKET\_IN(Sa+1..Sn, Da+1..Dn): OpenFlow PACKET\_IN with wrong version number
- Rn1: Total number of frames received at Test Port 2 with 1% incorrect frames
- Rn2: Total number of frames received at Test Port 2 with 2% incorrect frames

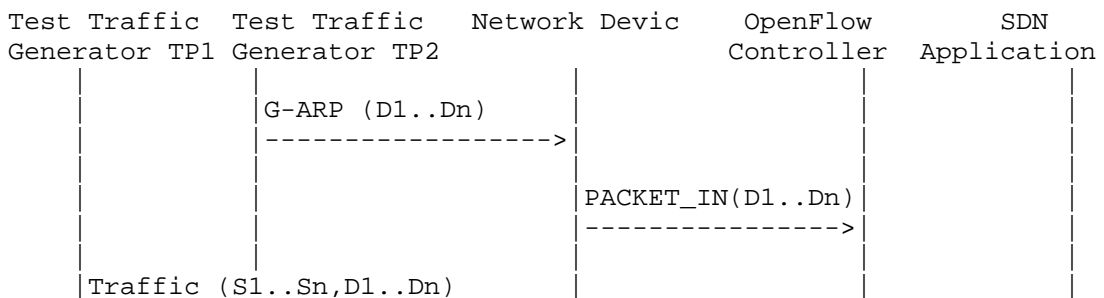
Discussion:

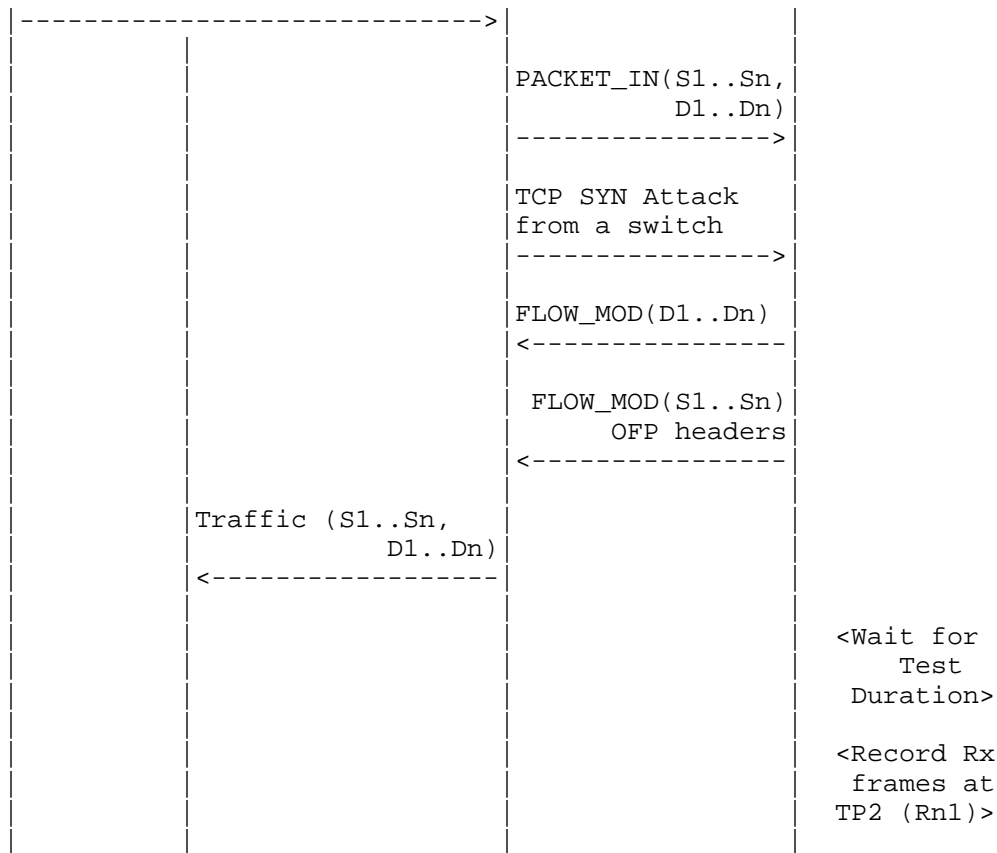
The traffic rate sent towards OpenFlow switch from Test Port 1 should be 1% higher than the Path Programming Rate. Rn1 will provide the Path Provisioning Rate of controller at 1% of incorrect frames handling and Rn2 will provide the Path Provisioning Rate of controller at 2% of incorrect frames handling.

The procedure defined above provides test steps to determine the effect of handling error packets on Path Programming Rate. Same procedure can be adopted to determine the effects on other performance tests listed in this benchmarking tests.

B.6.2. Denial of Service Handling

Procedure:





Legend:

G-ARP: Gratuitous ARP

Discussion:

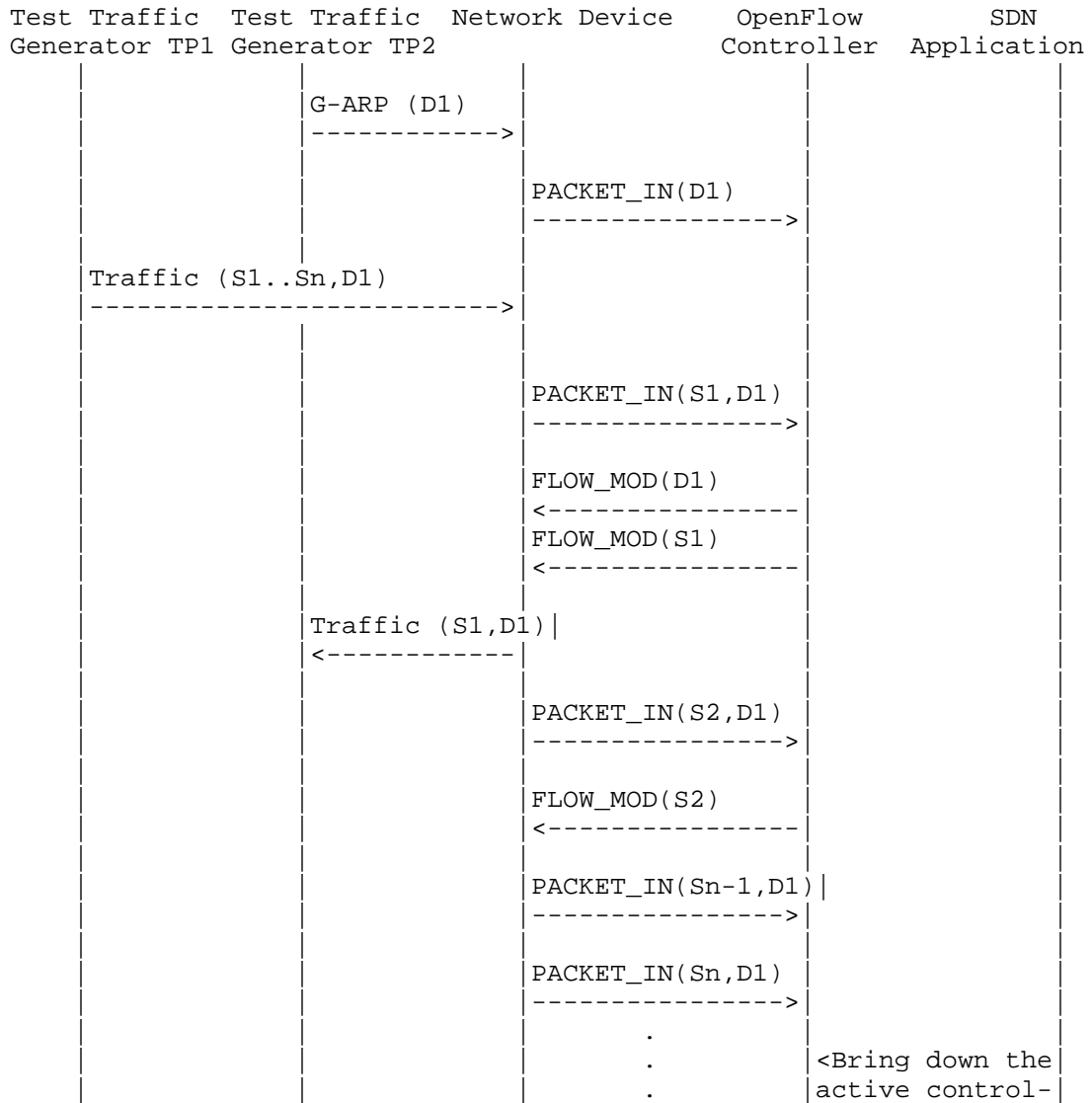
TCP SYN attack should be launched from one of the emulated/simulated OpenFlow Switch. Rn1 provides the Path Programming Rate of controller uponhandling denial of service attack.

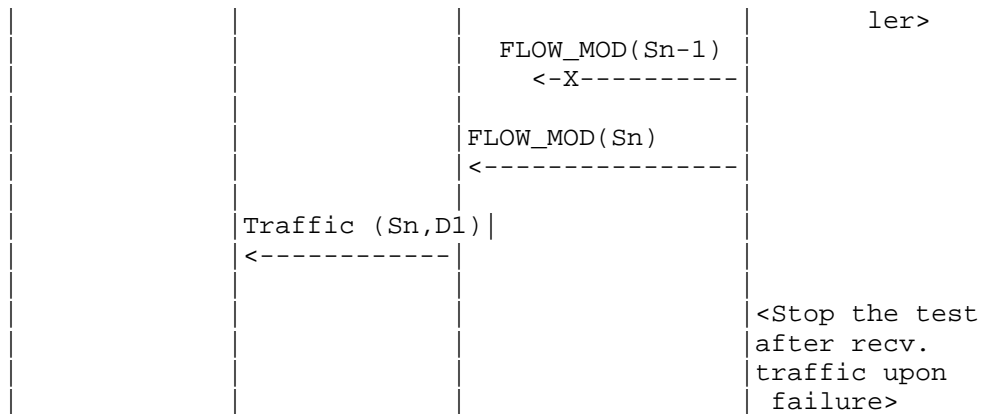
The procedure defined above provides test steps to determine the effect of handling denial of service on Path Programming Rate. Same procedure can be adopted to determine the effects on other performance tests listed in this benchmarking tests.

B.7. Reliability

B.7.1. Controller Failover Time

Procedure:





Legend:

G-ARP: Gratuitous ARP.

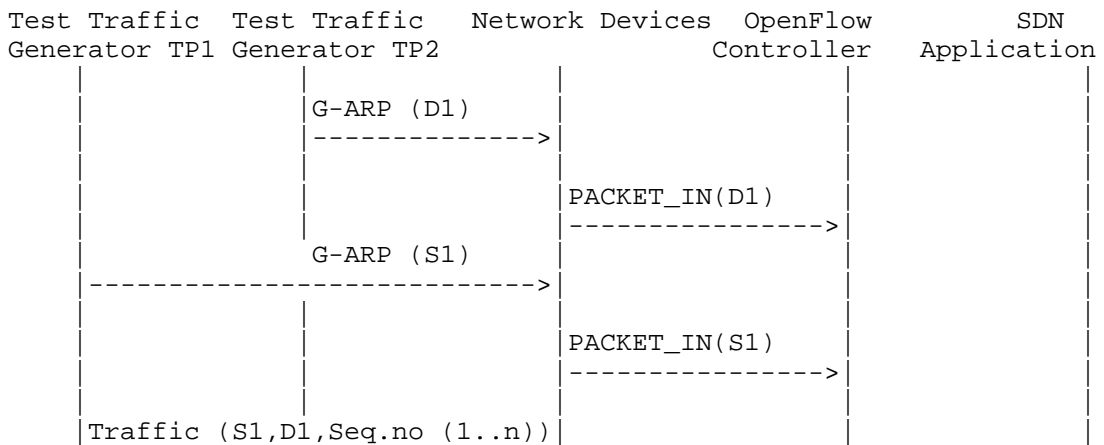
Discussion:

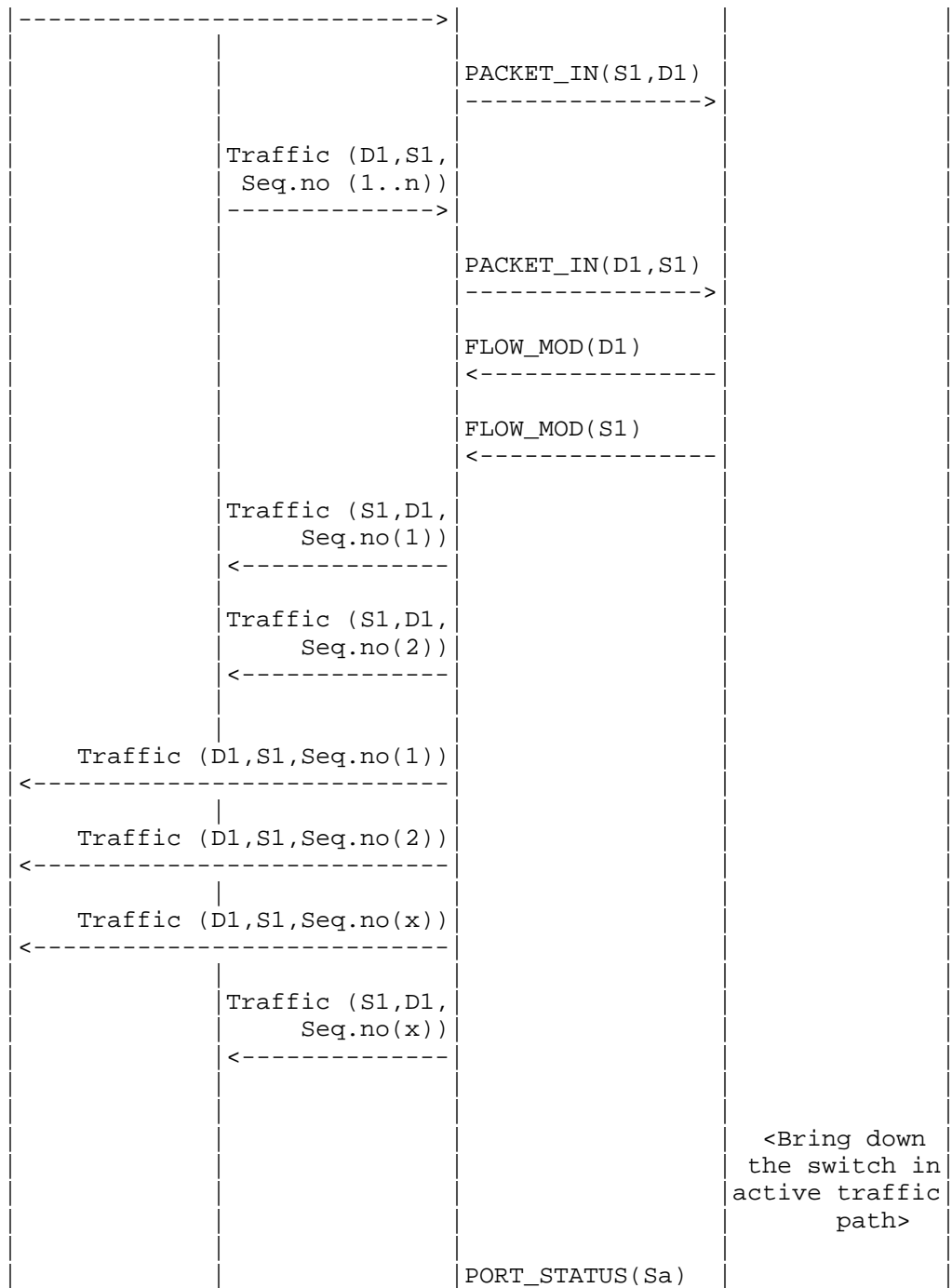
The time difference between the last valid frame received before the traffic loss and the first frame received after the traffic loss will provide the controller failover time.

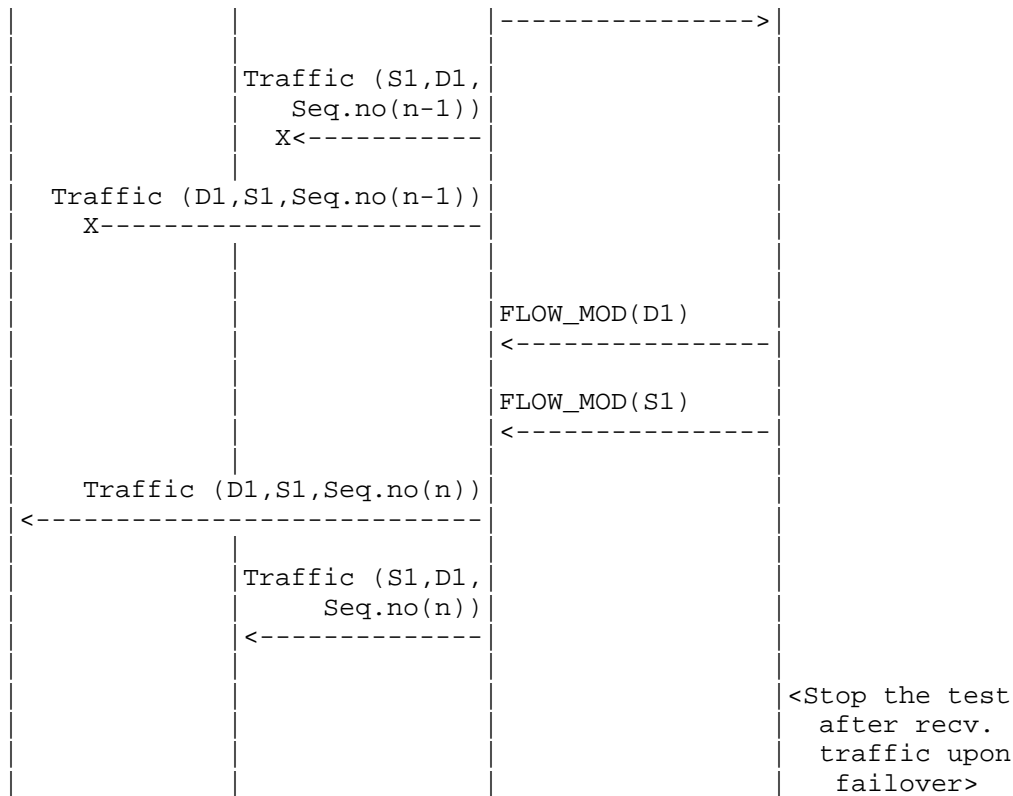
If there is no frame loss during controller failover time, the controller failover time can be deemed negligible.

B.7.2. Network Re-Provisioning Time

Procedure:







Legend:

- G-ARP: Gratuitous ARP message.
- Seq.no: Sequence number.
- Sa: Neighbour switch of the switch that was brought down.

Discussion:

The time difference between the last valid frame received before the traffic loss (Packet number with sequence number x) and the first frame received after the traffic loss (packet with sequence number n) will provide the network path re-provisioning time.

Note that the test is valid only when the controller provisions the alternate path upon network failure.

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June 28, 2017

Benchmarking Methodology for SDN Controller Performance  
draft-ietf-bmwg-sdn-controller-benchmark-meth-04

Abstract

This document defines the methodologies for benchmarking control plane performance of SDN controllers. Terminology related to benchmarking SDN controllers is described in the companion terminology document. SDN controllers have been implemented with many varying designs in order to achieve their intended network functionality. Hence, the authors have taken the approach of considering an SDN controller as a black box, defining the methodology in a manner that is agnostic to protocols and network services supported by controllers. The intent of this document is to provide a standard mechanism to measure the performance of all controller implementations.

Status of this Memo

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## 1. Introduction

This document provides generic methodologies for benchmarking SDN controller performance. An SDN controller may support many northbound and southbound protocols, implement a wide range of applications, and work solely, or as a group to achieve the desired functionality. This document considers an SDN controller as a black box, regardless of design and implementation. The tests defined in the document can be used to benchmark SDN controller for performance, scalability, reliability and security independent of northbound and southbound protocols. These tests can be performed on an SDN controller running as a virtual machine (VM) instance or on a bare metal server. This document is intended for those who want to measure the SDN controller performance as well as compare various SDN controllers performance.

Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119.

## 2. Scope

3. This document defines methodology to measure the networking metrics of SDN controllers. For the purpose of this memo, the SDN controller is a function that manages and controls Network Devices. Any SDN controller without a control capability is out of scope for this memo. The tests defined in this document enable benchmarking of SDN Controllers in two ways; as a standalone controller and as a cluster of homogeneous controllers. These tests are recommended for execution in lab environments rather than in live network deployments. Performance benchmarking of a federation of controllers is beyond the scope of this document. Test Setup

The tests defined in this document enable measurement of an SDN controllers performance in standalone mode and cluster mode. This section defines common reference topologies that are later referred to in individual tests (Additional forwarding Plane topologies are provided in Appendix A).

3.1. Test setup - Controller working in Standalone Mode

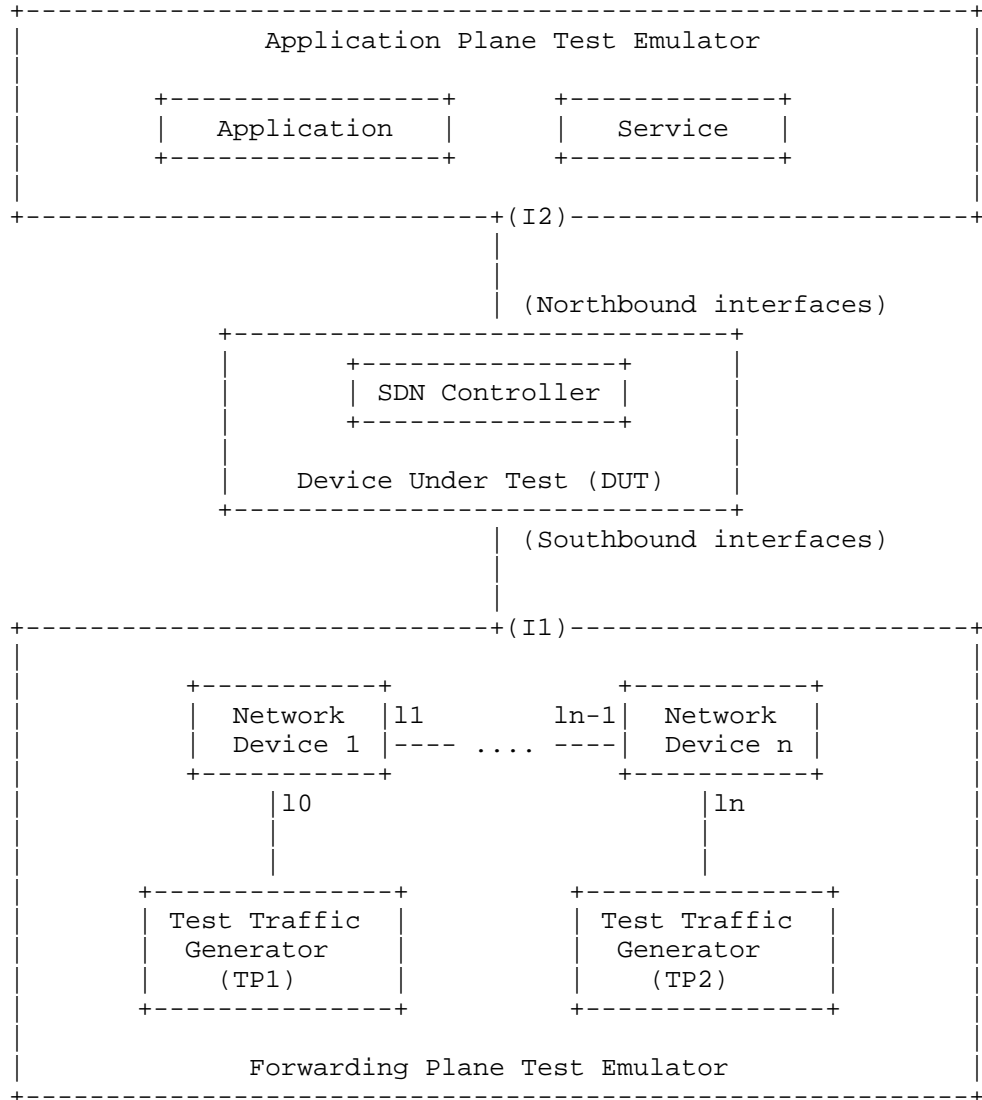


Figure 1

3.2. Test setup - Controller working in Cluster Mode

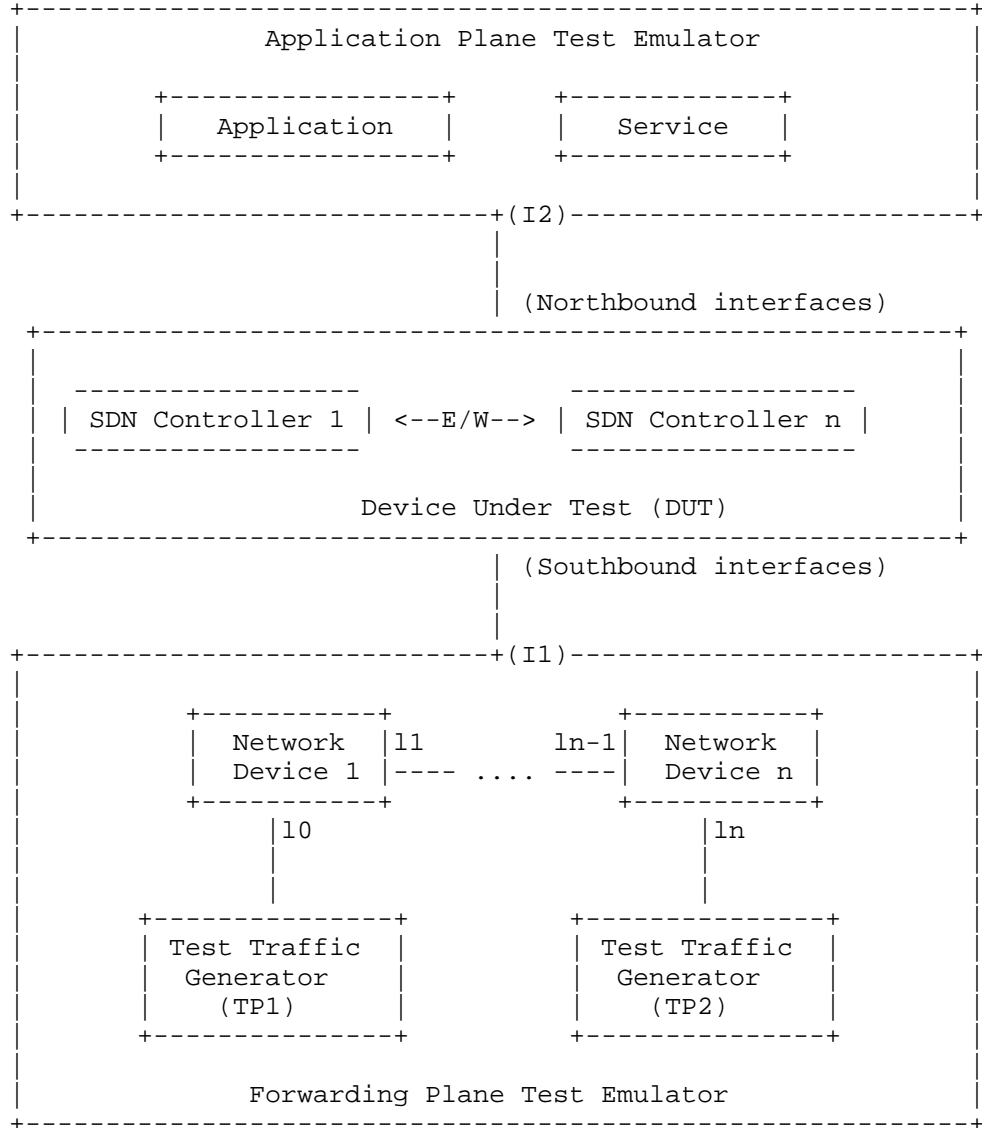


Figure 2

## 4. Test Considerations

### 4.1. Network Topology

The test cases SHOULD use Leaf-Spine topology with at least 1 Network Device in the topology for benchmarking. The test traffic generators TP1 and TP2 SHOULD be connected to the first and the last leaf Network Device. If a test case uses test topology with 1 Network Device, the test traffic generators TP1 and TP2 SHOULD be connected to the same node. However to achieve a complete performance characterization of the SDN controller, it is recommended that the controller be benchmarked for many network topologies and a varying number of Network Devices. This document includes two sample test topologies, defined in Section 10 - Appendix A for reference. Further, care should be taken to make sure that a loop prevention mechanism is enabled either in the SDN controller, or in the network when the topology contains redundant network paths.

### 4.2. Test Traffic

Test traffic is used to notify the controller about the asynchronous arrival of new flows. The test cases SHOULD use frame sizes of 128, 512 and 1508 bytes for benchmarking. Testing using jumbo frames are optional.

### 4.3. Test Emulator Requirements

The Test Emulator SHOULD time stamp the transmitted and received control messages to/from the controller on the established network connections. The test cases use these values to compute the controller processing time.

### 4.4. Connection Setup

There may be controller implementations that support unencrypted and encrypted network connections with Network Devices. Further, the controller may have backward compatibility with Network Devices running older versions of southbound protocols. It may be useful to measure the controller performance be measured with one or more applicable connection setup methods defined below.

1. Unencrypted connection with Network Devices, running same protocol version.
2. Unencrypted connection with Network Devices, running different protocol versions.

Example:



- a. Controller running current protocol version and switch running older protocol version
- b. Controller running older protocol version and switch running current protocol version
3. Encrypted connection with Network Devices, running same protocol version
4. Encrypted connection with Network Devices, running different protocol versions.

Example:

- a. Controller running current protocol version and switch running older protocol version
- b. Controller running older protocol version and switch running current protocol version

#### 4.5. Measurement Point Specification and Recommendation

The measurement accuracy depends on several factors including the point of observation where the indications are captured. For example, the notification can be observed at the controller or test emulator. The test operator SHOULD make the observations/measurements at the interfaces of test emulator unless it is explicitly mentioned otherwise in the individual test. In any case, the locations of measurement points MUST be reported.

#### 4.6. Connectivity Recommendation

The SDN controller in the test setup SHOULD be connected directly with the forwarding and the management plane test emulators to avoid any delays or failure introduced by the intermediate devices during benchmarking tests. When the controller is implemented as a virtual machine, details of the physical and logical connectivity MUST be reported.

#### 4.7. Test Repeatability

To increase the confidence in measured result, it is recommended that each test SHOULD be repeated a minimum of 10 times.

##### Test Reporting

Each test has a reporting format that contains some global and identical reporting components, and some individual components that are specific to individual tests. The following test configuration parameters and controller settings parameters MUST be reflected in the test report.

##### Test Configuration Parameters:

1. Controller name and version
2. Northbound protocols and versions
3. Southbound protocols and versions
4. Controller redundancy mode (Standalone or Cluster Mode)
5. Connection setup (Unencrypted or Encrypted)
6. Network Topology (Mesh or Tree or Linear)
7. Network Device Type (Physical or Virtual or Emulated)
8. Number of Nodes
9. Number of Links
10. Dataplane Test Traffic Type
11. Controller System Configuration (e.g., Physical or Virtual Machine, CPU, Memory, Caches, Operating System, Interface Speed, Storage)
12. Reference Test Setup (e.g., Section 3.1 etc.,)

Controller Settings Parameters:

1. Topology re-discovery timeout
2. Controller redundancy mode (e.g., active-standby etc.,)
3. Controller state persistence enabled/disabled

To ensure the repeatability of test, the following capabilities of test emulator SHOULD be reported

1. Maximum number of Network Devices that the forwarding plane emulates
2. Control message processing time (e.g., Topology Discovery Messages)

One way to determine the above two values are to simulate the required control sessions and messages from the control plane.

## 5. Benchmarking Tests

### 5.1. Performance

#### 5.1.1. Network Topology Discovery Time

Objective:

The time taken by controller(s) to determine the complete network topology, defined as the interval starting with the first discovery message from the controller(s) at its Southbound interface, ending with all features of the static topology determined.

## Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

## Prerequisite:

1. The controller MUST support network discovery.
2. Tester should be able to retrieve the discovered topology information either through the controller's management interface, or northbound interface to determine if the discovery was successful and complete.
3. Ensure that the controller's topology re-discovery timeout has been set to the maximum value to avoid initiation of re-discovery process in the middle of the test.

## Procedure:

1. Ensure that the controller is operational, its network applications, northbound and southbound interfaces are up and running.
2. Establish the network connections between controller and Network Devices.
3. Record the time for the first discovery message (Tm1) received from the controller at forwarding plane test emulator interface I1.
4. Query the controller every 3 seconds to obtain the discovered network topology information through the northbound interface or the management interface and compare it with the deployed network topology information.
5. Stop the test when the discovered topology information matches the deployed network topology, or when the discovered topology information for 3 consecutive queries return the same details.
6. Record the time last discovery message (Tmn) sent to controller from the forwarding plane test emulator interface (I1) when the test completed successfully. (e.g., the topology matches).

## Measurement:

Topology Discovery Time  $Tr1 = Tmn - Tm1$ .

$$\text{Average Topology Discovery Time} = \frac{Tr1 + Tr2 + Tr3 \dots Trn}{\text{Total Test Iterations}}$$

#### Reporting Format:

The Topology Discovery Time results MUST be reported in the format of a table, with a row for each successful iteration. The last row of the table indicates the average Topology Discovery Time.

If this test is repeated with varying number of nodes over the same topology, the results SHOULD be reported in the form of a graph. The X coordinate SHOULD be the Number of nodes (N), the Y coordinate SHOULD be the average Topology Discovery Time.

If this test is repeated with same number of nodes over different topologies, the results SHOULD be reported in the form of a graph. The X coordinate SHOULD be the Topology Type, the Y coordinate SHOULD be the average Topology Discovery Time.

#### 5.1.2. Asynchronous Message Processing Time

##### Objective:

The time taken by controller(s) to process an asynchronous message, defined as the interval starting with an asynchronous message from a network device after the discovery of all the devices by the controller(s), ending with a response message from the controller(s) at its Southbound interface.

##### Reference Test Setup:

This test SHOULD use one of the test setup described in section 3.1 or section 3.2 of this document in combination with Appendix A.

##### Prerequisite:

1. The controller MUST have successfully completed the network topology discovery for the connected Network Devices.

##### Procedure:

1. Generate asynchronous messages from every connected Network Device, to the SDN controller, one at a time in series from the forwarding plane test emulator for the test duration.
2. Record every request transmit (T1) timestamp and the corresponding response (R1) received timestamp at the forwarding plane test emulator interface (I1) for every successful message exchange.

Measurement:

$$\text{Asynchronous Message Processing Time } Tr1 = \frac{(R1-T1) + (R2-T2) \dots (Rn-Tn)}{Nrx}$$

Where Nrx is the total number of successful messages exchanged

$$\text{Average Asynchronous Message Processing Time} = \frac{Tr1 + Tr2 + Tr3 \dots Trn}{\text{Total Test Iterations}}$$

Reporting Format:

The Asynchronous Message Processing Time results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the average Asynchronous Message Processing Time.

The report should capture the following information in addition to the configuration parameters captured in section 5. - Successful messages exchanged (Nrx)

If this test is repeated with varying number of nodes with same topology, the results SHOULD be reported in the form of a graph. The X coordinate SHOULD be the Number of nodes (N), the Y coordinate SHOULD be the average Asynchronous Message Processing Time.

If this test is repeated with same number of nodes using different topologies, the results SHOULD be reported in the form of a graph. The X coordinate SHOULD be the Topology Type, the Y coordinate SHOULD be the average Asynchronous Message Processing Time.

### 5.1.3. Asynchronous Message Processing Rate

Objective:

The maximum number of asynchronous messages (session aliveness check message, new flow arrival notification message etc.) that the controller(s) can process, defined as the iteration starting with sending asynchronous messages to the controller (s) at the maximum possible rate and ending with an iteration that the controller(s) processes the received asynchronous messages without dropping.

Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

Prerequisite:

1. The controller MUST have successfully completed the network topology discovery for the connected Network Devices.

Procedure:

1. Generate asynchronous messages continuously at the maximum possible rate on the established connections from all the emulated/simulated Network Devices for the given Test Duration (Td).
2. Record the total number of responses received from the controller (Nrx1) as well as the number of messages sent (Ntx1) to the controller within the test duration(Td).
3. Repeat the test by generating the asynchronous messages equal to the number of responses received from the controller in last iteration for the given test duration (Td).
4. Test MUST be repeated until the generated asynchronous messages and the responses received from the controller are equal for two consecutive iterations.
5. Record the number of responses received from the controller (Nrxn) as well as the number of messages sent(Ntxn) to the controller in the last test iteration.

Measurement:

$$\text{Asynchronous Message Processing Rate Tr1} = \frac{\text{Nrxn}}{\text{Td}}$$

$$\text{Average Asynchronous Message Processing Rate} = \frac{\text{Tr1} + \text{Tr2} + \text{Tr3}.. \text{Trn}}{\text{Total Test Iterations}}$$

Reporting Format:

The Asynchronous Message Processing Rate results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the average Asynchronous Message Processing Rate.

The report should capture the following information in addition to the configuration parameters captured in section 5.

- Offered rate (Ntx)
- Loss Ratio

If this test is repeated with varying number of nodes over same topology, the results SHOULD be reported in the form of a graph. The X coordinate SHOULD be the Number of nodes (N), the Y coordinate SHOULD be the average Asynchronous Message Processing Rate.

If this test is repeated with same number of nodes over different topologies, the results SHOULD be reported in the form of a graph. The X coordinate SHOULD be the Topology Type, the Y coordinate SHOULD be the average Asynchronous Message Processing Rate.

#### 5.1.4. Reactive Path Provisioning Time

Objective:

The time taken by the controller to setup a path reactively between source and destination node, defined as the interval starting with the first flow provisioning request message received by the controller(s) at its Southbound interface, ending with the last flow provisioning response message sent from the controller(s) at its Southbound interface.

Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A. The number of Network Devices in the path is a parameter of the test that may be varied from 2 to maximum discovery size in repetitions of this test.

Prerequisite:

1. The controller MUST contain the network topology information for the deployed network topology.
2. The controller should have the knowledge about the location of destination endpoint for which the path has to be provisioned. This can be achieved through dynamic learning or static provisioning.

3. Ensure that the default action for 'flow miss' in Network Device is configured to 'send to controller'.
4. Ensure that each Network Device in a path requires the controller to make the forwarding decision while paving the entire path.

Procedure:

1. Send a single traffic stream from the test traffic generator TP1 to test traffic generator TP2.
2. Record the time of the first flow provisioning request message sent to the controller (Tsf1) from the Network Device at the forwarding plane test emulator interface (I1).
3. Wait for the arrival of first traffic frame at the Traffic Endpoint TP2 or the expiry of test duration (Td).
4. Record the time of the last flow provisioning response message received from the controller (Tdf1) to the Network Device at the forwarding plane test emulator interface (I1).

Measurement:

Reactive Path Provisioning Time  $Tr1 = Tdf1 - Tsf1$ .

$$\text{Average Reactive Path Provisioning Time} = \frac{Tr1 + Tr2 + Tr3 \dots Trn}{\text{Total Test Iterations}}$$

Reporting Format:

The Reactive Path Provisioning Time results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the Average Reactive Path Provisioning Time

The report should capture the following information in addition to the configuration parameters captured in section 5.

- Number of Network Devices in the path

#### 5.1.5. Proactive Path Provisioning Time

Objective:

The time taken by the controller to setup a path proactively between source and destination node, defined as the interval starting with



the first proactive flow provisioned in the controller(s) at its Northbound interface, ending with the last flow provisioning response message sent from the controller(s) at its Southbound interface.

#### Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

#### Prerequisite:

1. The controller MUST contain the network topology information for the deployed network topology.
2. The controller should have the knowledge about the location of destination endpoint for which the path has to be provisioned. This can be achieved through dynamic learning or static provisioning.
3. Ensure that the default action for flow miss in Network Device is 'drop'.

#### Procedure:

1. Send a single traffic stream from test traffic generator TP1 to TP2.
2. Install the flow entries to reach from test traffic generator TP1 to the test traffic generator TP2 through controller's northbound or management interface.
3. Wait for the arrival of first traffic frame at the test traffic generator TP2 or the expiry of test duration (Td).
4. Record the time when the proactive flow is provisioned in the Controller (Tsf1) at the management plane test emulator interface I2.
5. Record the time of the last flow provisioning message received from the controller (Tdf1) at the forwarding plane test emulator interface I1.

#### Measurement:

Proactive Flow Provisioning Time  $Tr1 = Tdf1 - Tsf1$ .

$$\text{Average Proactive Path Provisioning Time} = \frac{Tr1 + Tr2 + Tr3 \dots Trn}{\text{Total Test Iterations}}$$

#### Reporting Format:

The Proactive Path Provisioning Time results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the Average Proactive Path Provisioning Time.

The report should capture the following information in addition to the configuration parameters captured in section 5.

- Number of Network Devices in the path

#### 5.1.6. Reactive Path Provisioning Rate

##### Objective:

The maximum number of independent paths a controller can concurrently establish between source and destination nodes reactively, defined as the number of paths provisioned by the controller(s) at its Southbound interface for the flow provisioning requests received for path provisioning at its Southbound interface between the start of the test and the expiry of given test duration.

##### Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

##### Prerequisite:

1. The controller MUST contain the network topology information for the deployed network topology.
2. The controller should have the knowledge about the location of destination addresses for which the paths have to be provisioned. This can be achieved through dynamic learning or static provisioning.
3. Ensure that the default action for 'flow miss' in Network Device is configured to 'send to controller'.
4. Ensure that each Network Device in a path requires the controller to make the forwarding decision while provisioning the entire path.

##### Procedure:

1. Send traffic with unique source and destination addresses from test traffic generator TP1.
2. Record total number of unique traffic frames (Ndf) received at the test traffic generator TP2 within the test duration (Td).

Measurement:

$$\text{Reactive Path Provisioning Rate Tr1} = \frac{\text{Ndf}}{\text{Td}}$$

$$\text{Average Reactive Path Provisioning Rate} = \frac{\text{Tr1} + \text{Tr2} + \text{Tr3} \dots \text{Trn}}{\text{Total Test Iterations}}$$

Reporting Format:

The Reactive Path Provisioning Rate results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the Average Reactive Path Provisioning Rate.

The report should capture the following information in addition to the configuration parameters captured in section 5.

- Number of Network Devices in the path
- Offered rate

#### 5.1.7. Proactive Path Provisioning Rate

Objective:

Measure the maximum rate of independent paths a controller can concurrently establish between source and destination nodes proactively, defined as the number of paths provisioned by the controller(s) at its Southbound interface for the paths requested in its Northbound interface between the start of the test and the expiry of given test duration . The measurement is based on dataplane observations of successful path activation

Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

Prerequisite:

1. The controller MUST contain the network topology information for the deployed network topology.

2. The controller should have the knowledge about the location of destination addresses for which the paths have to be provisioned. This can be achieved through dynamic learning or static provisioning.

3. Ensure that the default action for flow miss in Network Device is 'drop'.

Procedure:

1. Send traffic continuously with unique source and destination addresses from test traffic generator TP1.

2. Install corresponding flow entries to reach from simulated sources at the test traffic generator TP1 to the simulated destinations at test traffic generator TP2 through controller's northbound or management interface.

3. Record total number of unique traffic frames received (Ndf) at the test traffic generator TP2 within the test duration (Td).

Measurement:

$$\text{Proactive Path Provisioning Rate } Tr1 = \frac{Ndf}{Td}$$

$$\text{Average Proactive Path Provisioning Rate} = \frac{Tr1 + Tr2 + Tr3 \dots Trn}{\text{Total Test Iterations}}$$

Reporting Format:

The Proactive Path Provisioning Rate results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the Average Proactive Path Provisioning Rate.

The report should capture the following information in addition to the configuration parameters captured in section 5.

- Number of Network Devices in the path
- Offered rate

## 5.1.8. Network Topology Change Detection Time

## Objective:

The amount of time required for the controller to detect any changes in the network topology, defined as the interval starting with the notification message received by the controller(s) at its Southbound interface, ending with the first topology rediscovery messages sent from the controller(s) at its Southbound interface.

## Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

## Prerequisite:

1. The controller MUST have successfully discovered the network topology information for the deployed network topology.
2. The periodic network discovery operation should be configured to twice the Test duration (Td) value.

## Procedure:

1. Trigger a topology change event by bringing down an active Network Device in the topology.
2. Record the time when the first topology change notification is sent to the controller (Tcn) at the forwarding plane test emulator interface (I1).
3. Stop the test when the controller sends the first topology re-discovery message to the Network Device or the expiry of test interval (Td).
4. Record the time when the first topology re-discovery message is received from the controller (Tcd) at the forwarding plane test emulator interface (I1)

## Measurement:

Network Topology Change Detection Time  $Tr1 = Tcd - Tcn$ .

$$\text{Average Network Topology Change Detection Time} = \frac{Tr1 + Tr2 + Tr3 \dots Trn}{\text{Total Test Iterations}}$$

**Reporting Format:**

The Network Topology Change Detection Time results MUST be reported in the format of a table with a row for each iteration. The last row of the table indicates the average Network Topology Change Time.

**5.2. Scalability****5.2.1. Control Session Capacity****Objective:**

Measure the maximum number of control sessions the controller can maintain, defined as the number of sessions that the controller can accept from network devices, starting with the first control session, ending with the last control session that the controller(s) accepts at its Southbound interface.

**Reference Test Setup:**

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

**Procedure:**

1. Establish control connection with controller from every Network Device emulated in the forwarding plane test emulator.
2. Stop the test when the controller starts dropping the control connections.
3. Record the number of successful connections established with the controller (CCn) at the forwarding plane test emulator.

**Measurement:**

Control Sessions Capacity = CCn.

**Reporting Format:**

The Control Session Capacity results MUST be reported in addition to the configuration parameters captured in section 5.

### 5.2.2. Network Discovery Size

#### Objective:

Measure the network size (number of nodes, links and hosts) that a controller can discover, defined as the size of a network that the controller(s) can discover, starting from a network topology given by the user for discovery, ending with the topology that the controller(s) could successfully discover.

#### Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

#### Prerequisite:

1. The controller MUST support automatic network discovery.
2. Tester should be able to retrieve the discovered topology information either through controller's management interface or northbound interface.

#### Procedure:

1. Establish the network connections between controller and network nodes.
2. Query the controller for the discovered network topology information and compare it with the deployed network topology information.
3. 3a. Increase the number of nodes by 1 when the comparison is successful and repeat the test.
4. 3b. Decrease the number of nodes by 1 when the comparison fails and repeat the test.
5. Continue the test until the comparison of step 3b is successful.
6. Record the number of nodes for the last iteration ( $N_s$ ) where the topology comparison was successful.

#### Measurement:

Network Discovery Size =  $N_s$ .

#### Reporting Format:

The Network Discovery Size results MUST be reported in addition to the configuration parameters captured in section 5.

### 5.2.3. Forwarding Table Capacity

#### Objective:

Measure the maximum number of flow entries a controller can manage in its Forwarding table.

#### Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

#### Prerequisite:

1. The controller Forwarding table should be empty.
2. Flow Idle time MUST be set to higher or infinite value.
3. The controller MUST have successfully completed network topology discovery.
4. Tester should be able to retrieve the forwarding table information either through controller's management interface or northbound interface.

#### Procedure:

##### Reactive Flow Provisioning Mode:

1. Send bi-directional traffic continuously with unique source and/or destination addresses from test traffic generators TP1 and TP2 at the asynchronous message processing rate of controller.
2. Query the controller at a regular interval (e.g., 5 seconds) for the number of learnt flow entries from its northbound interface.
3. Stop the test when the retrieved value is constant for three consecutive iterations and record the value received from the last query (Nrp).

##### Proactive Flow Provisioning Mode:

1. Install unique flows continuously through controller's northbound or management interface until a failure response is received from the controller.
2. Record the total number of successful responses (Nrp).

#### Note:

Some controller designs for proactive flow provisioning mode may require the switch to send flow setup requests in order to generate



flow setup responses. In such cases, it is recommended to generate bi-directional traffic for the provisioned flows.

Measurement:

Proactive Flow Provisioning Mode:

Max Flow Entries = Total number of flows provisioned (Nrp)

Reactive Flow Provisioning Mode:

Max Flow Entries = Total number of learnt flow entries (Nrp)

Forwarding Table Capacity = Max Flow Entries.

Reporting Format:

The Forwarding Table Capacity results MUST be tabulated with the following information in addition to the configuration parameters captured in section 5.

- Provisioning Type (Proactive/Reactive)

### 5.3. Security

#### 5.3.1. Exception Handling

Objective:

Determine the effect of handling error packets and notifications on performance tests. The impact MUST be measured for the following performance tests

- a. Path Provisioning Rate
- b. Path Provisioning Time
- c. Network Topology Change Detection Time

Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

## Prerequisite:

1. This test MUST be performed after obtaining the baseline measurement results for the above performance tests.
2. Ensure that the invalid messages are not dropped by the intermediate devices connecting the controller and Network Devices.

## Procedure:

1. Perform the above listed performance tests and send 1% of messages from the Asynchronous Message Processing Rate as invalid messages from the connected Network Devices emulated at the forwarding plane test emulator.
2. Perform the above listed performance tests and send 2% of messages from the Asynchronous Message Processing Rate as invalid messages from the connected Network Devices emulated at the forwarding plane test emulator.

## Note:

Invalid messages can be frames with incorrect protocol fields or any form of failure notifications sent towards controller.

## Measurement:

Measurement MUST be done as per the equation defined in the corresponding performance test measurement section.

## Reporting Format:

The Exception Handling results MUST be reported in the format of table with a column for each of the below parameters and row for each of the listed performance tests.

- Without Exceptions
- With 1% Exceptions
- With 2% Exceptions

### 5.3.2. Denial of Service Handling

#### Objective:

Determine the effect of handling DoS attacks on performance and scalability tests the impact MUST be measured for the following tests:

- a. Path Provisioning Rate
- b. Path Provisioning Time
- c. Network Topology Change Detection Time
- d. Network Discovery Size

#### Reference Test Setup:

The test SHOULD use one of the test setups described in section 3.1 or section 3.2 of this document in combination with Appendix A.

#### Prerequisite:

This test MUST be performed after obtaining the baseline measurement results for the above tests.

#### Procedure:

1. Perform the listed tests and launch a DoS attack towards controller while the test is running.

#### Note:

DoS attacks can be launched on one of the following interfaces.

- a. Northbound (e.g., Sending a huge number of requests on northbound interface)
- b. Management (e.g., Ping requests to controller's management interface)
- c. Southbound (e.g., TCP SYNC messages on southbound interface)

#### Measurement:

Measurement MUST be done as per the equation defined in the corresponding test's measurement section.

#### Reporting Format:

The DoS Attacks Handling results MUST be reported in the format of table with a column for each of the below parameters and row for each of the listed tests.

- Without any attacks
- With attacks

The report should also specify the nature of attack and the interface.

### 5.4. Reliability

#### 5.4.1. Controller Failover Time

##### Objective:

The time taken to switch from an active controller to the backup controller, when the controllers work in redundancy mode and the active controller fails, defined as the interval starting with the active controller bringing down, ending with the first re-discovery message received from the new controller at its Southbound interface.

##### Reference Test Setup:

The test SHOULD use the test setup described in section 3.2 of this document in combination with Appendix A.

##### Prerequisite:

1. Master controller election MUST be completed.
2. Nodes are connected to the controller cluster as per the Redundancy Mode (RM).
3. The controller cluster should have successfully completed the network topology discovery.
4. The Network Device MUST send all new flows to the controller when it receives from the test traffic generator.
5. Controller should have learnt the location of destination (D1) at test traffic generator TP2.

## Procedure:

1. Send uni-directional traffic continuously with incremental sequence number and source addresses from test traffic generator TP1 at the rate that the controller processes without any drops.
2. Ensure that there are no packet drops observed at the test traffic generator TP2.
3. Bring down the active controller.
4. Stop the test when a first frame received on TP2 after failover operation.
5. Record the time at which the last valid frame received (T1) at test traffic generator TP2 before sequence error and the first valid frame received (T2) after the sequence error at TP2

## Measurement:

Controller Failover Time = (T2 - T1)

Packet Loss = Number of missing packet sequences.

## Reporting Format:

The Controller Failover Time results MUST be tabulated with the following information.

- Number of cluster nodes
- Redundancy mode
- Controller Failover Time
- Packet Loss
- Cluster keep-alive interval

## 5.4.2. Network Re-Provisioning Time

## Objective:

The time taken to re-route the traffic by the Controller, when there is a failure in existing traffic paths, defined as the interval starting from the first failure notification message received by the controller, ending with the last flow re-provisioning message sent by the controller at its Southbound interface.

## Reference Test Setup:

This test SHOULD use one of the test setup described in section 3.1 or section 3.2 of this document in combination with Appendix A.

## Prerequisite:

1. Network with the given number of nodes and redundant paths MUST be deployed.
2. Ensure that the controller MUST have knowledge about the location of test traffic generators TP1 and TP2.
3. Ensure that the controller does not pre-provision the alternate path in the emulated Network Devices at the forwarding plane test emulator.

## Procedure:

1. Send bi-directional traffic continuously with unique sequence number from TP1 and TP2.
2. Bring down a link or switch in the traffic path.
3. Stop the test after receiving first frame after network re-convergence.
4. Record the time of last received frame prior to the frame loss at TP2 (TP2-Tlfr) and the time of first frame received after the frame loss at TP2 (TP2-Tffr). There must be a gap in sequence numbers of these frames
5. Record the time of last received frame prior to the frame loss at TP1 (TP1-Tlfr) and the time of first frame received after the frame loss at TP1 (TP1-Tffr).

## Measurement:

Forward Direction Path Re-Provisioning Time (FDRT)  
= (TP2-Tffr - TP2-Tlfr)

Reverse Direction Path Re-Provisioning Time (RDRT)  
= (TP1-Tffr - TP1-Tlfr)

Network Re-Provisioning Time = (FDRT+RDRT)/2

Forward Direction Packet Loss = Number of missing sequence frames at TP1

Reverse Direction Packet Loss = Number of missing sequence frames at TP2

## Reporting Format:

The Network Re-Provisioning Time results MUST be tabulated with the following information.

- Number of nodes in the primary path
- Number of nodes in the alternate path
- Network Re-Provisioning Time
- Forward Direction Packet Loss
- Reverse Direction Packet Loss

## 6. References

## 6.1. Normative References

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- [RFC6241] R. Enns, M. Bjorklund, J. Schoenwaelder, A. Bierman, "Network Configuration Protocol (NETCONF)", RFC 6241, July 2011.
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- [I-D.sdn-controller-benchmark-term] Bhuvaneshwaran.V, Anton Basil, Mark.T, Vishwas Manral, Sarah Banks, "Terminology for Benchmarking SDN Controller Performance", draft-ietf-bmwg-sdn-controller-benchmark-term-04 (Work in progress), June 28, 2017

## 6.2. Informative References

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[OpenContrail] Ankur Singla, Bruno Rijsman, "OpenContrail Architecture Documentation", <http://opencontrail.org/opencontrail-architecture-documentation>

[OpenDaylight] OpenDaylight Controller:Architectural Framework, [https://wiki.opendaylight.org/view/OpenDaylight\\_Controller](https://wiki.opendaylight.org/view/OpenDaylight_Controller)

## 7. IANA Considerations

This document does not have any IANA requests.

## 8. Security Considerations

Benchmarking tests described in this document are limited to the performance characterization of controller in lab environment with isolated network.

The benchmarking network topology will be an independent test setup and MUST NOT be connected to devices that may forward the test traffic into a production network, or misroute traffic to the test management network.

Further, benchmarking is performed on a "black-box" basis, relying solely on measurements observable external to the controller.

Special capabilities SHOULD NOT exist in the controller specifically for benchmarking purposes. Any implications for network security arising from the controller SHOULD be identical in the lab and in production networks

## 9. Acknowledgments

The authors would like to thank the following individuals for providing their valuable comments to the earlier versions of this document: Al Morton (AT&T), Sandeep Gangadharan (HP), M. Georgescu

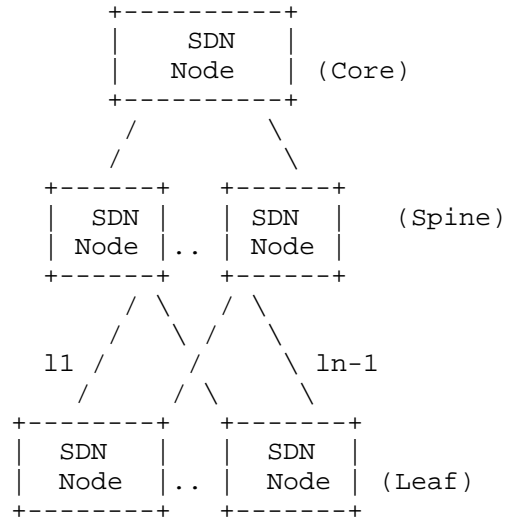


(NAIST), Andrew McGregor (Google), Scott Bradner (Harvard University), Jay Karthik (Cisco), Ramakrishnan (Dell), Khasanov Boris (Huawei), Brian Castelli (Spirent)

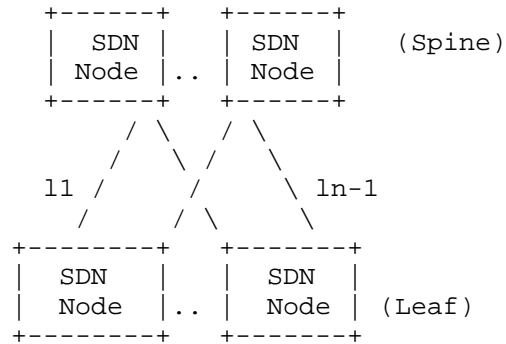
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Appendix A. Example Test Topologies

A.1. Leaf-Spine Topology - Three Tier Network Architecture



A.2. Leaf-Spine Topology - Two Tier Network Architecture



## Appendix B. Benchmarking Methodology using OpenFlow Controllers

This section gives an overview of OpenFlow protocol and provides test methodology to benchmark SDN controllers supporting OpenFlow southbound protocol.

### B.1. Protocol Overview

OpenFlow is an open standard protocol defined by Open Networking Foundation (ONF), used for programming the forwarding plane of network switches or routers via a centralized controller.

### B.2. Messages Overview

OpenFlow protocol supports three messages types namely controller-to-switch, asynchronous and symmetric.

Controller-to-switch messages are initiated by the controller and used to directly manage or inspect the state of the switch. These messages allow controllers to query/configure the switch (Features, Configuration messages), collect information from switch (Read-State message), send packets on specified port of switch (Packet-out message), and modify switch forwarding plane and state (Modify-State, Role-Request messages etc.).

Asynchronous messages are generated by the switch without a controller soliciting them. These messages allow switches to update controllers to denote an arrival of new flow (Packet-in), switch state change (Flow-Removed, Port-status) and error (Error).

Symmetric messages are generated in either direction without solicitation. These messages allow switches and controllers to set up connection (Hello), verify for liveness (Echo) and offer additional functionalities (Experimenter).

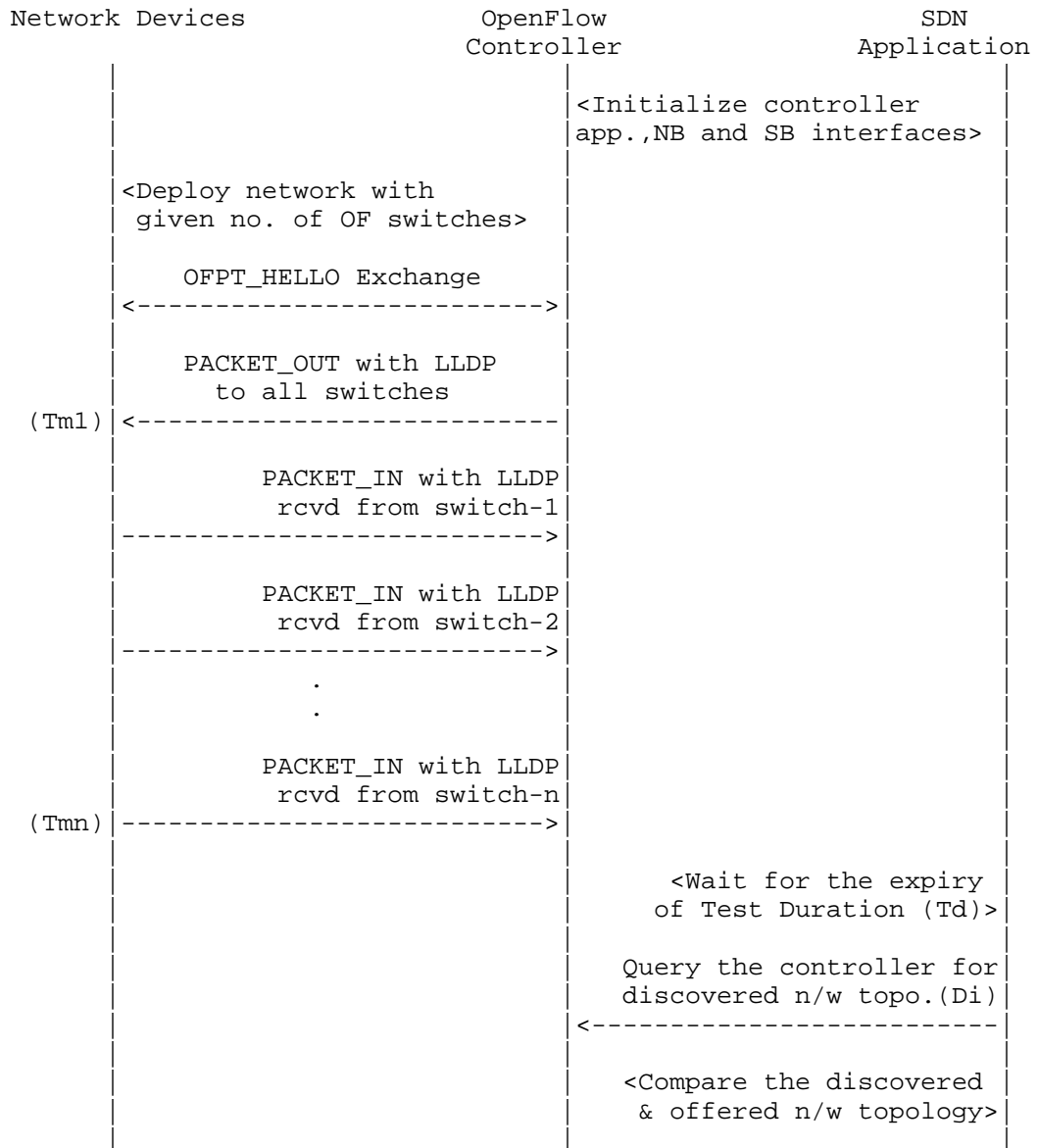
### B.3. Connection Overview

OpenFlow channel is used to exchange OpenFlow message between an OpenFlow switch and an OpenFlow controller. The OpenFlow channel connection can be setup using plain TCP or TLS. By default, a switch establishes single connection with SDN controller. A switch may establish multiple parallel connections to single controller (auxiliary connection) or multiple controllers to handle controller failures and load balancing.

B.4. Performance Benchmarking Tests

B.4.1. Network Topology Discovery Time

Procedure:



Legend:

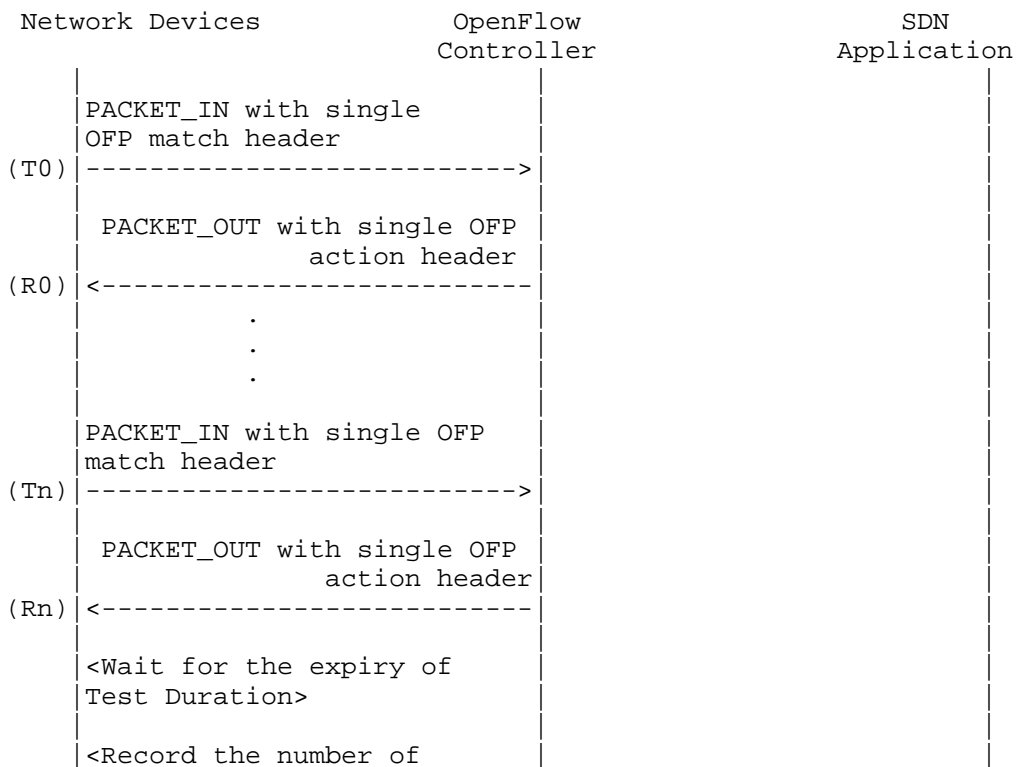
- NB: Northbound
- SB: Southbound
- OF: OpenFlow
- Tm1: Time of reception of first LLDP message from controller
- Tmn: Time of last LLDP message sent to controller

Discussion:

The Network Topology Discovery Time can be obtained by calculating the time difference between the first PACKET\_OUT with LLDP message received from the controller (Tm1) and the last PACKET\_IN with LLDP message sent to the controller (Tmn) when the comparison is successful.

B.4.2. Asynchronous Message Processing Time

Procedure:



PACKET_INs/PACKET_OUTs Exchanged (Nrx)>	
--	--

Legend:

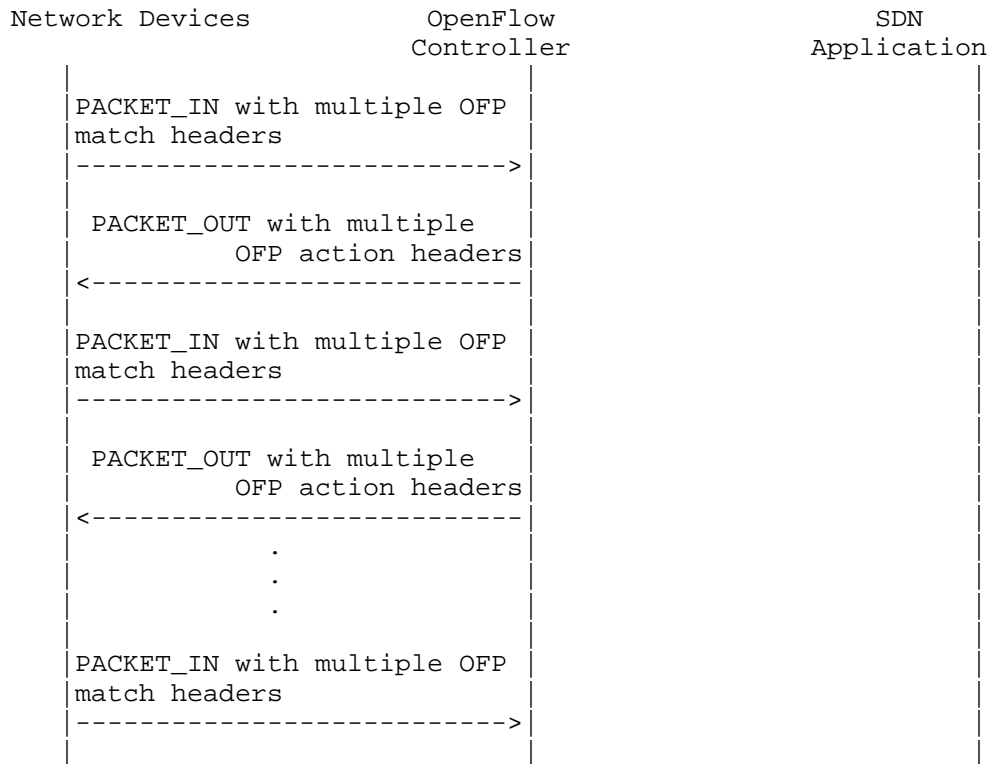
T0,T1, ..Tn are PACKET\_IN messages transmit timestamps.  
 R0,R1, ..Rn are PACKET\_OUT messages receive timestamps.  
 Nrx : Number of successful PACKET\_IN/PACKET\_OUT message exchanges

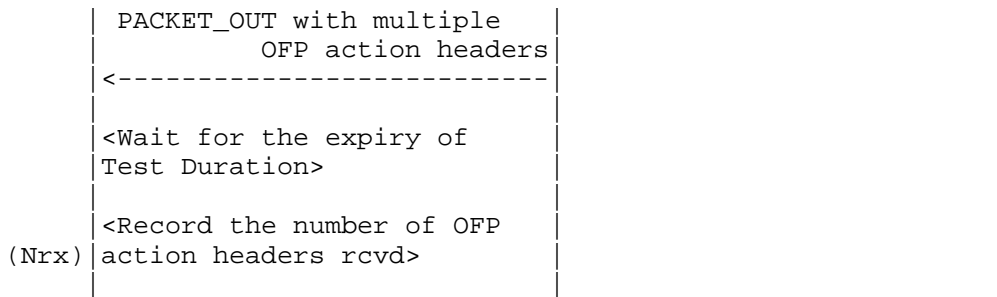
Discussion:

The Asynchronous Message Processing Time will be obtained by sum of  $((R0-T0), (R1-T1)..(Rn - Tn)) / Nrx$ .

B.4.3. Asynchronous Message Processing Rate

Procedure:



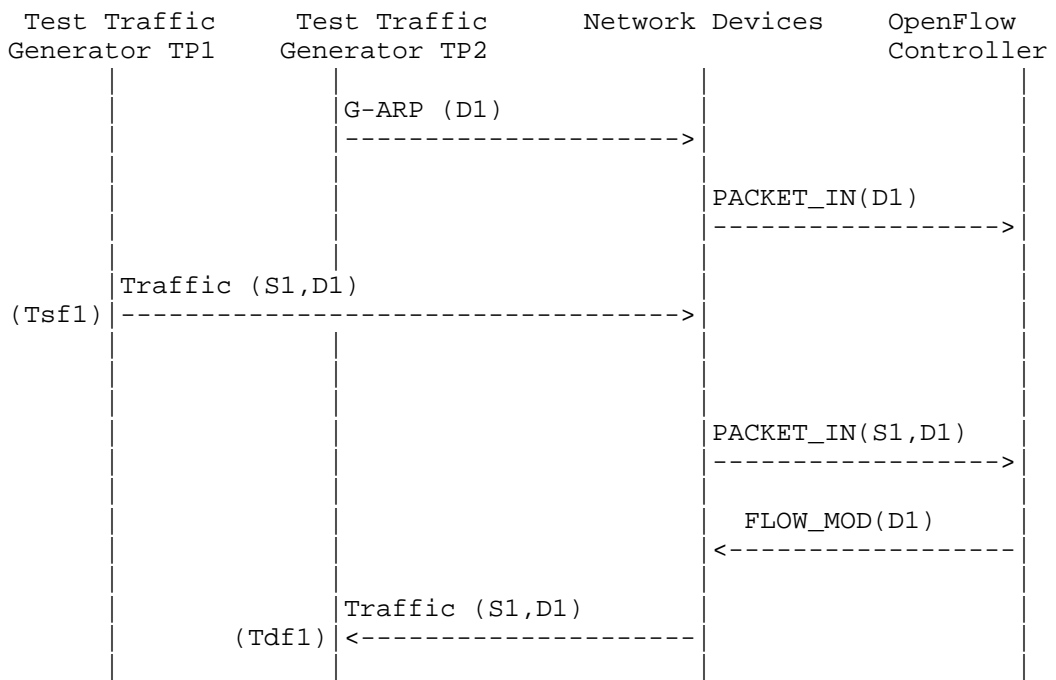


Discussion:

The Asynchronous Message Processing Rate will be obtained by calculating the number of OFP action headers received in all PACKET\_OUT messages during the test duration.

B.4.4. Reactive Path Provisioning Time

Procedure:



Legend:

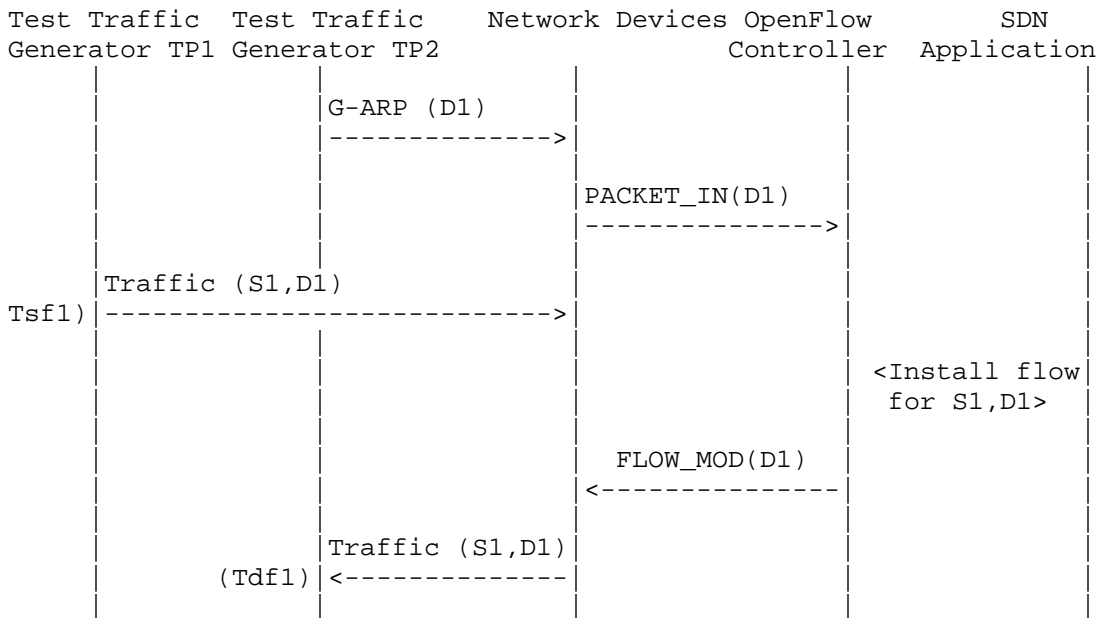
- G-ARP: Gratuitous ARP message.
- Tsfl: Time of first frame sent from TP1
- Tdf1: Time of first frame received from TP2

Discussion:

The Reactive Path Provisioning Time can be obtained by finding the time difference between the transmit and receive time of the traffic (Tsfl-Tdf1).

B.4.5. Proactive Path Provisioning Time

Procedure:



Legend:

- G-ARP: Gratuitous ARP message.
- Tsfl: Time of first frame sent from TP1
- Tdf1: Time of first frame received from TP2

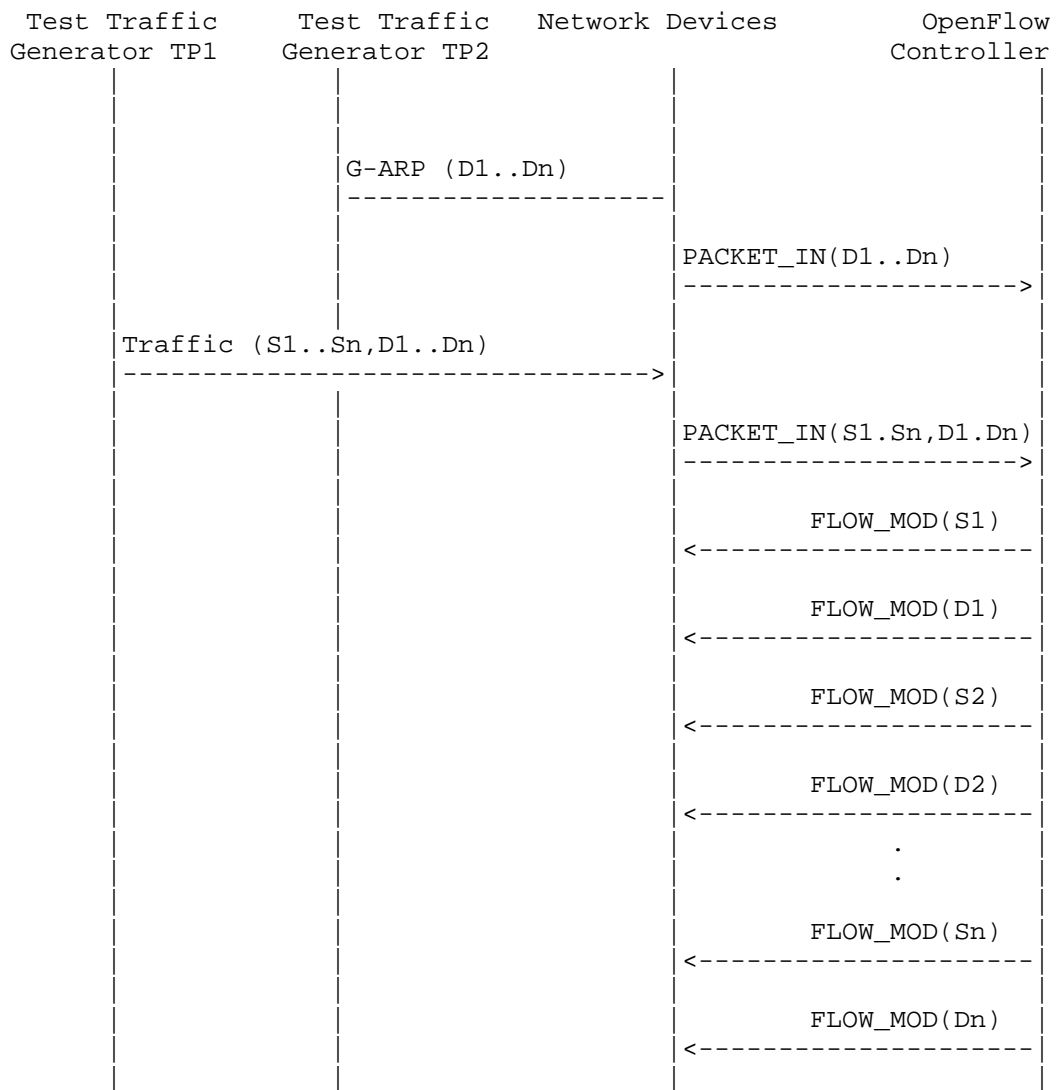


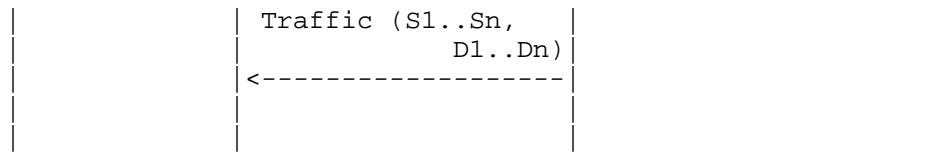
Discussion:

The Proactive Path Provisioning Time can be obtained by finding the time difference between the transmit and receive time of the traffic (Tsf1-Tdf1).

B.4.6. Reactive Path Provisioning Rate

Procedure:





Legend:

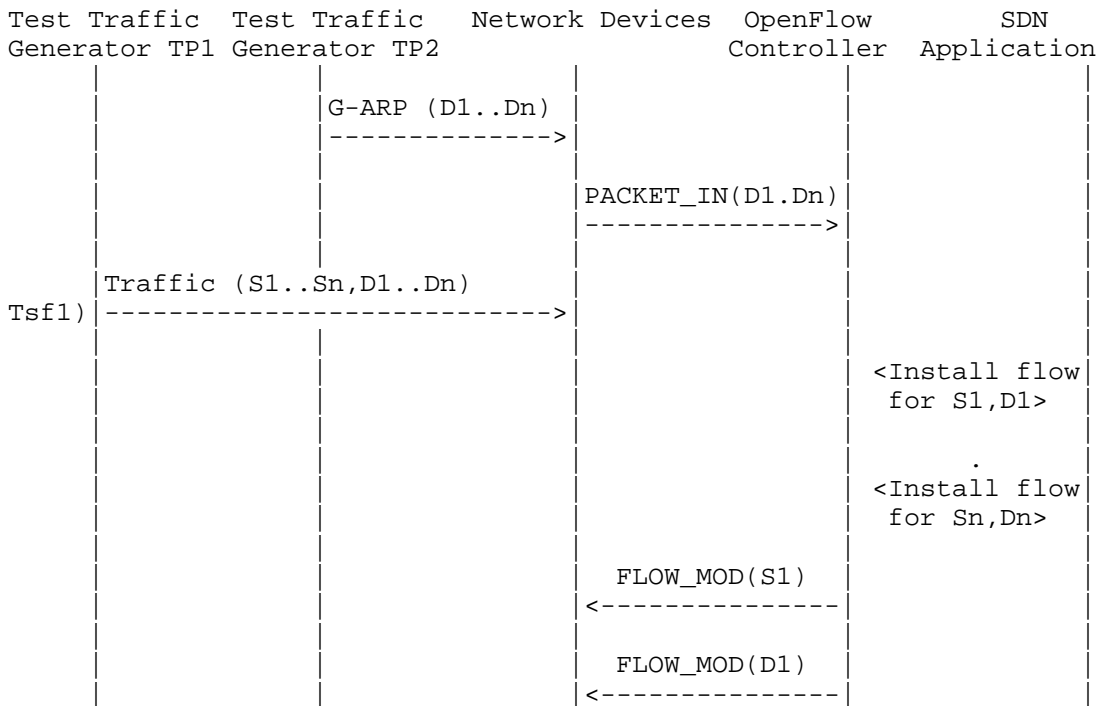
- G-ARP: Gratuitous ARP
- D1..Dn: Destination Endpoint 1, Destination Endpoint 2 .... Destination Endpoint n
- S1..Sn: Source Endpoint 1, Source Endpoint 2 .., Source Endpoint n

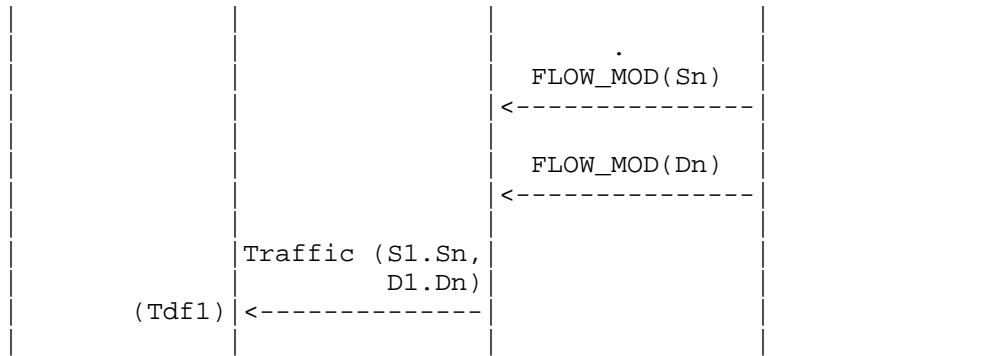
Discussion:

The Reactive Path Provisioning Rate can be obtained by finding the total number of frames received at TP2 after the test duration.

B.4.7. Proactive Path Provisioning Rate

Procedure:





Legend:

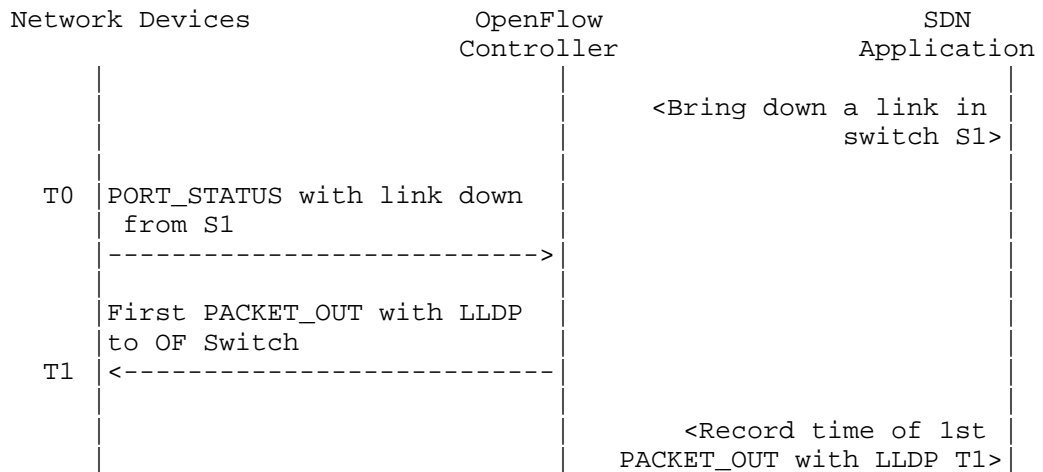
- G-ARP: Gratuitous ARP
- D1..Dn: Destination Endpoint 1, Destination Endpoint 2 .... Destination Endpoint n
- S1..Sn: Source Endpoint 1, Source Endpoint 2 .., Source Endpoint n

Discussion:

The Proactive Path Provisioning Rate can be obtained by finding the total number of frames received at TP2 after the test duration

B.4.8. Network Topology Change Detection Time

Procedure:



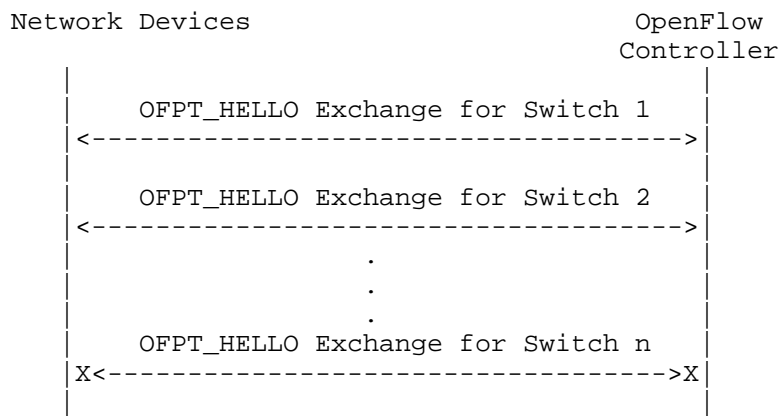
Discussion:

The Network Topology Change Detection Time can be obtained by finding the difference between the time the OpenFlow switch S1 sends the PORT\_STATUS message (T0) and the time that the OpenFlow controller sends the first topology re-discovery message (T1) to OpenFlow switches.

B.5. Scalability

B.5.1. Control Sessions Capacity

Procedure:

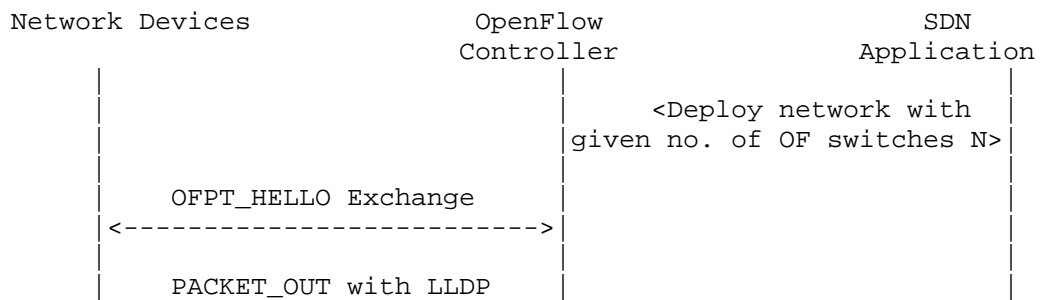


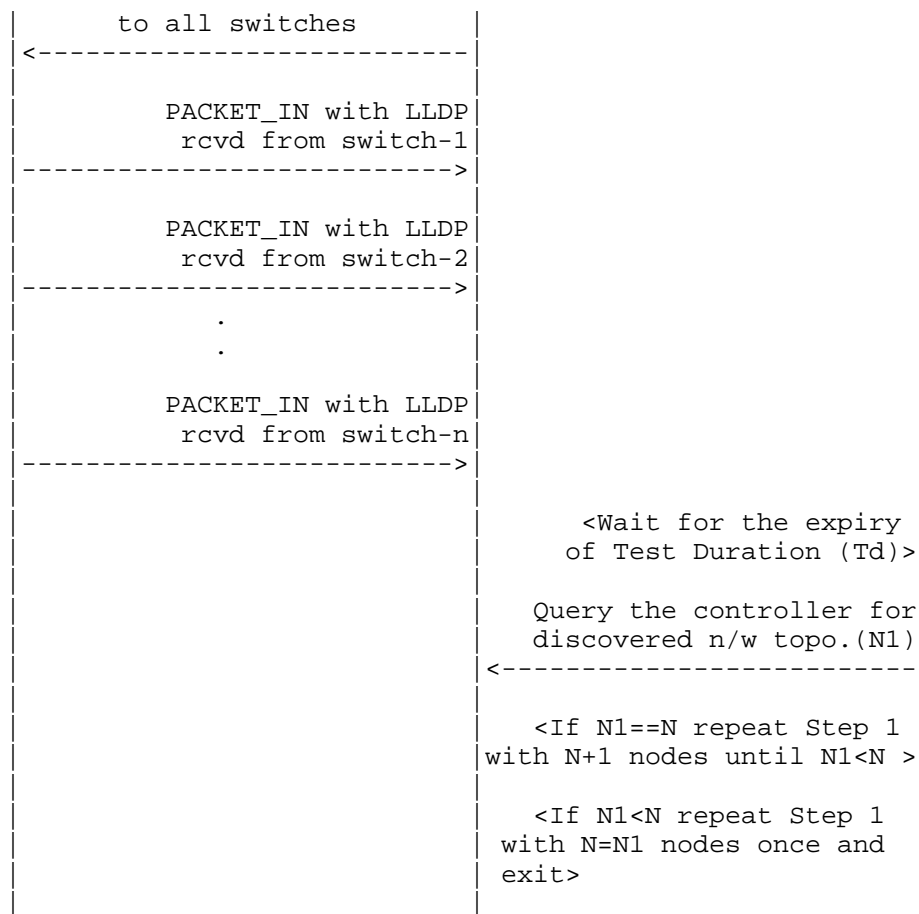
Discussion:

The value of Switch n-1 will provide Control Sessions Capacity.

B.5.2. Network Discovery Size

Procedure:





Legend:

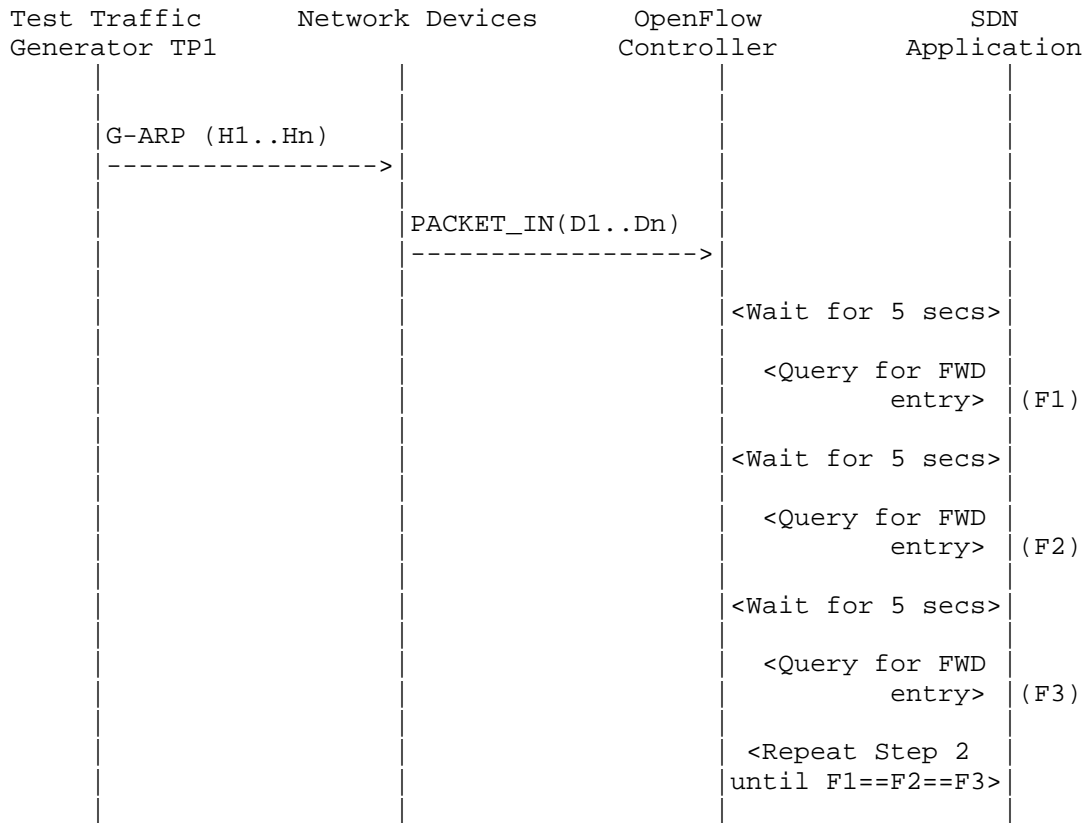
n/w topo: Network Topology  
 OF: OpenFlow

Discussion:

The value of N1 provides the Network Discovery Size value. The test duration can be set to the stipulated time within which the user expects the controller to complete the discovery process.

B.5.3. Forwarding Table Capacity

Procedure:



Legend:

- G-ARP: Gratuitous ARP
- H1..Hn: Host 1 .. Host n
- FWD: Forwarding Table

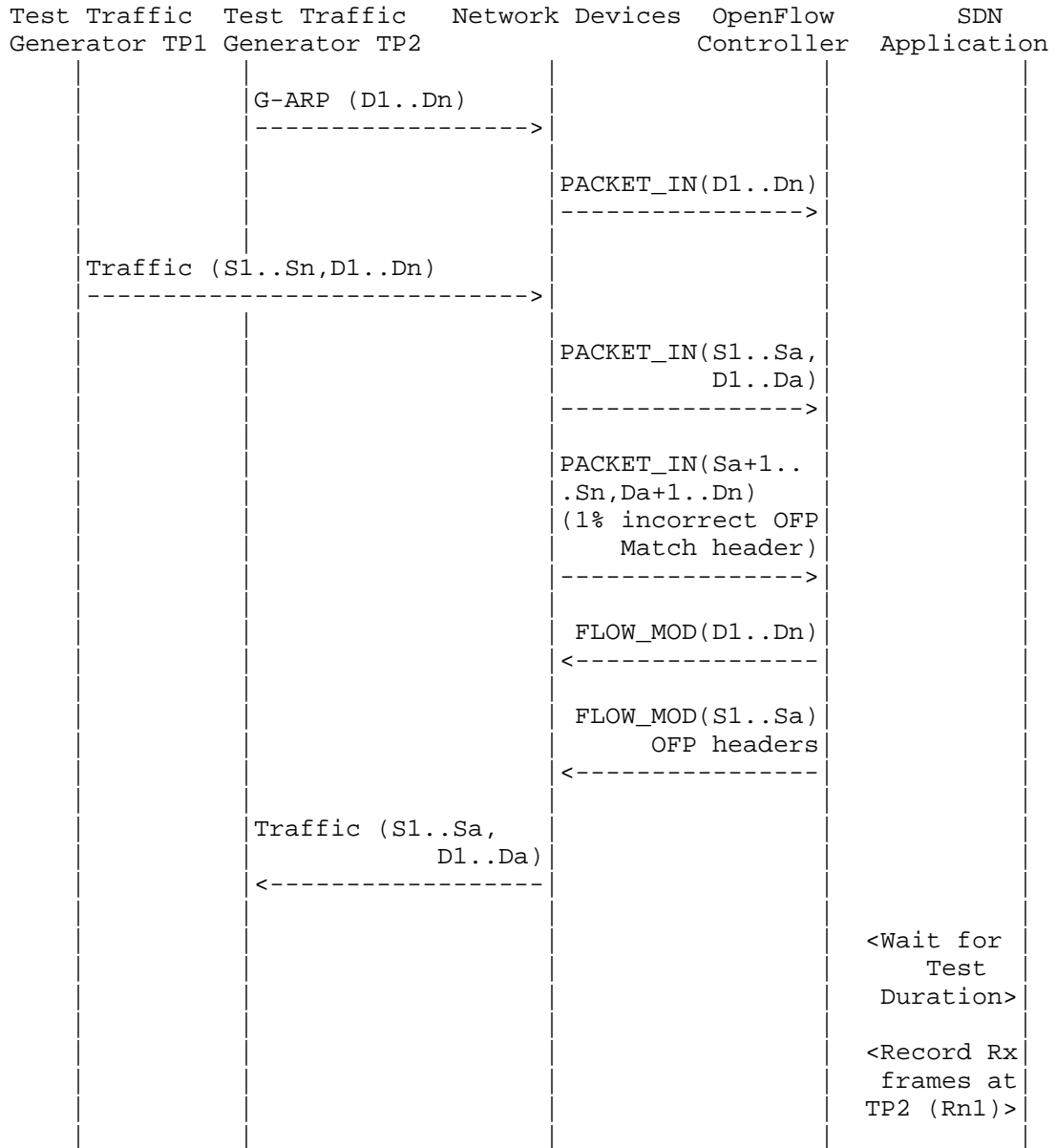
Discussion:

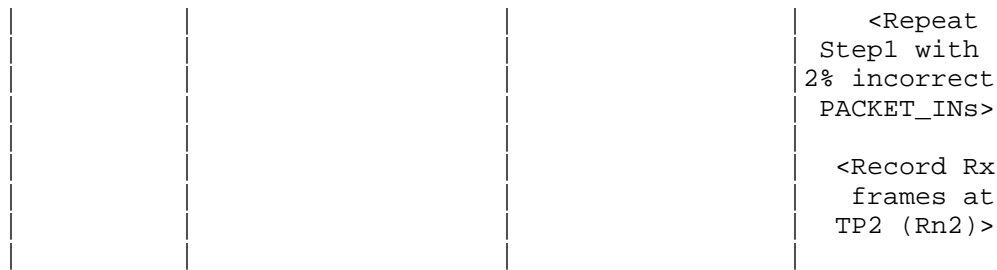
Query the controller forwarding table entries for multiple times until the three consecutive queries return the same value. The last value retrieved from the controller will provide the Forwarding Table Capacity value. The query interval is user configurable. The 5 seconds shown in this example is for representational purpose.

B.6. Security

B.6.1. Exception Handling

Procedure:





Legend:

- G-ARP: Gratuitous ARP
- PACKET\_IN(Sa+1..Sn, Da+1..Dn): OpenFlow PACKET\_IN with wrong version number
- Rn1: Total number of frames received at Test Port 2 with 1% incorrect frames
- Rn2: Total number of frames received at Test Port 2 with 2% incorrect frames

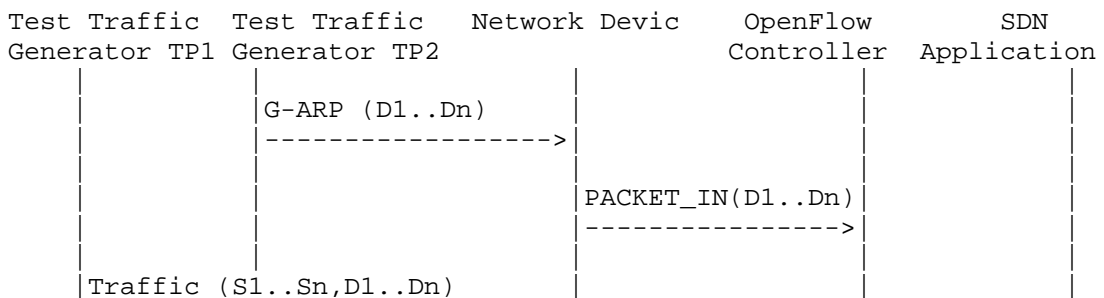
Discussion:

The traffic rate sent towards OpenFlow switch from Test Port 1 should be 1% higher than the Path Programming Rate. Rn1 will provide the Path Provisioning Rate of controller at 1% of incorrect frames handling and Rn2 will provide the Path Provisioning Rate of controller at 2% of incorrect frames handling.

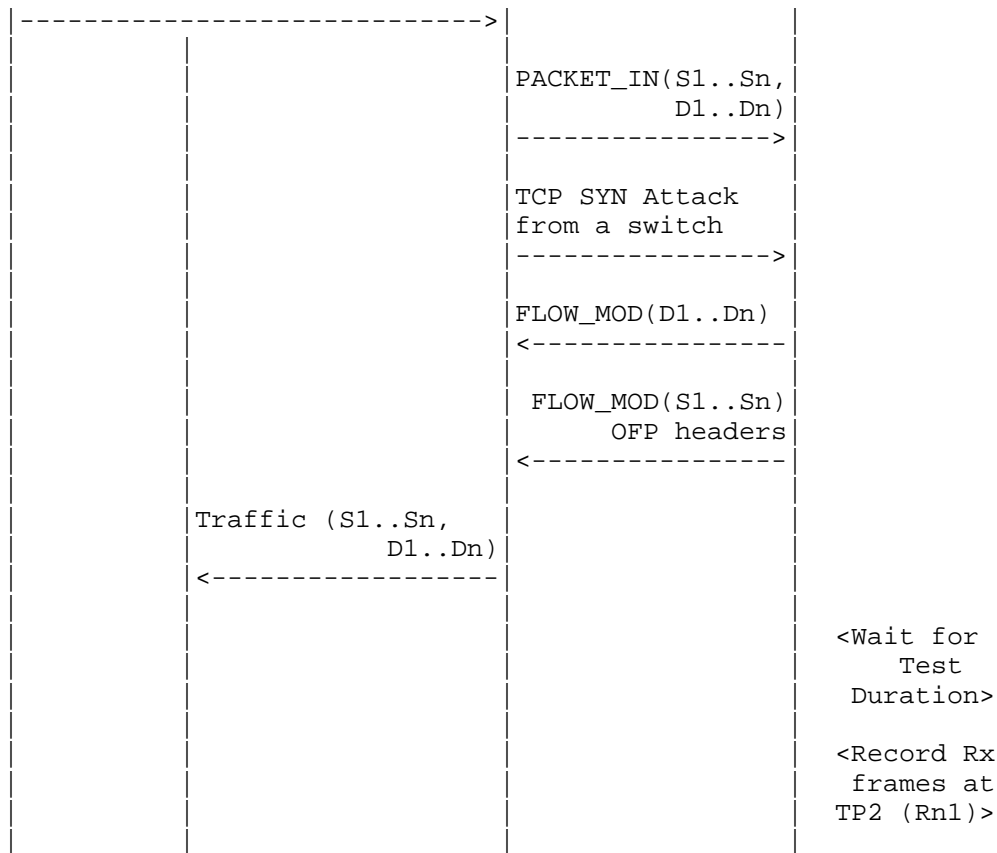
The procedure defined above provides test steps to determine the effect of handling error packets on Path Programming Rate. Same procedure can be adopted to determine the effects on other performance tests listed in this benchmarking tests.

B.6.2. Denial of Service Handling

Procedure:







Legend:

G-ARP: Gratuitous ARP

Discussion:

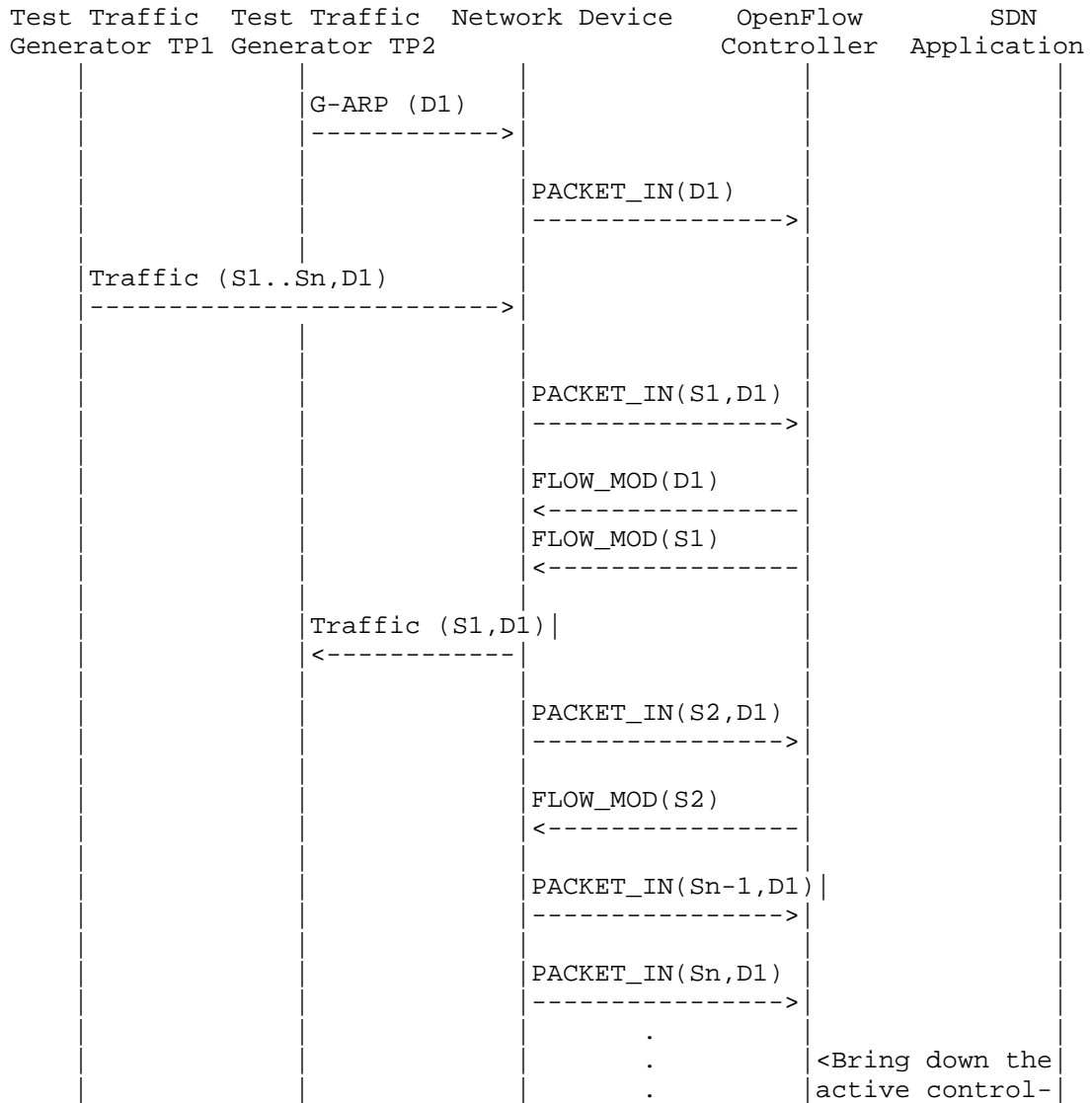
TCP SYN attack should be launched from one of the emulated/simulated OpenFlow Switch. Rn1 provides the Path Programming Rate of controller uponhandling denial of service attack.

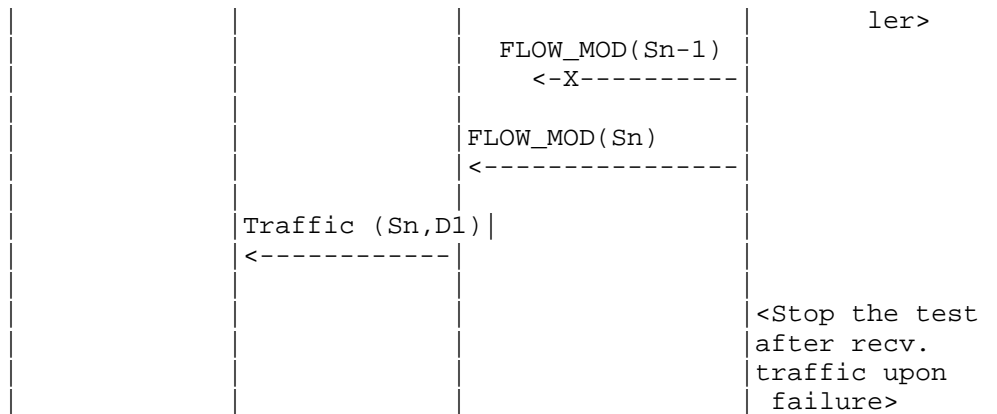
The procedure defined above provides test steps to determine the effect of handling denial of service on Path Programming Rate. Same procedure can be adopted to determine the effects on other performance tests listed in this benchmarking tests.

B.7. Reliability

B.7.1. Controller Failover Time

Procedure:





Legend:

G-ARP: Gratuitous ARP.

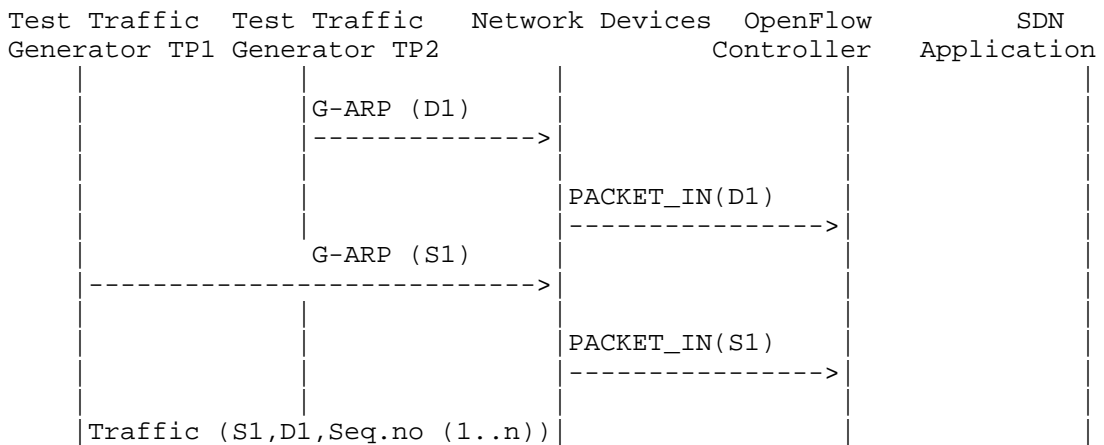
Discussion:

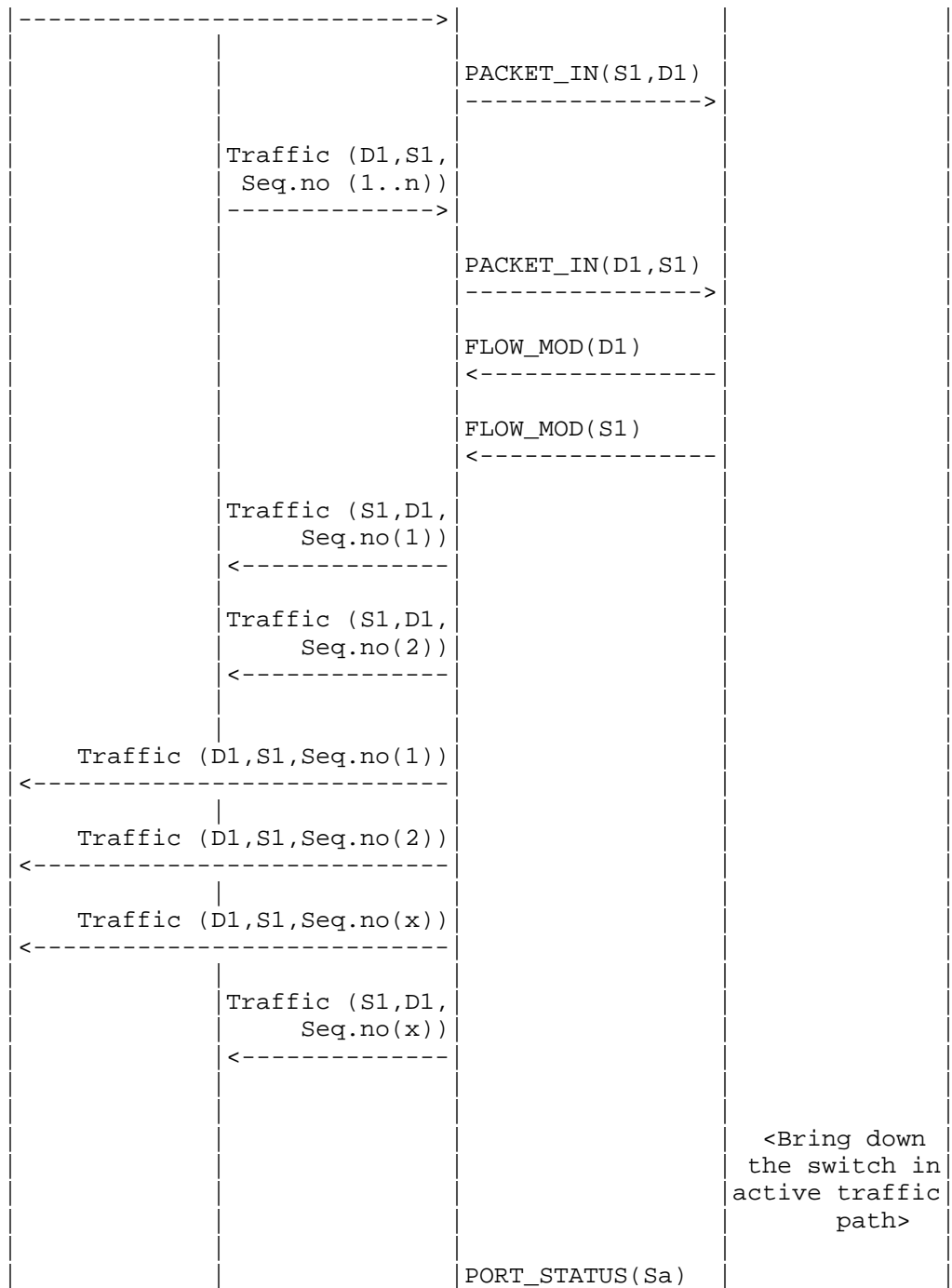
The time difference between the last valid frame received before the traffic loss and the first frame received after the traffic loss will provide the controller failover time.

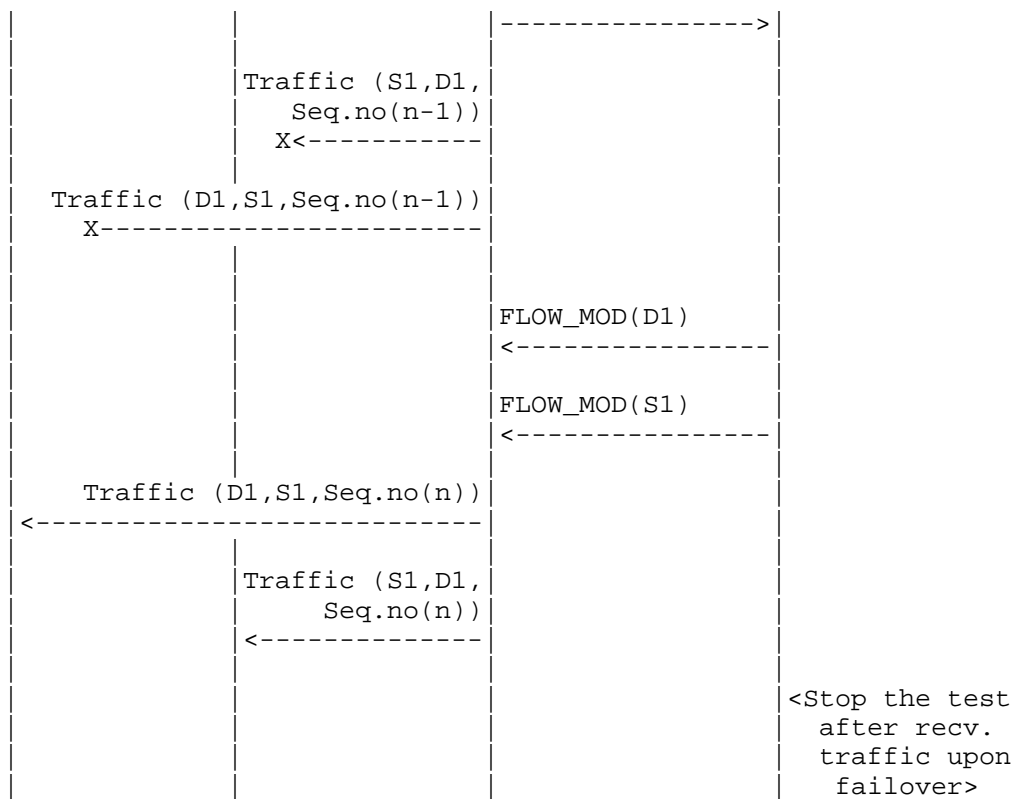
If there is no frame loss during controller failover time, the controller failover time can be deemed negligible.

B.7.2. Network Re-Provisioning Time

Procedure:







Legend:

- G-ARP: Gratuitous ARP message.
- Seq.no: Sequence number.
- Sa: Neighbour switch of the switch that was brought down.

Discussion:

The time difference between the last valid frame received before the traffic loss (Packet number with sequence number x) and the first frame received after the traffic loss (packet with sequence number n) will provide the network path re-provisioning time.

Note that the test is valid only when the controller provisions the alternate path upon network failure.

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Terminology for Benchmarking SDN Controller Performance  
draft-ietf-bmwg-sdn-controller-benchmark-term-03

Abstract

This document defines terminology for benchmarking an SDN controller's control plane performance. It extends the terminology already defined in RFC 7426 for the purpose of benchmarking SDN controllers. The terms provided in this document help to benchmark SDN controller's performance independent of the controller's supported protocols and/or network services. A mechanism for benchmarking the performance of SDN controllers is defined in the companion methodology document. These two documents provide a standard mechanism to measure and evaluate the performance of various controller implementations.

Status of this Memo

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## 1. Introduction

Software Defined Networking (SDN) is a networking architecture in which network control is decoupled from the underlying forwarding function and is placed in a centralized location called the SDN controller. The SDN controller abstracts the underlying network and offers a global view of the overall network to applications and business logic. Thus, an SDN controller provides the flexibility to program, control, and manage network behaviour dynamically through standard interfaces. Since the network controls are logically centralized, the need to benchmark the SDN controller performance becomes significant. This document defines terms to benchmark various controller designs for performance, scalability, reliability and security, independent of northbound and southbound protocols.

Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119.

## 2. Term Definitions

### 2.1. SDN Terms

The terms defined in this section are extensions to the terms defined in RFC 7426 "Software-Defined Networking (SDN): Layers and Architecture Terminology". This RFC should be referred before attempting to make use of this document.

#### 2.1.1. Flow

Definition:

The definition of Flow is same as microflows defined in RFC 4689 Section 3.1.5.

Discussion:

A flow can be set of packets having same source address, destination address, source port and destination port, or any of these combinations.

Measurement Units:

N/A

See Also:

None

### 2.1.2. Northbound Interface

**Definition:**

The definition of northbound interface is same Service Interface defined in RFC 7426.

**Discussion:**

The northbound interface allows SDN applications and orchestration systems to program and retrieve the network information through the SDN controller.

**Measurement Units:**

N/A

**See Also:**

None

### 2.1.3. Controller Forwarding Table

**Definition:**

A controller forwarding table contains flow entries learned in one of two ways: first, entries could be learned from traffic received through the data plane, or, second, these entries could be statically provisioned on the controller, and distributed to devices via the southbound interface.

**Discussion:**

The controller forwarding table has an aging mechanism which will be applied only for dynamically learnt entries.

**Measurement Units:**

N/A

**See Also:**

None

### 2.1.4. Proactive Flow Provisioning Mode

**Definition:**

Controller programming flows in Network Devices based on the flow entries provisioned through controller's northbound interface.

**Discussion:**

Orchestration systems and SDN applications can define the network forwarding behaviour by programming the controller using proactive flow provisioning. The controller can then program the Network Devices with the pre-provisioned entries.

Measurement Units:

N/A

See Also:

None

#### 2.1.5. Reactive Flow Provisioning Mode

Definition:

Controller programming flows in Network Devices based on the traffic received from Network Devices through controller's southbound interface

Discussion:

The SDN controller dynamically decides the forwarding behaviour based on the incoming traffic from the Network Devices. The controller then programs the Network Devices using Reactive Flow Provisioning.

Measurement Units:

N/A

See Also:

None

#### 2.1.6. Path

Definition:

Refer to Section 5 in RFC 2330.

Discussion:

None

Measurement Units:

N/A

See Also:

None

#### 2.1.7. Standalone Mode

Definition:

Single controller handling all control plane functionalities without redundancy, or the ability to provide high availability and/or automatic failover.

Discussion:

In standalone mode, one controller manages one or more network domains.

Measurement Units:

N/A

See Also:

None

#### 2.1.8. Cluster/Redundancy Mode

Definition:

A group of 2 or more controllers handling all control plane functionalities.

Discussion:

In cluster mode, multiple controllers are teamed together for the purpose of load sharing and/or high availability. The controllers in the group may work in active/standby (master/slave) or active/active (equal) mode depending on the intended purpose.

Measurement Units:

N/A

See Also:

None

#### 2.1.9. Asynchronous Message

Definition:

Any message from the Network Device that is generated for network events.

Discussion:

Control messages like flow setup request and response message is classified as asynchronous message. The controller has to return a response message. Note that the Network Device will not be in blocking mode and continues to send/receive other control messages

Measurement Units:

N/A

See Also:

None

#### 2.1.10. Test Traffic Generator

Definition:

Test Traffic Generator is an entity that generates/receives network traffic.

Discussion:

Test Traffic Generator can be an entity that interfaces with Network Devices to send/receive real-time network traffic.

Measurement Units:

N/A

See Also:

None

### 2.2. Test Configuration/Setup Terms

#### 2.2.1. Number of Network Devices

Definition:

The number of Network Devices present in the defined test topology.

Discussion:

The Network Devices defined in the test topology can be deployed using real hardware or emulated in hardware platforms.

Measurement Units:

N/A

See Also:

None

#### 2.2.2. Test Iterations

Definition:

The number of times the test needs to be repeated.

Discussion:

The test needs to be repeated for multiple iterations to obtain a reliable metric. It is recommended that this test SHOULD be performed for at least 10 iterations to increase the confidence in measured result.

Measurement Units:

N/A

See Also:

None

### 2.2.3. Test Duration

Definition:

Defines the duration of test trails for each iteration.

Discussion:

Test duration forms the basis for stop criteria for benchmarking tests. Test not completed within this time interval is considered as incomplete.

Measurement Units:

seconds

See Also:

None

### 2.2.4. Number of Cluster nodes

Definition:

Defines the number of controllers present in the controller cluster.

Discussion:

This parameter is relevant when testing the controller performance in clustering/teaming mode. The number of nodes in the cluster MUST be greater than 1.

Measurement Units:

N/A

See Also:

None



### 2.3. Benchmarking Terms

This section defines metrics for benchmarking the SDN controller. The procedure to perform the defined metrics is defined in the accompanying methodology document.

#### 2.3.1. Performance

##### 2.3.1.1. Network Topology Discovery Time

**Definition:**

The time taken by controller(s) to determine the complete network topology, defined as the interval starting with the first discovery message from the controller(s) at its Southbound interface, ending with all features of the static topology determined.

**Discussion:**

Network topology discovery is key for the SDN controller to provision and manage the network. So it is important to measure how quickly the controller discovers the topology to learn the current network state. This benchmark is obtained by presenting a network topology (Tree, Mesh or Linear) with the given number of nodes to the controller and wait for the discovery process to complete. It is expected that the controller supports network discovery mechanism and uses protocol messages for its discovery process.

**Measurement Units:**

milliseconds

**See Also:**

None

##### 2.3.1.2. Asynchronous Message Processing Time

**Definition:**

The time taken by controller(s) to process an asynchronous message, defined as the interval starting with an asynchronous message from a network device after the discovery of all the devices by the controller(s), ending with a response message from the controller(s) at its Southbound interface.

**Discussion:**

For SDN to support dynamic network provisioning, it is important to measure how quickly the controller responds to an event triggered from the network. The event could be any notification messages

generated by an Network Device upon arrival of a new flow, link down etc. This benchmark is obtained by sending asynchronous messages from every connected Network Devices one at a time for the defined test duration. This test assumes that the controller will respond to the received asynchronous message.

Measurement Units:  
milliseconds

See Also:  
None

#### 2.3.1.3. Asynchronous Message Processing Rate

Definition:

The maximum number of asynchronous messages (session aliveness check message, new flow arrival notification message etc.) that the controller(s) can process, defined as the iteration starting with sending asynchronous messages to the controller (s) at the maximum possible rate and ending with an iteration that the controller(s) processes the received asynchronous messages without dropping.

Discussion:

As SDN assures flexible network and agile provisioning, it is important to measure how many network events that the controller can handle at a time. This benchmark is obtained by sending asynchronous messages from every connected Network Devices at the rate that the controller processes without dropping. This test assumes that the controller will respond to all the received asynchronous messages.

Measurement Units:  
Messages processed per second.

See Also:  
None

#### 2.3.1.4. Reactive Path Provisioning Time

Definition:

The time taken by the controller to setup a path reactively between source and destination node, defined as the interval starting with the first flow provisioning request message received by the controller(s), ending with the last flow provisioning response message sent from the controller(s) at its Southbound interface.

Discussion:

As SDN supports agile provisioning, it is important to measure how fast that the controller provisions an end-to-end flow in the dataplane. The benchmark is obtained by sending traffic from a source endpoint to the destination endpoint, finding the time difference between the first and the last flow provisioning message exchanged between the controller and the Network Devices for the traffic path.

Measurement Units:  
milliseconds.

See Also:  
None

#### 2.3.1.5. Proactive Path Provisioning Time

Definition:

The time taken by the controller to setup a path proactively between source and destination node, defined as the interval starting with the first proactive flow provisioned in the controller(s) at its Northbound interface, ending with the last flow provisioning response message sent from the controller(s) at its Southbound interface.

Discussion:

For SDN to support pre-provisioning of traffic path from application, it is important to measure how fast that the controller provisions an end-to-end flow in the dataplane. The benchmark is obtained by provisioning a flow on controller's northbound interface for the traffic to reach from a source to a destination endpoint, finding the time difference between the first and the last flow provisioning message exchanged between the controller and the Network Devices for the traffic path.

Measurement Units:  
milliseconds.

See Also:  
None

#### 2.3.1.6. Reactive Path Provisioning Rate

Definition:

The maximum number of independent paths a controller can concurrently establish between source and destination nodes reactively, defined as the number of paths provisioned by the controller(s) at its Southbound interface for the flow provisioning

requests received for path provisioning at its Southbound interface between the start of the test and the expiry of given test duration

Discussion:

For SDN to support agile traffic forwarding, it is important to measure how many end-to-end flows that the controller could setup in the dataplane. This benchmark is obtained by sending traffic each with unique source and destination pairs from the source Network Device and determine the number of frames received at the destination Network Device.

Measurement Units:

Paths provisioned per second.

See Also:

None

### 2.3.1.7. Proactive Path Provisioning Rate

Definition:

Measure the maximum number of independent paths a controller can concurrently establish between source and destination nodes proactively, defined as the number of paths provisioned by the controller(s) at its Southbound interface for the paths provisioned in its Northbound interface between the start of the test and the expiry of given test duration

Discussion:

For SDN to support pre-provisioning of traffic path for a larger network from the application, it is important to measure how many end-to-end flows that the controller could setup in the dataplane. This benchmark is obtained by sending traffic each with unique source and destination pairs from the source Network Device. Program the flows on controller's northbound interface for traffic to reach from each of the unique source and destination pairs and determine the number of frames received at the destination Network Device.

Measurement Units:

Paths provisioned per second.

See Also:

None

### 2.3.1.8. Network Topology Change Detection Time

Definition:

The amount of time required for the controller to detect any changes in the network topology, defined as the interval starting with the notification message received by the controller(s) at its Southbound interface, ending with the first topology rediscovery messages sent from the controller(s) at its Southbound interface.

Discussion:

In order to for the controller to support fast network failure recovery, it is critical to measure how fast the controller is able to detect any network-state change events. This benchmark is obtained by triggering a topology change event and measuring the time controller takes to detect and initiate a topology re-discovery process.

Measurement Units:

milliseconds

See Also:

None

### 2.3.2. Scalability

#### 2.3.2.1. Control Sessions Capacity

Definition:

Measure the maximum number of control sessions the controller can maintain, defined as the number of sessions that the controller can accept from network devices, starting with the first control session, ending with the last control session that the controller(s) accepts at its Southbound interface.

Discussion:

Measuring the controller's control sessions capacity is important to determine the controller's system and bandwidth resource requirements. This benchmark is obtained by establishing control session with the controller from each of the Network Device until it fails. The number of sessions that were successfully established will provide the Control Sessions Capacity.

Measurement Units:

N/A

See Also:

None

#### 2.3.2.2. Network Discovery Size

**Definition:**

Measure the network size (number of nodes, links and hosts) that a controller can discover, defined as the size of a network that the controller(s) can discover, starting from a network topology given by the user for discovery, ending with the topology that the controller(s) could successfully discover.

**Discussion:**

For optimal network planning, it is key to measure the maximum network size that the controller can discover. This benchmark is obtained by presenting an initial set of Network Devices for discovery to the controller. Based on the initial discovery, the number of Network Devices is increased or decreased to determine the maximum nodes that the controller can discover.

**Measurement Units:**

N/A

**See Also:**

None

#### 2.3.2.3. Forwarding Table Capacity

**Definition:**

The maximum number of flow entries that a controller can manage in its Forwarding table.

**Discussion:**

It is significant to measure the capacity of controller's Forwarding Table to determine the number of flows that controller could forward without flooding/dropping. This benchmark is obtained by continuously presenting the controller with new flow entries through reactive or proactive flow provisioning mode until the forwarding table becomes full. The maximum number of nodes that the controller can hold in its Forwarding Table will provide Forwarding Table Capacity.

**Measurement Units:**

Maximum number of flow entries managed.

**See Also:**

None

### 2.3.3. Security

#### 2.3.3.1. Exception Handling

**Definition:**

To determine the effect of handling error packets and notifications on performance tests.

**Discussion:**

This benchmark test is to be performed after obtaining the baseline performance of the performance tests defined in Section 2.3.1. This benchmark determines the deviation from the baseline performance due to the handling of error or failure messages from the connected Network Devices.

**Measurement Units:**

N/A

**See Also:**

None

#### 2.3.3.2. Denial of Service Handling

**Definition:**

To determine the effect of handling denial of service (DoS) attacks on performance and scalability tests.

**Discussion:**

This benchmark test is to be performed after obtaining the baseline performance of the performance and scalability tests defined in section 2.3.1 and section 2.3.1.. This benchmark determines the deviation from the baseline performance due to the handling of denial of service attacks on controller.

**Measurement Units:**

Deviation of baseline metrics while handling Denial of Service Attacks.

**See Also:**

None

#### 2.3.4. Reliability

##### 2.3.4.1. Controller Failover Time

**Definition:**

The time taken to switch from an active controller to the backup controller, when the controllers work in redundancy mode and the active controller fails, defined as the interval starting with the active controller bringing down, ending with the first re-discovery message received from the new controller at its Southbound interface.

**Discussion:**

This benchmark determine the impact of provisioning new flows when controllers are teamed and the active controller fails.

**Measurement Units:**

milliseconds.

**See Also:**

None

##### 2.3.4.2. Network Re-Provisioning Time

**Definition:**

The time taken to re-route the traffic by the Controller, when there is a failure in existing traffic paths, defined as the interval starting from the first failure notification message received by the controller, ending with the last flow re-provisioning message sent by the controller at its Southbound interface .

**Discussion:**

This benchmark determines the controller's re-provisioning ability upon network failures. This benchmark test assumes the following:

- i. Network topology supports redundant path between source and destination endpoints.
- ii. Controller does not pre-provision the redundant path.

**Measurement Units:**

milliseconds.

**See Also:**

None







Figure 2

4. Test Coverage

	Speed	Scalability	Reliability
Setup	<ol style="list-style-type: none"> <li>1. Network Topology Discovery</li> <li>2. Reactive Path Provisioning Time</li> <li>3. Proactive Path Provisioning Time</li> <li>4. Reactive Path Provisioning Rate</li> <li>5. Proactive Path Provisioning Rate</li> </ol>	<ol style="list-style-type: none"> <li>1. Network Discovery Size</li> </ol>	
Operational	<ol style="list-style-type: none"> <li>1. Asynchronous Message Processing Rate</li> <li>2. Asynchronous Message Processing Time</li> </ol>	<ol style="list-style-type: none"> <li>1. Control Sessions Capacity</li> <li>2. Forwarding Table Capacity</li> </ol>	<ol style="list-style-type: none"> <li>1. Network Topology Change Detection Time</li> <li>2. Exception Handling</li> <li>3. Denial of Service Handling</li> <li>4. Network Re-Provisioning Time</li> </ol>
Tear Down			<ol style="list-style-type: none"> <li>1. Controller</li> </ol>

			Failover Time

## 5. References

### 5.1. Normative References

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## 6. IANA Considerations

This document does not have any IANA requests.

7. Security Considerations

Security issues are not discussed in this memo.

8. Acknowledgements

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Terminology for Benchmarking SDN Controller Performance  
draft-ietf-bmwg-sdn-controller-benchmark-term-04

Abstract

This document defines terminology for benchmarking an SDN controller's control plane performance. It extends the terminology already defined in RFC 7426 for the purpose of benchmarking SDN controllers. The terms provided in this document help to benchmark SDN controller's performance independent of the controller's supported protocols and/or network services. A mechanism for benchmarking the performance of SDN controllers is defined in the companion methodology document. These two documents provide a standard mechanism to measure and evaluate the performance of various controller implementations.

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## 1. Introduction

Software Defined Networking (SDN) is a networking architecture in which network control is decoupled from the underlying forwarding function and is placed in a centralized location called the SDN controller. The SDN controller abstracts the underlying network and offers a global view of the overall network to applications and business logic. Thus, an SDN controller provides the flexibility to program, control, and manage network behaviour dynamically through standard interfaces. Since the network controls are logically centralized, the need to benchmark the SDN controller performance becomes significant. This document defines terms to benchmark various controller designs for performance, scalability, reliability and security, independent of northbound and southbound protocols. The methodologies are defined in [I-D.sdn-controller-benchmark-meth].

Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119.

## 2. Term Definitions

### 2.1. SDN Terms

The terms defined in this section are extensions to the terms defined in [RFC7426] "Software-Defined Networking (SDN): Layers and Architecture Terminology". This RFC should be referred before attempting to make use of this document.

#### 2.1.1. Flow

Definition:

The definition of Flow is same as microflows defined in [RFC4689] Section 3.1.5.

Discussion:

A flow can be set of packets having same source address, destination address, source port and destination port, or any of these combinations.

Measurement Units:

N/A

See Also:

None

### 2.1.2. Northbound Interface

**Definition:**

The definition of northbound interface is same Service Interface defined in [RFC7426].

**Discussion:**

The northbound interface allows SDN applications and orchestration systems to program and retrieve the network information through the SDN controller.

**Measurement Units:**

N/A

**See Also:**

None

### 2.1.3. Controller Forwarding Table

**Definition:**

A controller forwarding table contains flow entries learned in one of two ways: first, entries could be learned from traffic received through the data plane, or, second, these entries could be statically provisioned on the controller, and distributed to devices via the southbound interface.

**Discussion:**

The controller forwarding table has an aging mechanism which will be applied only for dynamically learnt entries.

**Measurement Units:**

N/A

**See Also:**

None

### 2.1.4. Proactive Flow Provisioning Mode

**Definition:**

Controller programming flows in Network Devices based on the flow entries provisioned through controller's northbound interface.

**Discussion:**

Orchestration systems and SDN applications can define the network forwarding behaviour by programming the controller using proactive flow provisioning. The controller can then program the Network Devices with the pre-provisioned entries.

Measurement Units:

N/A

See Also:

None

#### 2.1.5. Reactive Flow Provisioning Mode

Definition:

Controller programming flows in Network Devices based on the traffic received from Network Devices through controller's southbound interface

Discussion:

The SDN controller dynamically decides the forwarding behaviour based on the incoming traffic from the Network Devices. The controller then programs the Network Devices using Reactive Flow Provisioning.

Measurement Units:

N/A

See Also:

None

#### 2.1.6. Path

Definition:

Refer to Section 5 in [RFC2330].

Discussion:

None

Measurement Units:

N/A

See Also:

None

#### 2.1.7. Standalone Mode

Definition:

Single controller handling all control plane functionalities without redundancy, or the ability to provide high availability and/or automatic failover.

Discussion:

In standalone mode, one controller manages one or more network domains.

Measurement Units:

N/A

See Also:

None

#### 2.1.8. Cluster/Redundancy Mode

Definition:

A group of 2 or more controllers handling all control plane functionalities.

Discussion:

In cluster mode, multiple controllers are teamed together for the purpose of load sharing and/or high availability. The controllers in the group may work in active/standby (master/slave) or active/active (equal) mode depending on the intended purpose.

Measurement Units:

N/A

See Also:

None

#### 2.1.9. Asynchronous Message

Definition:

Any message from the Network Device that is generated for network events.

Discussion:

Control messages like flow setup request and response message is classified as asynchronous message. The controller has to return a response message. Note that the Network Device will not be in blocking mode and continues to send/receive other control messages

Measurement Units:

N/A

See Also:

None

#### 2.1.10. Test Traffic Generator

Definition:

Test Traffic Generator is an entity that generates/receives network traffic.

Discussion:

Test Traffic Generator can be an entity that interfaces with Network Devices to send/receive real-time network traffic.

Measurement Units:

N/A

See Also:

None

### 2.2. Test Configuration/Setup Terms

#### 2.2.1. Number of Network Devices

Definition:

The number of Network Devices present in the defined test topology.

Discussion:

The Network Devices defined in the test topology can be deployed using real hardware or emulated in hardware platforms.

Measurement Units:

N/A

See Also:

None

#### 2.2.2. Test Iterations

Definition:

The number of times the test needs to be repeated.

Discussion:

The test needs to be repeated for multiple iterations to obtain a reliable metric. It is recommended that this test SHOULD be performed for at least 10 iterations to increase the confidence in measured result.

Measurement Units:

N/A

See Also:

None

### 2.2.3. Test Duration

Definition:

Defines the duration of test trails for each iteration.

Discussion:

Test duration forms the basis for stop criteria for benchmarking tests. Test not completed within this time interval is considered as incomplete.

Measurement Units:

seconds

See Also:

None

### 2.2.4. Number of Cluster nodes

Definition:

Defines the number of controllers present in the controller cluster.

Discussion:

This parameter is relevant when testing the controller performance in clustering/teaming mode. The number of nodes in the cluster MUST be greater than 1.

Measurement Units:

N/A

See Also:

None



### 2.3. Benchmarking Terms

This section defines metrics for benchmarking the SDN controller. The procedure to perform the defined metrics is defined in the accompanying methodology document.

#### 2.3.1. Performance

##### 2.3.1.1. Network Topology Discovery Time

**Definition:**

The time taken by controller(s) to determine the complete network topology, defined as the interval starting with the first discovery message from the controller(s) at its Southbound interface, ending with all features of the static topology determined.

**Discussion:**

Network topology discovery is key for the SDN controller to provision and manage the network. So it is important to measure how quickly the controller discovers the topology to learn the current network state. This benchmark is obtained by presenting a network topology (Tree, Mesh or Linear) with the given number of nodes to the controller and wait for the discovery process to complete. It is expected that the controller supports network discovery mechanism and uses protocol messages for its discovery process.

**Measurement Units:**

milliseconds

**See Also:**

None

##### 2.3.1.2. Asynchronous Message Processing Time

**Definition:**

The time taken by controller(s) to process an asynchronous message, defined as the interval starting with an asynchronous message from a network device after the discovery of all the devices by the controller(s), ending with a response message from the controller(s) at its Southbound interface.

**Discussion:**

For SDN to support dynamic network provisioning, it is important to measure how quickly the controller responds to an event triggered from the network. The event could be any notification messages

generated by an Network Device upon arrival of a new flow, link down etc. This benchmark is obtained by sending asynchronous messages from every connected Network Devices one at a time for the defined test duration. This test assumes that the controller will respond to the received asynchronous message.

Measurement Units:  
milliseconds

See Also:  
None

#### 2.3.1.3. Asynchronous Message Processing Rate

Definition:

The maximum number of asynchronous messages (session aliveness check message, new flow arrival notification message etc.) that the controller(s) can process, defined as the iteration starting with sending asynchronous messages to the controller (s) at the maximum possible rate and ending with an iteration that the controller(s) processes the received asynchronous messages without dropping.

Discussion:

As SDN assures flexible network and agile provisioning, it is important to measure how many network events that the controller can handle at a time. This benchmark is obtained by sending asynchronous messages from every connected Network Devices at the rate that the controller processes without dropping. This test assumes that the controller will respond to all the received asynchronous messages.

Measurement Units:  
Messages processed per second.

See Also:  
None

#### 2.3.1.4. Reactive Path Provisioning Time

Definition:

The time taken by the controller to setup a path reactively between source and destination node, defined as the interval starting with the first flow provisioning request message received by the controller(s), ending with the last flow provisioning response message sent from the controller(s) at its Southbound interface.

Discussion:

As SDN supports agile provisioning, it is important to measure how fast that the controller provisions an end-to-end flow in the dataplane. The benchmark is obtained by sending traffic from a source endpoint to the destination endpoint, finding the time difference between the first and the last flow provisioning message exchanged between the controller and the Network Devices for the traffic path.

Measurement Units:  
milliseconds.

See Also:  
None

#### 2.3.1.5. Proactive Path Provisioning Time

Definition:

The time taken by the controller to setup a path proactively between source and destination node, defined as the interval starting with the first proactive flow provisioned in the controller(s) at its Northbound interface, ending with the last flow provisioning response message sent from the controller(s) at its Southbound interface.

Discussion:

For SDN to support pre-provisioning of traffic path from application, it is important to measure how fast that the controller provisions an end-to-end flow in the dataplane. The benchmark is obtained by provisioning a flow on controller's northbound interface for the traffic to reach from a source to a destination endpoint, finding the time difference between the first and the last flow provisioning message exchanged between the controller and the Network Devices for the traffic path.

Measurement Units:  
milliseconds.

See Also:  
None

#### 2.3.1.6. Reactive Path Provisioning Rate

Definition:

The maximum number of independent paths a controller can concurrently establish between source and destination nodes reactively, defined as the number of paths provisioned by the controller(s) at its Southbound interface for the flow provisioning

requests received for path provisioning at its Southbound interface between the start of the test and the expiry of given test duration

Discussion:

For SDN to support agile traffic forwarding, it is important to measure how many end-to-end flows that the controller could setup in the dataplane. This benchmark is obtained by sending traffic each with unique source and destination pairs from the source Network Device and determine the number of frames received at the destination Network Device.

Measurement Units:

Paths provisioned per second.

See Also:

None

### 2.3.1.7. Proactive Path Provisioning Rate

Definition:

Measure the maximum number of independent paths a controller can concurrently establish between source and destination nodes proactively, defined as the number of paths provisioned by the controller(s) at its Southbound interface for the paths provisioned in its Northbound interface between the start of the test and the expiry of given test duration

Discussion:

For SDN to support pre-provisioning of traffic path for a larger network from the application, it is important to measure how many end-to-end flows that the controller could setup in the dataplane. This benchmark is obtained by sending traffic each with unique source and destination pairs from the source Network Device. Program the flows on controller's northbound interface for traffic to reach from each of the unique source and destination pairs and determine the number of frames received at the destination Network Device.

Measurement Units:

Paths provisioned per second.

See Also:

None

### 2.3.1.8. Network Topology Change Detection Time

Definition:

The amount of time required for the controller to detect any changes in the network topology, defined as the interval starting with the notification message received by the controller(s) at its Southbound interface, ending with the first topology rediscovery messages sent from the controller(s) at its Southbound interface.

Discussion:

In order to for the controller to support fast network failure recovery, it is critical to measure how fast the controller is able to detect any network-state change events. This benchmark is obtained by triggering a topology change event and measuring the time controller takes to detect and initiate a topology re-discovery process.

Measurement Units:

milliseconds

See Also:

None

### 2.3.2. Scalability

#### 2.3.2.1. Control Sessions Capacity

Definition:

Measure the maximum number of control sessions the controller can maintain, defined as the number of sessions that the controller can accept from network devices, starting with the first control session, ending with the last control session that the controller(s) accepts at its Southbound interface.

Discussion:

Measuring the controller's control sessions capacity is important to determine the controller's system and bandwidth resource requirements. This benchmark is obtained by establishing control session with the controller from each of the Network Device until it fails. The number of sessions that were successfully established will provide the Control Sessions Capacity.

Measurement Units:

N/A

See Also:

None

### 2.3.2.2. Network Discovery Size

**Definition:**

Measure the network size (number of nodes, links and hosts) that a controller can discover, defined as the size of a network that the controller(s) can discover, starting from a network topology given by the user for discovery, ending with the topology that the controller(s) could successfully discover.

**Discussion:**

For optimal network planning, it is key to measure the maximum network size that the controller can discover. This benchmark is obtained by presenting an initial set of Network Devices for discovery to the controller. Based on the initial discovery, the number of Network Devices is increased or decreased to determine the maximum nodes that the controller can discover.

**Measurement Units:**

N/A

**See Also:**

None

### 2.3.2.3. Forwarding Table Capacity

**Definition:**

The maximum number of flow entries that a controller can manage in its Forwarding table.

**Discussion:**

It is significant to measure the capacity of controller's Forwarding Table to determine the number of flows that controller could forward without flooding/dropping. This benchmark is obtained by continuously presenting the controller with new flow entries through reactive or proactive flow provisioning mode until the forwarding table becomes full. The maximum number of nodes that the controller can hold in its Forwarding Table will provide Forwarding Table Capacity.

**Measurement Units:**

Maximum number of flow entries managed.

**See Also:**

None

### 2.3.3. Security

#### 2.3.3.1. Exception Handling

**Definition:**

To determine the effect of handling error packets and notifications on performance tests.

**Discussion:**

This benchmark test is to be performed after obtaining the baseline performance of the performance tests defined in Section 2.3.1. This benchmark determines the deviation from the baseline performance due to the handling of error or failure messages from the connected Network Devices.

**Measurement Units:**

N/A

**See Also:**

None

#### 2.3.3.2. Denial of Service Handling

**Definition:**

To determine the effect of handling denial of service (DoS) attacks on performance and scalability tests.

**Discussion:**

This benchmark test is to be performed after obtaining the baseline performance of the performance and scalability tests defined in section 2.3.1 and section 2.3.1.. This benchmark determines the deviation from the baseline performance due to the handling of denial of service attacks on controller.

**Measurement Units:**

Deviation of baseline metrics while handling Denial of Service Attacks.

**See Also:**

None

### 2.3.4. Reliability

#### 2.3.4.1. Controller Failover Time

**Definition:**

The time taken to switch from an active controller to the backup controller, when the controllers work in redundancy mode and the active controller fails, defined as the interval starting with the active controller bringing down, ending with the first re-discovery message received from the new controller at its Southbound interface.

**Discussion:**

This benchmark determine the impact of provisioning new flows when controllers are teamed and the active controller fails.

**Measurement Units:**

milliseconds.

**See Also:**

None

#### 2.3.4.2. Network Re-Provisioning Time

**Definition:**

The time taken to re-route the traffic by the Controller, when there is a failure in existing traffic paths, defined as the interval starting from the first failure notification message received by the controller, ending with the last flow re-provisioning message sent by the controller at its Southbound interface .

**Discussion:**

This benchmark determines the controller's re-provisioning ability upon network failures. This benchmark test assumes the following:

- i. Network topology supports redundant path between source and destination endpoints.
- ii. Controller does not pre-provision the redundant path.

**Measurement Units:**

milliseconds.

**See Also:**

None



### 3. Test Setup

This section provides common reference topologies that are later referred to in individual tests defined in the companion methodology document.

#### 3.1. Test setup - Controller working in Standalone Mode

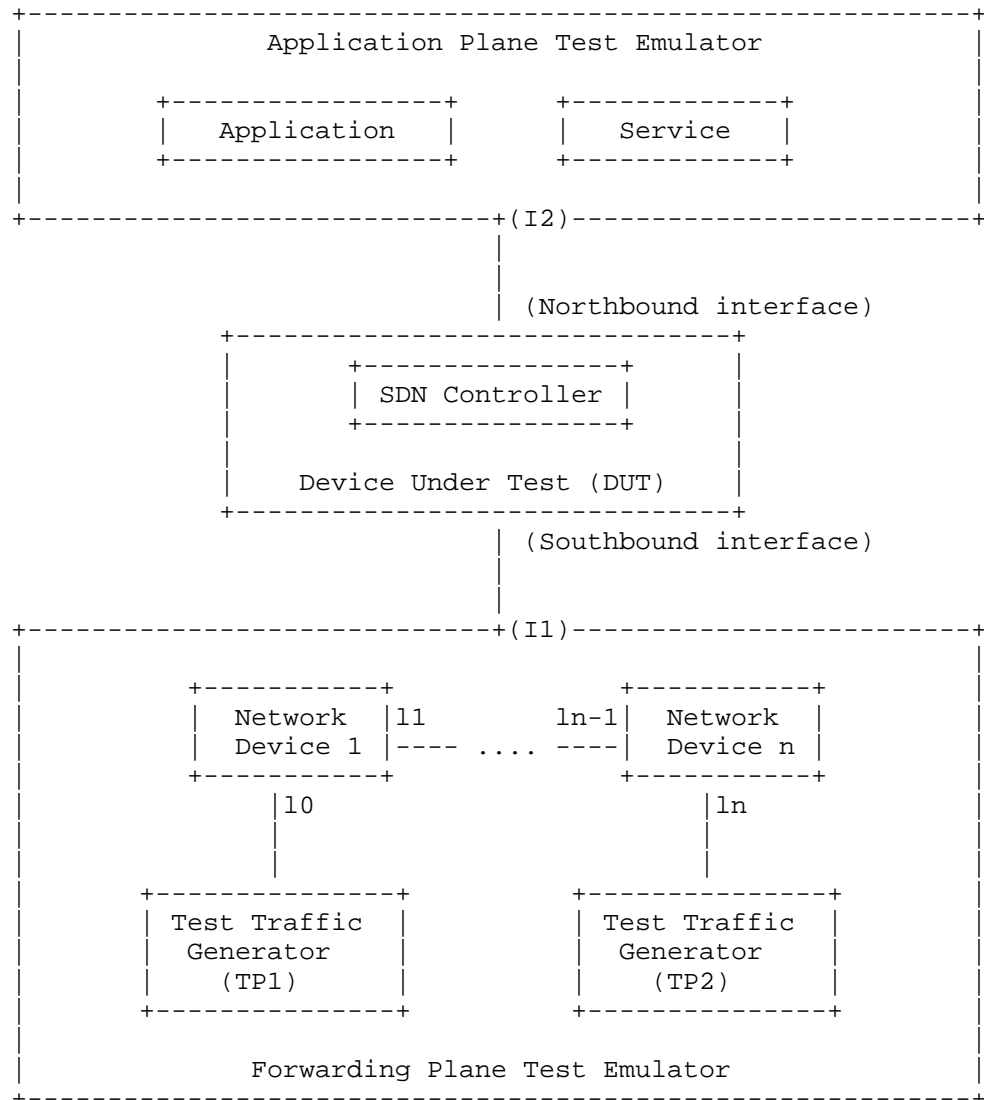


Figure 1

3.2. Test setup - Controller working in Cluster Mode

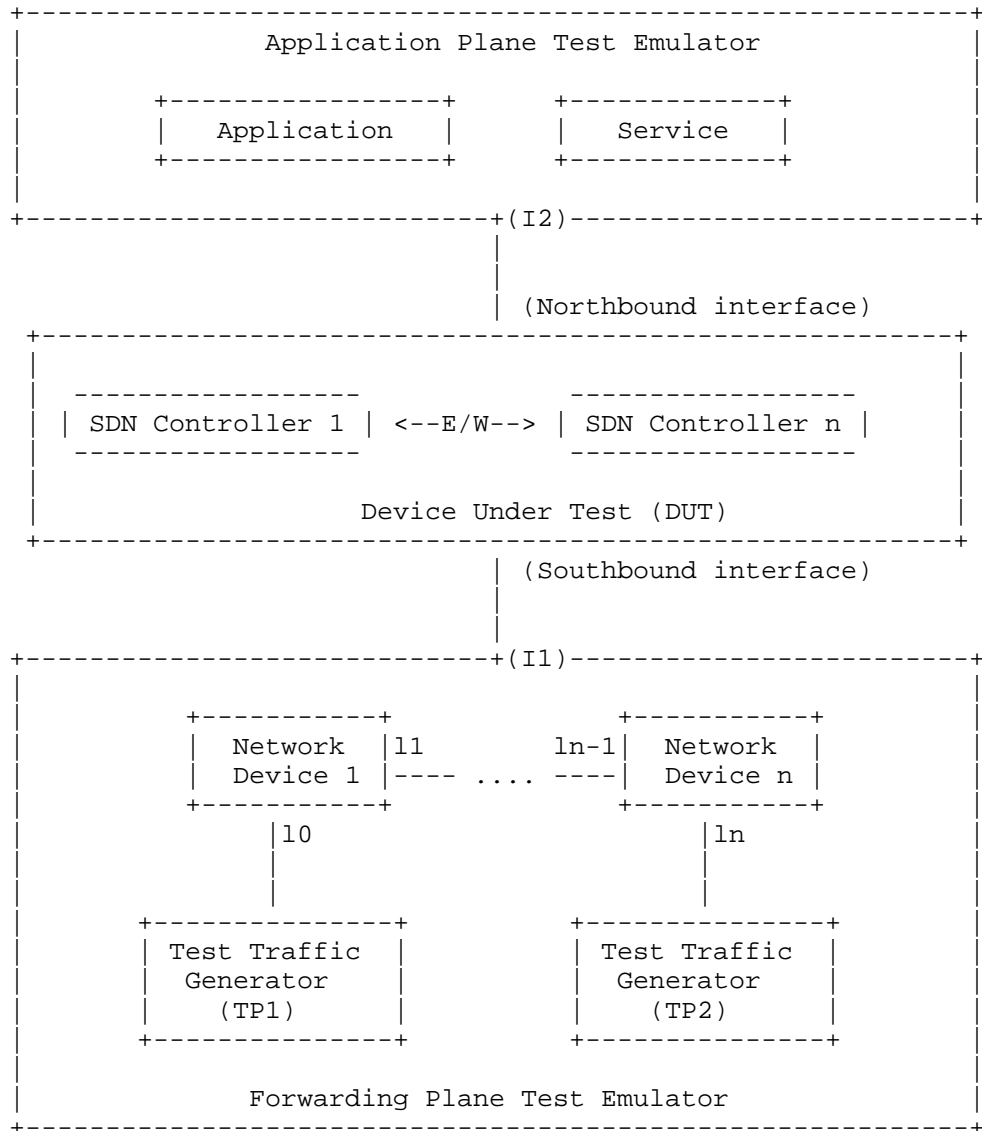


Figure 2

4. Test Coverage

	Speed	Scalability	Reliability
Setup	<ol style="list-style-type: none"> <li>1. Network Topology Discovery</li> <li>2. Reactive Path Provisioning Time</li> <li>3. Proactive Path Provisioning Time</li> <li>4. Reactive Path Provisioning Rate</li> <li>5. Proactive Path Provisioning Rate</li> </ol>	<ol style="list-style-type: none"> <li>1. Network Discovery Size</li> </ol>	
Operational	<ol style="list-style-type: none"> <li>1. Asynchronous Message Processing Rate</li> <li>2. Asynchronous Message Processing Time</li> </ol>	<ol style="list-style-type: none"> <li>1. Control Sessions Capacity</li> <li>2. Forwarding Table Capacity</li> </ol>	<ol style="list-style-type: none"> <li>1. Network Topology Change Detection Time</li> <li>2. Exception Handling</li> <li>3. Denial of Service Handling</li> <li>4. Network Re-Provisioning Time</li> </ol>
Tear Down			<ol style="list-style-type: none"> <li>1. Controller</li> </ol>

			Failover Time

## 5. References

### 5.1. Normative References

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- [I-D.sdn-controller-benchmark-meth] Bhuvaneshwaran.V, Anton Basil, Mark.T, Vishwas Manral, Sarah Banks "Benchmarking Methodology for SDN Controller Performance", draft-ietf-bmwg-sdn-controller-benchmark-meth-04 (Work in progress), June 8, 2017

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This document does not have any IANA requests.

7. Security Considerations

Security issues are not discussed in this memo.

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Benchmarking of Y1731 Performance Monitoring  
draft-jacpra-bmwg-pmtest-03

Abstract

The draft defines the methodologies for benchmarking of the Y1731 performance monitoring on DUT in various methods like Calculation of near-end and far-end data. Measurement is done in scenarios by using pre-defined COS and without COS in the network. The test includes Impairment test, High Availability test and soak tests.

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## 1. Introduction

Performance monitoring is explained in ITU Y1731.This document defines the methodologies for benchmarking performance of Y1731 over a point to point service. Performance Monitoring has been implemented with many varying designs in order to achieve their intended network functionality. The scope of this document is to define methodologies for benchmarking Y1731 performance measurement. The following protocols under Y.1731 will be benchmarked.

1. Two-way delay measurement
2. One-way delay measurement
3. Loss measurement
4. Synthetic loss measurement

### 1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

### 1.2. Terminologies

PM Performance monitoring

COS Class of Service

In-profile CIR termed as green packets.

Out-profile EIR Yellow/Amber packet.

LMM Loss Measurement Message

LMR Loss Measurement Reply

DMM Delay Measurement Message

DMR Delay MEasurement Reply

P Router Provider Router.

PE Router Provider Edge Router

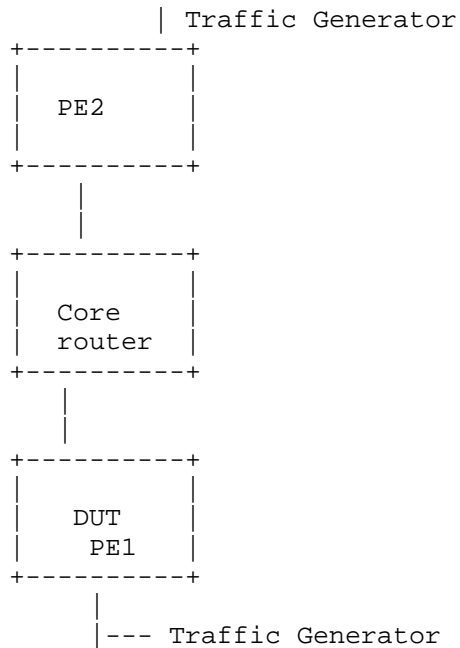
CE Router customer Edge Router

DUT Device under Test.

CCM Continuity check messages

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2.1 Test Topology

[Page 3]



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3. Network

[Page 4]

The benchmarking topology consists of 3 routers and 2 traffic generators. DUT is PE1 connected to CE. The core router is the P router mentioned in the topology. There is layer two(point-to-point) services running from PE1 to PE2. On the top of that performance monitoring such as loss,delay and synthetic measurements are running.PE1 is acting as DUT.The traffic will be layer 2 with vlan tag.The frame size will be 64,128,512,1024 and 1400.The tests are carried out using these various frame size.The traffic will be uni directional or bi directional.

#### 4. Test Procedure

The tests are defined to benchmark the Y1731 performance monitoring in High Availability,Impairment,SOAK,Scale,with traffic of various line rate and frame sizes.

##### 4.1 Performance Monitoring with traffic

Traffic is send with different .lp priorities,line rate and frame size of 64, 128,512,1024,1400.The PM values are measured with each frame size with various line rates.

## 4.2 High Availability

The traffic is flowing bi-direction. Then traffic is flowing at "P" packets per sec. The traffic generator is measuring the Tx and Rx packets, while the routing engine failover there should not any packet loss the router tester must show both "P" packet per seconds. The PM historical data should not reset.

## 4.3 Scale

This is to measure the performance of DUT in scaling to "X" CFM sessions with Performance monitoring running over it. There should not be any crashes, memory leaks.

## 4.4 SOAK

This test is used to measure the performance of DUT over a period of time, with scaled configuration and traffic over a period of time "T". In each interval "t1" the parameters measured are CPU usage, memory usage and crashes.

## 4.5 Measurement Statistics

The test is repeated for "N" times and the value is taken by averaging the values.

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5 Test Cases

[Page 5]

### 5.1 Y.1731 Two-way Delay Measurement Test procedure

#### Basic Testing Objective

Check the round trip delay of the network in different conditions of traffic load in the network.

#### Test Procedure

Configure a layer 2 point-to-point service between PE1 and PE2.  
Configure Y.1731 Two way delay measurement over the service. Observe the delay measurement in the following conditions of traffic in the network

- a. Send 80% of Line-rate traffic with different priorities and frame size.
- b. Send 40% of Line-rate traffic with different priorities and frame size.
- c. Without any line traffic

The result of all the 3 conditions above are noted and correlated.

#### Test Measurement

The following factors need to be measured to benchmark the result

1. The average two-way delay
2. The average two-way delay variation

In the above 3 conditions the results obtained must be similar

#### 1. Ideal case

In this case the hardware aspects of processing capacity and the link level anomalies are not considered. The benchmark is just on the protocol

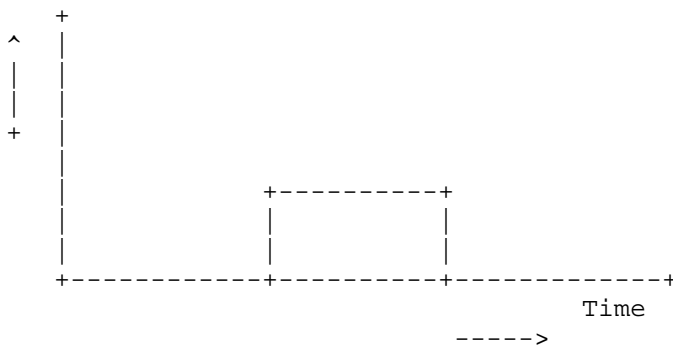
functioning. In such environment where for an ideal case the system should expect delay variation to be zero.

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2. Practical case

[Page 6]

This case is used to benchmark results when delay measurement is done on physical hardware (like a router). The factors of packet process jitter and link level delays needs to be considered here. The delay variation in such cases will defer based on the above parameters on different hardware systems. Result will very base on the exact hardware.

Delay Variation



Traffic (0 to 100 percent line rate)

Impairment

This is to benchmark two-way delay measurement even when both data and PDUs are dropped in the network using the impairment tool.

Measurement

The results must show similar results before and after this test.

High Availability

During routing engine failover the historical data must not reset.

Scale

This is to measure the performance of DUT in scaling to "X" CFM sessions with Performance monitoring running over it. There should not be any crashes, memory leaks.

Soak

The bi directional traffic is send over service over 24 to 48 hours and measure after the stipulated time there must not be any change in behavior in the network for performance monitoring

Measurement

There should not be any core or crashes, memory leaks.

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5.2 One-Way delay measurement Test Procedure

[Page 7]



Traffic (0 to 100 percent line rate)

Impairment

This is to benchmark one-way delay measurement even when both data and PDUs are dropped in the network using the impairment tool.

Measurement

The results must show similar results before and after this test.

High Availability

During routing engine failover the historical data must not reset.

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Scale

[Page 9]

This is to measure the performance of DUT in scaling to "X" CFM sessions with Performance monitoring running over it. There should not be any crashes, memory leaks.

Soak

The bi directional traffic is send over service over 24 to 48 hours and measure after the stipulated time there must not be any change in behavior in the network for performance monitoring

Measurement

There should not be any core or crashes, memory leaks.

### 5.3 Loss measurement without COS Test Procedure

Basic Testing Objective

The test defined methodology for benchmarking data loss in the network on real customer traffic. The Y.1731 indicates to consider only in-profile (green) packet for loss measurement. For this, the testing needs to be done in multiple environment where

a. All data packets from traffic generator are sent with single 802.1p priority and the network do not have a COS profile defined.

b. All data packets from traffic generator are sent with 0 to 7 values for 802.1p priority and the network do not have a COS profile defined.

The objective is to benchmark the protocol behavior under different networking conditions and correlate the data. The objective is not to test the actual functioning of Y.1731 Loss measurement. The loss measurement must count only in profile packet, since there is no COS defined. All the packets must be recorded as green.

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Test Procedure

[Page 10]

Configure a layer2 point-to-point service between PE1 and PE2.  
Configure Y.1731 loss measurement over the service.  
Observe the loss measurement in the following conditions of traffic in the network

- a.Send 80% of Line-rate traffic with different priorities with different frame size.
- b.Send 40% of Line-rate traffic with different priorities with different frame size.
- c.Without any line traffic

The result of all the 3 conditions above are noted and correlated.

#### Test Measurement

The factors which need to be considered is the acceptable absolute loss for the given network.

#### Impairment

This is to benchmark loss measurement even when both data and PDUs are dropped in the network using the impairment tool.

#### Measurement

When the data is dropped it must show the loss correctly and PM PDUs are dropped the counting should not be affected,ther should not be any abnormal output.

#### High Availability

During routing engine failover the historical data must not reset. Ideal case there must be 0 packet loss.

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#### Scale

This is to measure the performance of DUT in scaling to "X" CFM sessions with Performance monitoring running over it.There should not be any crashes,memory leaks.Each session must record loss measurement correctly.

#### Soak

The bi directional traffic is send over service over 24 to 48 hours and measure after the stipulated time there must not be any change in behavior in the network for performance monitoring

#### Measurement

There should not be any core or crashes,memory leaks.

#### Result

Traffic sent over the service for bi direction	Loss measurement (without cos)
7 Streams at 100% line rate with priority	Near End = 100% Far End = 100%

from 0 to 7	
Dropping 50% of line rate at near end.	Near End 50% Far end 100% Near End loss observed 50%
Dropping 50% of line rate at far end.	Near End 100% Far end 50% Far End Loss observed 50%

Praveen & Sudhin Expires August 03,2017  
5.4. Loss measurement with COS Test Procedure

[Page 12]

#### Basic Testing Objective

The test defined methodology for benchmarking data loss in the network on real customer traffic. The Y.1731 indicates to consider only in-profile(green) packet for loss measurement. For this, the testing needs to be done in multiple environment where

- a. All data packets from traffic generator are sent with single 802.1p priority and the network have pre-defined COS profile defined.
- b. All data packets from traffic generator are sent with 0 to 7 values for 802.1p priority and the network have pre-defined COS profile defined.

The COS profile defined needs to have 2 factors

- a. COS needs to treat different 802.1p as separate class of packets.
- b. Each Class of packets needs to be an defined CIR for the specific network.

The objective is to benchmark the protocol behavior under different networking conditions and correlate the data. The objective is not to test the actual functioning of Y.1731 Loss measurement. The loss measurement must show in profile packet for each COS levels. Each COS level must count only its own defined in profile packets. The Packets, which are termed, as out profile by COS marking must not be counted. When the traffic is send with single 802.1p priority the loss measurement must record value only for that particular COS level.

#### Test Procedure

Configure a layer2 point-to-point service between PE1 and PE2.  
Configure Y.1731 loss measurement over the service.  
Observe the loss measurement in the following conditions of traffic in the network.

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[Page 13]

- d. Send 80% of Line-rate traffic with different priorities with different frame size.
- e. Send 40% of Line-rate traffic with different priorities with different frame size.
- f. Without any line traffic

The result of all the 3 conditions above are noted and correlated.



Test Measurement

The factors which need to be considered is the acceptable absolute loss for the given network.

Impairment

This is to benchmark loss measurement even when both data and PDUs are dropped in the network using the impairment tool.

Measurement

When the data is dropped it must show the loss correctly and PM PDUs are dropped the counting should not be affected,there should not be any abonormal output.

High Availability

During routing engine failover the historical data must not reset. Ideal case there must be 0 packet loss.

Scale

This is to measure the performance of DUT in scaling to "X" CFM sessions with Performance monitoring running over it. There should not be any crashes, memory leaks. Each session must record loss measurement correctly.

Soak

The bi directional traffic is send over service over 24 to 48 hours and measure after the stipulated time there must not be any change in behavior in the network for performance monitoring

There should not be any core or crashes, memory leaks.

Result

+-----+-----+	
Traffic sent over the service for bi direction	Loss measurement (With cos)
+-----+-----+	
7 Streams at 100% line rate with priority from 0 to 7	Near End = 100% Far End = 100%
+-----+-----+	
Dropping 50% of line rate at near end for priority marked 0	Near End 50% Far end 100% Near End loss observed 50% (priority 0)
+-----+-----+	
Dropping 50% of line rate at far end for priority 0	Near End 100% Far end 50% Far End Loss observed 50%
+-----+-----+	

| (priority 0) |  
+-----+

#### 5.5.1 Basic Testing Objective

The test defined methodology for benchmarking synthetic loss in the network. The testing needs to be done in multiple environment where

- a. All data packets from traffic generator are sent with single 802.1p priority and the network do not have a COS profile defined. The synthetic loss measurement also uses the same 802.1p priority as that of traffic.
- b. All data packets from traffic generator are sent with single 802.1p priority and the network have pre-defined COS profile defined. The synthetic loss measurement also uses the same 802.1p priority as that of traffic.
- c. All data packets from traffic generator are sent with 0 to 7 values for 802.1p priority and the network do not have a COS profile defined. The synthetic loss measurement also uses the same 802.1p priority as that of traffic. Hence 8 sessions are tested in parallel.
- d. All data packets from traffic generator are sent with 0 to 7 values for 802.1p priority and the network have pre-defined COS profile defined. The synthetic loss measurement also uses the same 802.1p priority as that of traffic. Hence 8 sessions are tested in parallel.

The COS profile defined needs to have 2 factors

1. COS needs to treat different 802.1p as separate class of packets.
2. Each Class of packets needs to have defined CIR for the specific network.

The objective is to benchmark the protocol behavior under different networking conditions and correlate the data. The objective is not to test the actual functioning of Y.1731 Loss measurement.

#### Test Procedure

Configure a layer2 point-to-point service between PE1 and PE2.  
Configure Y.1731 loss measurement over the service. Observe the synthetic loss measurement in the following conditions of traffic in the network

- a. Send 80% of Line-rate traffic with different priorities
  - b. Send 40% of Line-rate traffic with different priorities
  - c. Without any line traffic
- The result of all the 3 conditions above are noted and correlated.

The factors which need to be considered is the acceptable absolute loss

for the given network.

#### Impairment

This is to benchmark synthetic loss measurement even when both data and PDUs are dropped in the network using the impairment tool.

#### Measurement

When the data is dropped it must not affect the SLM counters but if synthetic frames are dropped the loss must be shown accordingly.

#### High Availability

During routing engine failover the historical data must not reset.

#### Scale

This is to measure the performance of DUT in scaling to "X" CFM sessions with Performance monitoring running over it. There should not be any crashes, memory leaks.

#### Soak

The bi directional traffic is send over service over 24 to 48 hours and measure after the stipulated time there must not be any change in behavior in the network for performance monitoring

#### Measurement

There should not be any core or crashes, memory leaks.

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[Page 17]

#### 6. Acknowledgements

We would like to thank Al Morton of (ATT) for their support and encouragement. We would like to thank Fioccola Giuseppe of Telecom Italia reviewing our draft and commenting it.

#### 7. Security Considerations

NA

#### 8. IANA Considerations

NA

#### Appendix A. Appendix

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[Page 18]

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July 03, 2017

Considerations for Benchmarking Service Function Chain  
draft-kim-bmwg-sfc-benchmark-00

Abstract

Service Function Chain(SFC) is a ordered set of service functions. Packets flow restrictively at the service functions according to the order. To enable a network service, operator composes the service function chain logically. Though SFC is efficient where network/ service requirements are dynamically changing, the reliability of SFC should be guaranteed. This memo describes the considerations for benchmarking SFC reliability.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

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1. Introduction

As Service Function Chain(SFC) is the ordered set of service functions. It is logically defined on demand of a service. To enable the service, SDN controller set flow rules at each physical/virtual switch which belongs to the SFC. SFC is efficient where the network/service requirements are keep changing dynamically. The number of physical/virtual switches which will accept the flow rules is differ from the size of the domain or service.

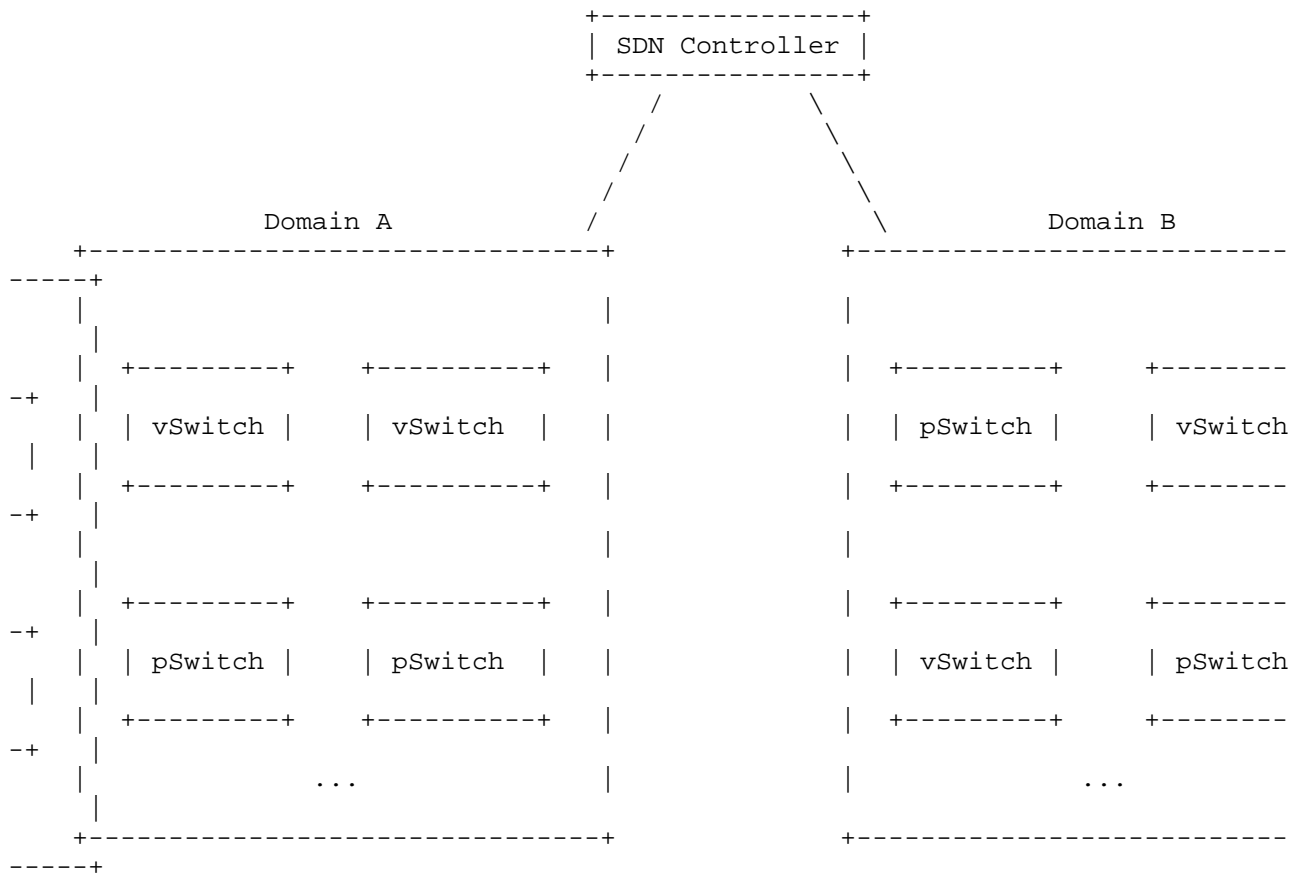
As an operator perspective, at the stage of SFC creation, modification, and deletion, the reliability of SFC should always be guaranteed. To apply the change of the SFC, SDN controller will set flow rules at some switches and delete flow rules at other switches. For certain reasons such as the heavy traffic on the target switches which should accept new rules or the link failure between the target switches and the SDN controller, the new SFC may not be applied properly.

This draft memo describes considerations for benchmarking Service Function Chain reliability.

2. Scope

At the time of writing this memo, SFC standardization is now in progress. But operators and vendors are implementing SFC their own way. This memo does not target NSH enabled architecture and target general operation circumstances. The scope of SFC reliability benchmark is when the initial SFC is already provisioned and the traffic also flows over the certain SFCs, and SFC needs to be updated. Also, SFC is made over multi-domain network, which covers the whole country.

This figure is an example of the network.



3. Considerations for Benchmarking SFC Reliability

This section defines and lists considerations which must be addressed to benchmark the reliability of SFC

3.1. Configuration Parameters for Benchmarking Test

This section lists the parameters affecting the SFC reliability. To apply new SFC, SDN controller set rules to the target switches. Depending on the status of the swithes and the network, the new SFC can be applied right as intended, or not. The right operation of SFC as intended includes the right time of the operation activates.





- o Types of Switches : Virtual switch or Physical switch
- o The number of switches in target SFC domain
  - \* Depending on the composition of the target SFC, the number of switches which need to update their flow tables is different.
- o The Usage of Flow table of the target switch
  - \* When the new SFC rule needs to setup, if the flow table entries are not enough and have to stored elsewhere, not TCAM, the usage of flow table can affect the reliability of SFC.
    - + TCAM Usage
    - + Flow table Entries
- o The physical distances between the Controller and Switch
  - \* As the network grows broad, the delay is same as propagation delay. And this make SFC Activation time different.
- o The traffic loads on the target switch
  - \* The limitaion of the CPU, when the target switch needs to process large amount of the traffic, the new SFC rules setup cannot be done in intended time.

### 3.2. Testing Parameter Benchmarking Test

This section describes the testing parameter for Benchmark SFC Reliability. In terms of operation, the reliability of SFC is "operate the SFC in right time and at right path."

#### Rule Activation Time

- o The time interval from the new flow rule setup requests to the time when packets start to flow following the new matched rule.

TBD

### 4. Security Considerations

TBD.

5. IANA Considerations

No IANA Action is requested at this time.

6. Normative References

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May 1,2017

Benchmarking Methodology for EVPN and PBB-EVPN  
draft-kishjac-bmwg-evptest-07

Abstract

This document defines the methodologies for benchmarking performance of EVPN and PBB-EVPN. EVPN is defined in RFC 7432. It is being deployed in provider network. This document provides the benchmarking methodologies for EVPN/PBB-EVPN convergence, data plane, control plane learning of mac.

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1 Introduction

EVPN which is defined in RFC7432 which describes procedures for BGP MPLS-based Ethernet VPNs(EVPN).This document defines the methodologies for benchmarking performance of EVPN.EVPN has been implemented with many varying designs in order to achieve their intended network functionality.The scope of this document is to provide methodologies for benchmarking evpn data,control plane mac learning,mac flush,mac ageing,convergence,high availability,scale. The methodologies defined for evpn can be used for benchmarking the performance of PBB-EVPN.PBB-EVPN is defined in RFC 7623.It is being deployed in provider network.The difference between PBB-EVPN and EVPN is the former learns the customer mac in data plane the later learns in control plane.

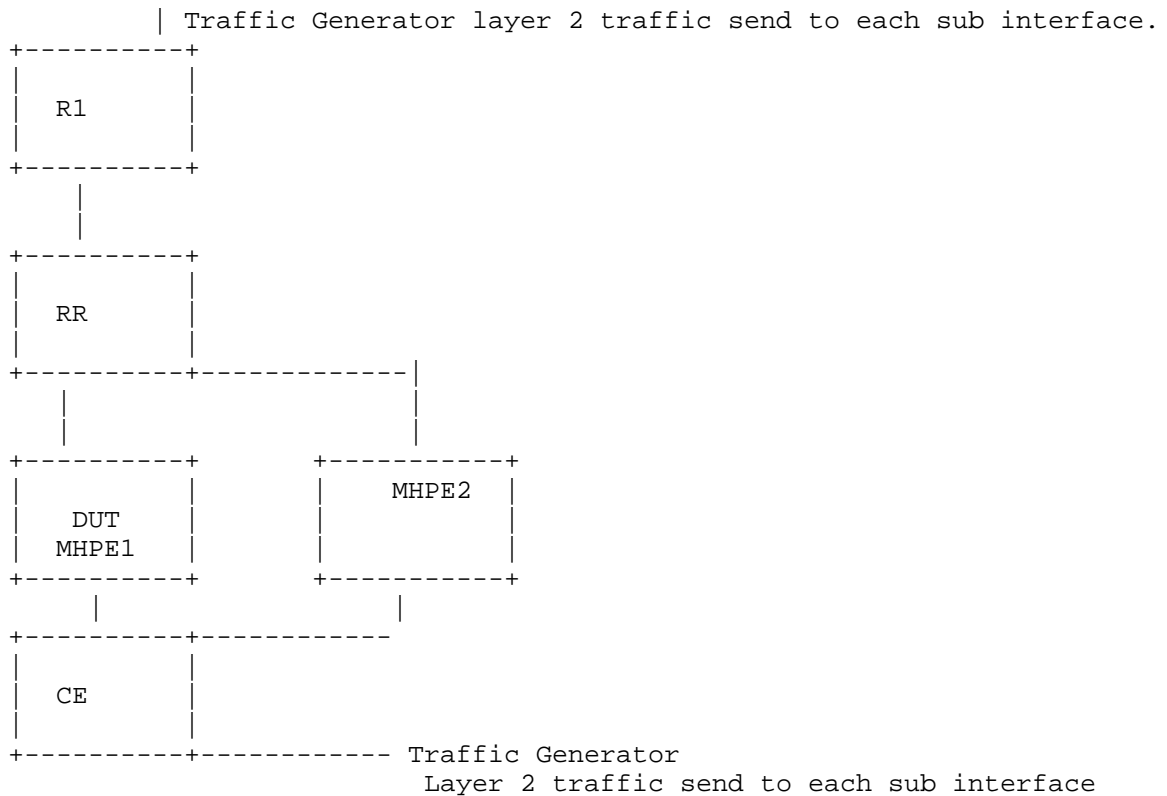
1.1 Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

2.Test Topology

Topology Diagram

Topology Diagram



Topology Diagram

Figure 1

<Jacob&Kishore>

Expires <October 1,2017>

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## 2.1 Terminologies

MHPE Multi homed Provide Edge router.

RR Route Reflector

CE Customer Router/Devices

PE2 Provider Edge router 2

AA EVPN Terminologies AA All-Active

SA EVPN Terminologies SA Single-Active

RT Router Tester

## 3. Network

The network consists of 5 routers and 2 traffic generator ports. DUT is acting as one of the MHPE to CE. The RR is acting as route reflector and core router. R1 is a Single home router running evpn. All four routers except CE are running mpls, bgp emulating a provider scenario. CE is a dual home connected to DUT and MHPE2. The testing will be done on DUT in order to bench mark the service. DUT and the MHPE2 is running EVPN with SA/AA, CE will be configured with layer 2 bridge. In AA EVPN there will be LAG running from CE to both MHPE's. The DUT and other PE's will be running X EVI's (EVPN instances) on X sub interfaces. The traffic generator will be connected to R1 and the CE, which is capable of sending layer 2 frames. The traffic will be send either uni directional or bi directional based on the benchmark parameters to be measured.

### 3.1 PBB-EVPN Network Setup

The network consists of 5 routers and 2 traffic generator ports. DUT is acting as one of the MHPE to CE. The RR is acting as route reflector and core router. R1 is a Single home router running pbbvpn. All four routers except CE are running mpls, bgp emulating a provider scenario. CE is a dual home connected to DUT and MHPE2. DUT and MHPE2 is running PBB-EVPN with SA/AA with CE. CE will be configured with layer 2 bridge. In AA PBB-EVPN there will be LAG running from CE to both MHPE's. The DUT and other PE's will be running X EVI's (PBB-EVPN instances) on X sub interfaces. The traffic generator will be connected to R1 and the CE, which is capable of sending layer 2 frames. The traffic will be send either uni directional or bi directional based on the benchmark parameters to be measured.

#### 4. Test Procedure

The test defined to bench mark the performance of EVPN mac learning in control pland and data plane. Mac flush,High Availability, convergence time in link failures,scale scenarios.

##### 4.1 MAC Learning in Control plane and Data Plane

The MAC will be learned in data plane and control plane, test is to measure the time taken to learn the "X" number of mac's in time "T" sec. The data plane learning will from the locally connected interface. The control plane learning is through BGP advertisements from the remote PE. Let the local learning time be "T" and control plane learning time be "T' ". The data plane mac learning can be measured using the parameters defined in RFC 2889 section 5.8.

##### 4.2 MAC flush for locally learned and remote learned MAC

The time taken to flush the "X" locally learned mac, let it be "T1" sec, once the traffic is stopped. The time taken to flush the remote mac which is learned by control plane let it be "X" macs.The time taken to flush the "X" remote macs, which is measured as "T2" sec.

##### 4.3 High Availability

The traffic is flowing bi direction. The bgp is converged,consider there are "X" numbers of macs learned locally and remotely. Then traffic is flowing at "P" packets per sec. The traffic generator is measuring the Tx and Rx packets, while the routing engine fail over there should not any packet loss the router tester must show both "P" packet per seconds.

##### 4.4 Convergence Time

During any events like link failure, hard reset measure the time taken to learn "X" mac's locally and remotely.

##### 4.5 Scale

This is to measure the performance of DUT in scaling to "X" EVPN instances. The measured parameters are CPU usage, memory leak,crashes.

#### 4.6 SOAK

This test is used to measure the performance of DUT over a period of time,with scaled configuration and traffic over a period of time "T' ". In each interval "t1" the parameters measured are CPU usage, memory usage and crashes.

#### 4.7 Measurement Statistics

The test is repeated for "N" times and the value is taken by averaging the values.

### 5 Test Cases

The following tests are conducted to measure mac learning of local as well as remote.

#### 5.1.1 To check the time taken to learn the mac address in DUT

##### Objective:

To check the time taken to learn the mac address locally and time taken to send the locally learned routes to peers.

a. Send X unicast frames from CE to MHPE1(DUT) working in SA mode with different source and destination address, where DUT is the DF so that it can forward the traffic.Measure the time taken to learn these mac in forwarding table and in control plane. The data plane learning is measured using RFC 2889 section 5.8. Sending frames to the limit of bridge domain of particular EVI. Measure the time taken to learn all X mac in data plane/hardware. The Range of MAC is known from RT and this is verified in DUT.

b. Measure the time taken to send these X type 2 routes from DUT to its peers.

##### Procedure:

Configure EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MH PE ESI must

be configured per IFD/Interface.Using RT (traffic generator) to send the traffic to the CE. The traffic is unidirectional.Since CE is working in bridge mode,frames will be send to ingress sub interface of DUT.

#### Measurement

The DUT mac table must learn the X macs in data plane in T time frame.The DUT must send type 2 routes to remote router in T' time frame.Repeat the test and plot the data.The data plane measurement is taken by considering DUT as black box the range of X mac is known from RT and the same is learned in DUT, the time to learn that is measured.

PBB-EVPN To check the time taken to learn the mac address in DUT

#### Objective:

To check the time taken to learn the mac address locally.

a. Send X unicast frames from CE to MHPE1(DUT) working in SA mode with different source and destination address, where DUT is the DF so that it can forward the traffic. Measure the time taken to learn these mac in forwarding table.The data plane learning is measured using RFC 2889 section 5.8.Sending frames to the limit of bridge domain of particular EVI.Measure the time taken to learn all X mac in data plane/hardware.The Range of MAC is known from RT and this is verified in DUT.

#### Procedure:

Configure PBB-EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MH PE ESI must be configured per IFD/Interface.Using RT (traffic generator) to send the traffic to the routers.

## Measurement

The DUT mac table must learn the X macs in data plane in T time frame. Repeat the test and plot the data. The data plane measurement is taken by considering DUT as black box the range of X mac is known from RT and the same is learned in DUT, the time to learn that is measured.

## 5.1.2. To check the time taken to learn X macs from remote peer by DUT

## Objective:

Send X frames with different SA and DA to DUT from R1 using traffic generator. Measure the time taken to learn these X macs from remote peer and program the mac address table.

## Procedure:

Configure EVPN EVI in R1, MHPE2, DUT. All 4 routers except CE are running mpls, bgp, RR is acting as route reflector to R1, MHPE2 and DUT. Once the bgp comes up check the DUT evpn table. For MH PE ESI must be configured per IFD/Interface. Using RT (traffic generator) send the traffic to R1. The traffic is uni directional. There wont be any traffic flow from CE to DUT during this test.

## Measurement:

The DUT mac table must learn the X mac address in T time frame. Repeat these test and plot the data.

PBB-EVPN To check the time taken to learn X mac's from remote peer by DUT.

## Objective:

Send X frames with different SA and DA to DUT from R1 using traffic generator. Measure the time taken to learn these X macs from remote peer and program the mac address table.

## Procedure:

Configure PBB-EVPN EVI in R1, MHPE2, DUT. All 4 routers except CE are running mpls, bgp, RR is acting as route reflector to R1, MHPE2 and

DUT.Once the bgp comes up check the DUT pbb-evpn table. For MHPE ESI must be configured per IFD/Interface.Using RT(traffic generator) send the traffic to R1. The traffic is uni directional. There wont be any traffic flow from CE to DUT during this test.

Measurement:

The DUT mac table must learn the X mac address in T time frame. Repeat these test and plot the data.

The following test cases are executed to measure the time taken to flush the mac table in case of an event

5.1.3. To check the time taken to flush the local entry due to CE link failure

Objective:

Send X frames with different SA and DA to DUT from CE using traffic generator.Wait for a while to learn all X mac address. Then fail the DUT CE link and measure the time taken to flush these X macs from the mac table and from control plane.

Procedure:

Configure EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT. Once the bgp comes up check the DUT evpn table. For MH PE ESI must be configured per IFD/Interface. Using RT(traffic generator) to send the traffic to the routers.In this traffic will be only send from CE.

Measurement:

Measure the time taken for flushing these X mac address.Repeat the test and plot the data.

PBB-EVPN To check the time taken to flush the local entry due to CE link failure

Objective:

Send X frames with different SA and DA to DUT from CE using traffic generator.Wait for a while to learn all X mac address.Then

fail the DUT CE link and measure the time taken to flush these X macs from the mac table.

Procedure:

Configure PBB-EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT. Once the bgp comes up check the DUT pbb-evpn table. For MH PE ESI must be configured per IFD/Interface. Using RT(traffic generator) to send the traffic to the routers.In this traffic will be only send from CE.

Measurement:

The DUT mac table must learn the X mac address and measure the time taken for flushing these X mac address.

5.1.4. To check the time taken by DUT to flush X routes learned from remote PE after R1 traffic generator link failure

Objective:

Send X frames with different SA and DA to DUT from R1 using traffic generator.Bring down the link between R1 and traffic generator.Then measure the time taken to flush the DUT mac address table.

Procedure:

Configure EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MH PE ESI must be configured per IFD/Interface. Using RT(traffic generator) to send the traffic to the R1.There wont be any traffic flowing to CE from RT.

Measurement:

Measure the time taken to flush X remote routes from mac table of DUT.Repeat the test and plot the data.

PBB-EVPN To check the time taken by DUT to flush X macs learned from remote PE after R1 traffic generator link failure

Objective:

Send X frames with different SA and DA to DUT from R1 using traffic generator. Bring down the link between R1 and traffic generator. Then measure the time taken to flush the DUT mac address table. The remote macs will be learned by Data plane, but the B-MAC will be learned by control plane.

Procedure:

Configure PBB-EVPN EVI in R1, MHPE2, DUT. All 4 routers except CE are running mpls, bgp, RR is acting as route reflector to R1, MHPE2 and DUT. Once the bgp comes up check the DUT pbb-evpn table. For MH PE ESI must be configured per IFD/Interface. Using RT(traffic generator) to send the traffic to the routers. In this traffic will be only send from CE.

Measurement:

Measure the time taken to flush X remote macs from mac table of DUT.

The following test cases are executed to measure the mac ageing in locally learned and remote mac learned by control plane.

5.1.5. To measure the mac ageing time.

Objective:

Send X frames with different SA and DA to DUT from CE using traffic generator. Wait to learn all X mac address. Then stop the traffic. Wait to see how long it takes to flush these mac entries due to ageing.

Procedure:

Configure EVPN EVI in R1, MHPE2, DUT. All 4 routers except CE are



running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table. For MH PE ESI must be configured per IFD/Interface.Using RT(traffic generator) to send the traffic to the routers.The traffic will be flowing from CE to DUT.There wont be any traffic from R1.

Measurement:

Measure the time taken to flush X mac address due to ageing.Repeat the test and plot the data.

PBB-EVPN To measure the mac ageing time.

Objective:

Send X frames with different SA and DA to DUT from CE using traffic generator.Wait to learn all X mac address.Then stop the traffic.Wait to see how long it takes to flush these mac entries due to ageing.

Procedure:

Configure PBB-EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT mac table. For MH PE ESI must be configured per IFD/Interface. Using RT(traffic generator) to send the traffic to the routers.

Measurement:

The DUT mac table must learn the X mac address, measure the time taken for flushing these X mac address due to ageing.

5.1.6. To check the time taken by DUT to age X routes learned from remote PE after stopping the traffic at remote PE.

Objective:

Send X frames with different SA and DA to DUT from R1 using traffic generator. After stopping the traffic at remote PE R1 traffic generator due to mac ageing it will withdraw its routes from remote PE's. Measure the time taken to remove these macs from DUT mac table.

Procedure:

Configure EVPN EVI in R1, MHPE2, DUT. All 4 routers except CE are running mpls, bgp, RR is acting as route reflector to R1, MHPE2 and DUT. Once the bgp comes up check the DUT evpn table. For MH PE ESI must be configured per IFD/Interface. Using RT (traffic generator) to send the traffic to R1. There won't be any traffic from CE.

Measurement:

Measure the time taken to flush X remote macs from mac table of DUT due to ageing. Repeat the test and plot the data.

PBB-EVPN To check the time taken by DUT to age X mac from remote PE after stopping the traffic at remote PE.

Objective:

Send X frames with different SA and DA to DUT from R1 using traffic generator. After stopping the traffic at remote PE (R1) traffic generator. Measure the time taken to remove these macs from DUT mac table.

Procedure:

Configure PBB-EVPN EVI in R1, MHPE2, DUT. All 4 routers except CE are running mpls, bgp, RR is acting as route reflector to R1, MHPE2 and DUT. Once the bgp comes up check the DUT mac table. For MH PE ESI must be configured per IFD/Interface. Using RT (traffic generator) to send the traffic to the routers.

Measurement:

Measure the time taken to flush the remote macs from mac table of DUT due to ageing.

The following tests are executed to measure the convergence time in case of an event or by learning the mac without any external trigger.

- 5.1.7. To check the time taken by DUT to learn X routes from local and X from remote and measure the time of flood from DUT.

Objective:

Send X frames with different SA and DA to DUT from R1 using traffic generator. Send X frames with different SA and DA from traffic generator connected to CE. The SA and DA of flows must be complimentary to have unicast flows. Measure the time taken by the DUT to learn 2X in mac table and in control plane. Measure the flood time period of DUT.

Procedure:

Configure EVPN EVI in R1, MHPE2, DUT. All 4 routers except CE are running mpls, bgp, RR is acting as route reflector to R1, MHPE2 and DUT. Once the bgp comes up check the DUT evpn table. For MH PE ESI must be configured per IFD/Interface. Using RT (traffic generator) to send the traffic to the routers. The traffic is bi directional.

Measurement:

Measure the time taken to learn 2X routes in control and mac address table in DUT and measure the flood time of DUT. Repeat the test and plot the data.

PBB-EVPN To check the time taken by DUT to learn X macs from local and X from remote and measure the time of flood from DUT.

Objective:

Send X frames with different SA and DA to DUT from R1 using traffic generator. Send X frames with different SA and DA from traffic generator connected to CE. The SA and DA of flows must be complimentary to have unicast flows. Measure the time taken by the DUT to learn 2X in mac table. Measure the flood time period of DUT.

## Procedure:

Configure PBB-EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MH PE ESI must be configured per IFD/Interface.Using RT(traffic generator) to send the traffic to the routers.

## Measurement:

Measure the time taken to learn 2X mac address table in DUT. and measure the flood time of DUT.Repeat the test and plot the data.

5.1.8. To measure the time taken to elect a new DF by adding a a MHPE.

## Objective:

Send X frames from CE to DUT from traffic generator with different SA and DA.Wait to learn all X mac address.Then add a new router configured with evpn to the same ethernet segment.Configure same ESI value which is configured in DUT and in MHPE1 on IFD.Then the new DF election take place during that time there should not be any loop and measure the time taken to come up the new DF.Measure the time taken to elect the new DF.

## Procedure:

Configure EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MHPE ESI must be configured per IFD/Interface.Using RT(traffic generator) to send the traffic to the routers.

## Measurement:

Measure the time taken for new DF election in DUT and there should

not be any loop or forwarding the BUM traffic back to the same segment.

PBB-EVPN To measure the time taken to elect a new DF by adding a a MHPE.

Objective:

Send X frames from CE to DUT from traffic generator with different SA and DA.Wait to learn all X mac address.Then add a new router to the same Ethernet segment by configuring the same ESI value configured in DUT,MHPE2 in IFD.Then the new DF election take place during that time there should not be any loop and measure the time taken to come up the new DF.Measure the time taken to elect the new DF.

Procedure:

Configure PBB-EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table. For MH PE ESI must be configured per IFD/Interface. Using RT(traffic generator) to send the traffic to the routers.

Measurement:

Measure the time taken for new DF election in DUT and there should not be any loop or forwarding the BUM traffic back to the same segment.

## 5.2 High Availability

These tests are conducted to check after an event there wont be any change in functionality.

### 5.2.1 To check the whether there is traffic loss due to routing engine failover for redundancy test.

#### Objective:

Send X frames from CE to DUT from traffic generator with different SA and DA. Send X frames from traffic generator to R1 with different SA and DA so that 2X mac address will be learned in DUT. There is a bi directional traffic flow with X pps in each direction. Then do a routing engine failover.

#### Procedure:

Configure EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MH PE ESI must be configured per IFD/Interface.Using RT(traffic generator) to send the traffic to the routers.

#### Measurement:

There should be 0 traffic loss which is the ideal case,No change in the DF role.No withdraw of any routes.

PBB-EVPN To check the whether there is traffic loss due to routing engine failover for redundancy test.

#### Objective:

Send X frames from CE to DUT from traffic generator with different SA and DA.Send X frames from traffic generator to R1 with different SA and DA so that 2X mac address will be learned in DUT. There is a bi directional traffic flow with X pps in each direction.Then do a routing engine failover.

#### Procedure:

Configure PBB-EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are

running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MH PE ESI must be configured per IFD/Interface. Using RT(traffic generator) to send the traffic to the routers.

Measurement:

There should be 0 packet loss loss which is a ideal case,No change in the DF role. No withdraw of any routes.

### 5.3 ARP/ND Scaling

These tests are conducted to check the scaling parameter of arp/ND of the DUT.

EVPN: To check the ARP/ND scale of the DUT when the gateway is configured.

Objective:

Send X arp/icmpv6 request from RT to DUT,that with different sender ip/ipv6 address to the same target gateway ip address.

Procedure:

Configure EPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MH PE ESI must be configured per IFD/Interface.Using RT(traffic generator) to send the arp request to the DUT which has gateway configured.

Measurement:

The DUT must learn X mac+ip/mac+ipv6 and it must advertise the X mac+ip/mac+ipv6 to the remote router.

#### 5.4 Type 5 Route scaling

These tests are conducted to scale the type 5 route or the IP prefixes in DUT.

EVPN: To check the scale of ip prefixes advertised by DUT to the peer router.

Objective:

To check the scale of IP Prefixes advertised by the DUT to the peer router.

Procedure:

Configure EPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MH PE ESI must be configured per IFD/Interface.Configure the X IRB sub interface in the DUT which is not extended to peer router.

Measurement:

The DUT must advertise X IP prefixes of the IRB to the peer router.

#### 6. Scale

6.1. To Scale the DUT to N EVI and clear bgp in DUT with out traffic.

Objective:



The main purpose of the test the DUT performance to scale N EVI's. Then clear bgp neighbor. There should not be any loss of routes or any crashes.

Procedure:

Configure EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MHPE,DUT ESI must be configured per IFD/Interface. Using RT(traffic generator) to send the traffic to the routers.

Measurement

There should not be any loss of route types 1,2,3 and 4 in DUT.

PBB-EVPN To Scale the DUT to N PBB-EVPN instances and clear bgp in DUT without traffic.

Objective:

The main purpose of the test the DUT performance to scale N PBB-EVPN instances.Then clear bgp neighbor.There should not be any loss of routes or any crashes.

Procedure:

Configure PBB-EVPN instances in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MH PE ESI must be configured per IFD/Interface.Using RT(traffic generator) to send the traffic to the routers.

Measurement

There should not be any loss of route types 2,3 and 4 in DUT.

6.2. To Scale the DUT to N EVI and clear bgp in DUT with traffic.Measure the convergence time

Objective:

The main purpose of the test the DUT performance to scale N EVI's with traffic. Then clear bgp neighbor.There should not be any loss of routes or any crashes. Send F frames from CE to DUT from traffic generator with different SA and DA for N EVI's. Send F frames from traffic generator to R1 with different SA and DA for N EVI's.so that 2F number of mac address will be learned in DUT. There is a bi directional traffic flow with F pps in each direction. Then clear the bgp nei in DUT after the bgp comes up and started learning the routes, measure the time taken to learn all 2F mac routes.

Procedure:

Configure EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MH PE ESI must be configured per IFD/Interface. Using RT(traffic generator) to send the traffic to the routers.

Measurement:

The DUT must learn all 2F mac address.Measure the time taken to learn 2F mac in DUT, measure the flood traffic time "t" of DUT

PBB-EVPN To Scale the DUT to "N" PBB-EVPN instances and clear bgp in DUT with traffic.Measure the convergence time

Objective:

The main purpose of the test the DUT performance to scale N pbb-evpn instances with traffic.Then clear bgp neighbor.There should not be any loss of routes or any crashes.Send F frames from CE to DUT from traffic generator with different SA and DA for N pbb-evpn instances.Send F frames from traffic generator to R1 with different SA and DA for N pbb-evpn instances.so that F mac address will be learned in DUT.There is a bi directional traffic flow with F pps in each direction.Then clear the bgp nei in DUT after the bgp comes up and started learning the routes, measure the time taken to learn all 2F macs in DUT.

## Procedure:

Configure PBB-EVPN instances in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MH PE ESI must be configured per IFD/Interface. Using RT(traffic generator) to send the traffic to the routers.

## Measurement:

The DUT must learn all 2F mac address.Measure the time taken to learn 2F mac in DUT, measure the flood traffic time "t" of DUT

## 7. Soak Test

- 7.1. To Scale the DUT to N EVI in DUT with traffic and run the set up for 24hrs

## Objective:

The main purpose of the test the DUT performance to scale N EVI's with traffic.There should not be any loss of routes or any crashes.

Send F frames from CE to DUT from traffic generator with different SA and DA for N EVI's.Send F frames from traffic generator to R1 with different SA and DA for N EVI's.so that 2F mac address will be learned in DUT. There is a bi directional traffic flow with F pps in each direction.Keep the setup up and running for 24 hrs, take hourly CPU utilization,memory usage.

## Procedure:

Configure EVPN EVI in R1,MHPE2,DUT.All 4 routers except CE are running mpls,bgp,RR is acting as route reflector to R1,MHPE2 and DUT.Once the bgp comes up check the DUT evpn table.For MH PE ESI must be configured per IFD/Interface. Using RT(traffic generator) to send the traffic to the routers.

## Measurement:

Take the hourly reading of CPU,process memory.There should not be any leak,crashes,CPU spikes.

PBB-EVPN To Scale the DUT to N PBB-EVPN instances in DUT with traffic and run the set up for 24hrs

Objective:

The main purpose of the test the DUT performance to scale N EVI's with traffic. There should not be any loss of routes or any crashes. Send F frames from CE to DUT from traffic generator with different SA and DA for N EVI's. Send F frames from traffic generator to R1 with different SA and DA for N EVI's. so that 2F mac address will be learned in DUT. There is a bi directional traffic flow with F pps in each direction. Keep the setup up and running for 24 hrs, take hourly CPU utilization, memory usage.

Procedure:

Configure PBB-EVPN instances in R1, MHPE2, DUT. All 4 routers except CE are running mpls, bgp, RR is acting as route reflector to R1, MHPE2 and DUT. Once the bgp comes up check the DUT evpn table. For MH PE ESI must be configured per IFD/Interface. Using RT(traffic generator) to send the traffic to the routers.

Measurement:

Take the hourly reading of CPU, process memory. There should not be any leak, crashes, CPU spikes.

## 8. Acknowledgements

We would like to thank Fioccola Giuseppe of Telecom Italia reviewing our draft and commenting it.

## 9. IANA Considerations

This memo includes no request to IANA.

## 10. Security Considerations

There is no additional consideration from RFC 6192.

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Appendix A. Appendix

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VNF Benchmarking Methodology  
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Abstract

This document describes VNF benchmarking methodologies.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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## 1. Introduction

New paradigms of network services envisioned by NFV bring VNFs as software based entities, which can be deployed in virtualized environments [ETSI14a]. In order to be managed/orchestrated or compared with physical network functions, VNF Descriptors can specify performance profiles containing metrics (e.g., throughput) associated with allocated resources (e.g., vCPU). This document describes benchmarking methodologies to obtain VNF profiles (resource - performance figures).

## 2. Terminology

The reader is assumed to be familiar with the terminology as defined in the European Telecommunications Standards Institute (ETSI) NFV document [ETSI14b]. Some of these terms, and others commonly used in this document, are defined below.

NFV: Network Function Virtualization - The principle of separating network functions from the hardware they run on by using virtual hardware abstraction.

NFVI PoP: NFV Infrastructure Point of Presence - Any combination of virtualized compute, storage and network resources.

NFVI: NFV Infrastructure - Collection of NFVI PoPs under one orchestrator.



VIM: Virtualized Infrastructure Manager - functional block that is responsible for controlling and managing the NFVI compute, storage and network resources, usually within one operator's Infrastructure Domain (e.g. NFVI-PoP).

NFVO: NFV Orchestrator - functional block that manages the Network Service (NS) life-cycle and coordinates the management of NS life-cycle, VNF life-cycle (supported by the VNFM) and NFVI resources (supported by the VIM) to ensure an optimized allocation of the necessary resources and connectivity

VNF: Virtualized Network Function - a software-based network function.

VNFD: Virtualised Network Function Descriptor - configuration template that describes a VNF in terms of its deployment and operational behaviour, and is used in the process of VNF onboarding and managing the life cycle of a VNF instance.

VNF-FG: Virtualized Network Function Forwarding Graph - an ordered list of VNFs creating a service chain.

MANO: Management and Orchestration - In the ETSI NFV framework [ETSI14a], this is the global entity responsible for management and orchestration of NFV life-cycle.

Network Service: composition of Network Functions and defined by its functional and behavioural specification.

Additional terminology not defined by ETSI NFV ISG.

VNF-BP: VNF Benchmarking Profile - the specification how to measure a VNF Profile. VNF-BP may be specific to a VNF or applicable to several VNF types. The specification includes structural and functional instructions, and variable parameters (metrics) at different abstractions (e.g., vCPU, memory, throughput, latency; session, transaction, tenants, etc.).

VNF Profile: is a mapping between virtualized resources (e.g., vCPU, memory) and VNF performance (e.g., throughput, latency between in/out ports) at a given NFVI PoP. An orchestration function can use the VNF Profile to select a host (NFVI PoP) for a VNF and to allocate necessary resources to deliver the required performance characteristics.

Customer: A user/subscriber/consumer of ETSI's Network Service.

Agents: Network Functions performing benchmarking tasks (e.g., synthetic traffic sources and sinks; measurement and observation functions, etc.).

SUT: System Under Test comprises the VNF under test.

### 3. Scope

This document assumes VNFs as black boxes when defining VNF performance benchmarking methodologies. White box benchmarking of VNFs are left for further studies and may be added later.

### 4. Assumptions

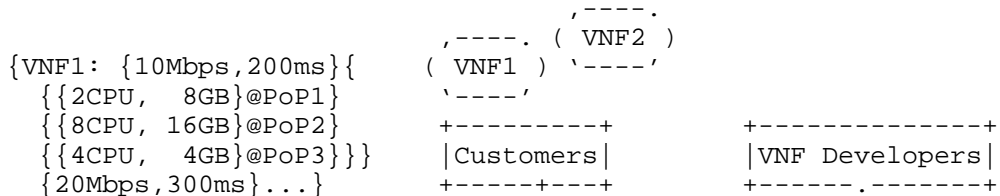
We assume a VNF benchmarking set-up as shown in Figure 1. Customers can request Network Services (NS) from an NFVO with associated service level specifications (e.g., throughput and delay). The NFVO, in turn, must select hosts and software resource allocations for the VNFs and build the necessary network overlay to meet the requirements. Therefore, the NFVO must know VNF Profiles per target hosts to perform location and resource assignments.

In a highly dynamic environment, where both the VNF instances (e.g., revised VM image) and the NFVI resources (e.g., hw upgrades) are changing, the NFVO should be able to create VNF Profiles on-demand.

We assume, that based on VNF Benchmarking Profile definitions NFVOs can run benchmarking evaluations to learn VNF Profiles per target hosts.

In a virtualization environment, however, not only the SUT but all the other benchmarking agents may be software defined (physical or virtualized network functions).

Figure 1 shows an example, where the NFVO can use PoPa and PoPb to set-up benchmarking functions to test VNFs hosted in PoP 1, 2, 3 domains corresponding to VIM 1, 2 and 3. The NFVO uses the VNF Benchmarking Profiles to deploy agents according to the SUT VNF. The VNF Benchmarking Profile is defined by the VNF Developer. The results of the VNF benchmarking is stored in a VNF Profile.



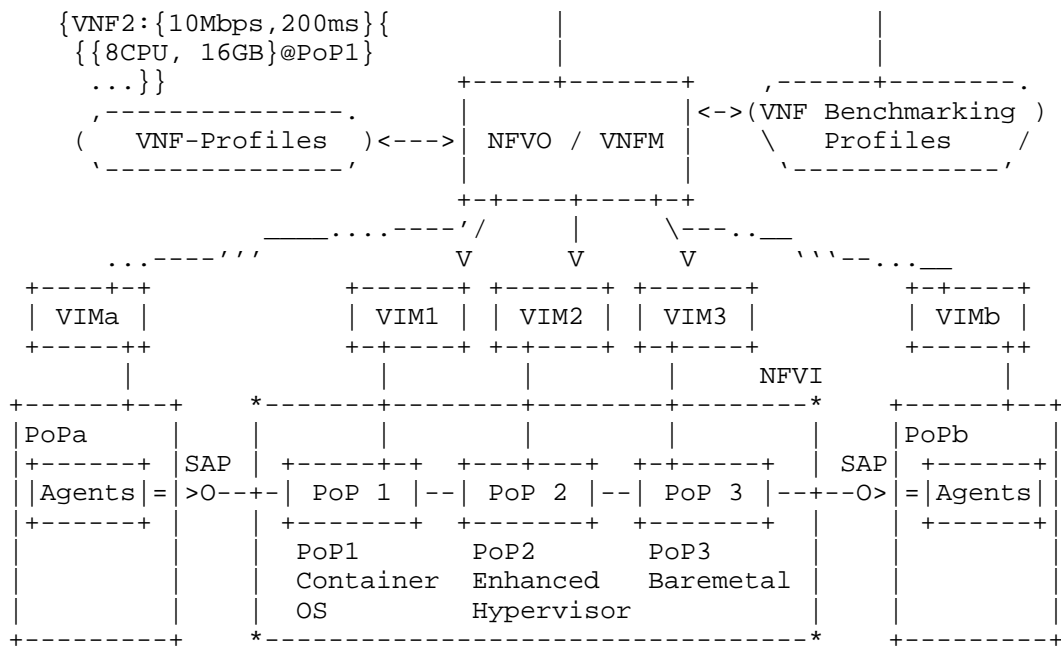


Figure 1: VNF Testing Scenario

5. VNF Benchmarking Considerations

VNF benchmarking considerations are defined in [Mor15]. Additionally, VNF pre-deployment testing considerations are well explored in [ETS14c].

This document list further considerations:

Black-Box SUT with Black-Box Benchmarking Agents: In virtualization environments neither the VNF instance nor the underlying virtualization environment nor the agents specifics may be known by the entity managing abstract resources. This implies black box testing with black box functional components, which are configured by opaque configuration parameters defined by the VNF developers or alike for the benchmarking entity (e.g., NFVO).

6. Methodology

Following the ETSI's model ([ETS14c]), we distinguish three methods for VNF evaluation:

Benchmarking: Where resource {cpu, memory, storage} parameters are provided and the corresponding {latency, throughput} performance

parameters are obtained. Note, such request might create multiple reports, for example, with minimal latency or maximum throughput results.

**Verification:** Both resources {cpu, memory, storage} and performance {latency, throughput} parameters are provided and agents verifies if the given association is correct or not.

**Dimensioning:** Where performance parameters {latency, throughput} are provided and the corresponding {cpu, memory, storage} resource parameters obtained. Note, multiple deployment interactions may be required, or if possible, underlying allocated resources need to be dynamically altered.

**Note:** Verification and Dimensioning can be reduced to Benchmarking. Therefore, we detail Benchmarking in what follows.

## 6.1. Benchmarking

All benchmarking methodologies described in this section consider the definition of VNF-BPs for each testing procedure. Information about Benchmarking Methodology for Network Interconnect Devices, defined in [rfc2544], is considered in all subsections below. Besides, the tests are defined based on notions introduced and discussed in the IP Performance Metrics (IPPM) Framework document [rfc2330].

### 6.1.1. Throughput

**Objective:** Provide, for a particular set of resources allocated, the throughput among two or more VNF ports, expressed in VNF-BP.

**Prerequisite:** VNF (SUT) must be deployed and stable and its allocated resources collected. VNF must be reachable by agents. The frame size to be used for agents must be defined in the VNF-BP.

**Procedure:**

1. Establish connectivity between agents and VNF ports.
2. Agents initiate source of traffic, specifically designed for VNF test, increasing rate periodically.
3. Throughput is measured when traffic rate is achieved without frame losses.

**Reporting Format:** report must contain VNF allocated resources and throughput measured (aka throughput in [rfc2544]).

### 6.1.2. Latency

Objective: Provide, for a particular set of resources allocated, the latency among two or more VNF ports, expressed in VNF-BP.

Prerequisite: VNF (SUT) must be deployed and stable and its allocated resources collected. VNF must be reachable by agents. The frame size and respective throughput to be used for agents must be defined in the VNF-BP.

Procedure:

1. Establish connectivity between agents and VNF ports.
2. Agents initiate source of traffic, throughput and frame size specifically designed for VNF test.
3. Latency is measured when throughput is achieved for the period of time specified in VNF-BP.

Reporting Format: report must contain VNF allocated resources, throughput used for stimulus and latency measurement (aka latency in [rfc2544]).

### 6.1.3. Frame Loss Rate

Objective: Provide, for a particular set of resources allocated, the frame loss rate among two or more VNF ports, expressed in VNF-BP.

Prerequisite: VNF (SUT) must be deployed and stable, its allocated resources collected specifying any particular feature of the underlying VNF virtualized environment, provided by NFVO/VIM or independently extracted. VNF must be reachable by agents. Rate of source traffic and frame type used for agents stimulus must be defined in VNF-BP.

Procedure:

1. Establish connectivity between agents and VNF ports.
2. Agents initiate source of traffic, specifically designed for VNF test, achieving rate of source traffic defined in VNF-BP.
3. Frame loss rate is measured when pre-defined traffic rate is achieved for period of time established in VNF-BP.

Reporting Format: report must contain VNF allocated resources, rate of source traffic used as stimulus and frame loss rate measurement (aka frame loss rate in [rfc2544]).

## 7. Summary

This document describes black-box benchmarking methodologies for black-box VNFs in virtualization environments (e.g., ETSI NFV framework) to create VNF Profiles containing the association of resources and performance metrics of a given VNF at a given host (e.g., NFVI PoP).

The authors see the following next steps:

VNF Scaling: Two scaling options: single instance with more resources or multiple instances. Questions: What is the maximum performance of a single instance VNF at a given host with increasing resources? How many independent VNF instances (or components) can be run with maximum performance at a given host? On the other hand, what is the performance of the smallest resource footprint VNF allocation?

VNF instantiation time: this metric concerns at least three components: VNF bootstrapping (SUT), execution environment and the orchestration process.

## 8. IANA Considerations

This memo includes no request to IANA.

## 9. Security Considerations

TBD

## 10. Acknowledgement

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Considerations for Benchmarking Network Virtualization Platforms  
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## Abstract

Current network benchmarking methodologies are focused on physical networking components and do not consider the actual application layer traffic patterns and hence do not reflect the traffic that virtual networking components work with. The purpose of this document is to distinguish and highlight benchmarking considerations when testing and evaluating virtual networking components in the data center.

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## 1. Introduction

Datacenter virtualization that includes both compute and network virtualization is growing rapidly as the industry continues to look for ways to improve productivity, flexibility and at the same time

cut costs. Network virtualization, is comparatively new and expected to grow tremendously similar to compute virtualization. There are multiple vendors and solutions out in the market, each with their own benchmarks to showcase why a particular solution is better than another. Hence, the need for a vendor and product agnostic way to benchmark multivendor solutions to help with comparison and make informed decisions when it comes to selecting the right network virtualization solution.

Applications traditionally have been segmented using VLANs and ACLs between the VLANs. This model does not scale because of the 4K scale limitations of VLANs. Overlays such as VXLAN were designed to address the limitations of VLANs

With VXLAN, applications are segmented based on VXLAN encapsulation (specifically the VNI field in the VXLAN header), which is similar to VLAN ID in the 802.1Q VLAN tag, however without the 4K scale limitations of VLANs. For a more detailed discussion on this subject please refer RFC 7364 "Problem Statement: Overlays for Network Virtualization".

VXLAN is just one of several Network Virtualization Overlays(NVO). Some of the others include STT, Geneve and NVGRE. . STT and Geneve have expanded on the capabilities of VXLAN. Please refer IETF's nvo3 working group <<https://datatracker.ietf.org/wg/nvo3/documents/>> for more information.

Modern application architectures, such as Micro-services, are going beyond the three tier app models such as web, app and db. Benchmarks MUST consider whether the proposed solution is able to scale up to the demands of such applications and not just a three-tier architecture.

## 2. Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

In this document, these words will appear with that interpretation only when in ALL CAPS. Lower case uses of these words are not to be interpreted as carrying significance described in RFC 2119.

### 3. Definitions

#### 3.1. System Under Test (SUT)

Traditional hardware based networking devices generally use the device under test (DUT) model of testing. In this model, apart from any allowed configuration, the DUT is a black box from a testing perspective. This method works for hardware based networking devices since the device itself is not influenced by any other components outside the DUT.

Virtual networking components cannot leverage DUT model of testing as the DUT is not just the virtual device but includes the hardware components that were used to host the virtual device

Hence SUT model MUST be used instead of the traditional device under test

With SUT model, the virtual networking component along with all software and hardware components that host the virtual networking component MUST be considered as part of the SUT.

Virtual networking components may also work with higher level TCP segments such as TSO. In contrast, all physical switches and routers, including the ones that act as initiators for NVOs, work with L2/L3 packets.

Please refer to section 5 Figure 1 for a visual representation of System Under Test in the case of Intra-Host testing and section 5 Figure 2 for System Under Test in the case of Inter-Host testing

#### 3.2. Network Virtualization Platform

This document does not focus on Network Function Virtualization.

Network Function Virtualization (NFV) focuses on being independent of networking hardware while providing the same functionality. In the case of NFV, traditional benchmarking methodologies recommended by IETF may be used. Considerations for Benchmarking Virtual Network Functions and Their Infrastructure IETF document addresses benchmarking NFVs.

Typical NFV implementations emulate in software, the characteristics and features of physical switches. They are similar to any physical L2/L3 switch from the perspective of the packet size, which is typically enforced based on the maximum transmission unit used.

Network Virtualization platforms on the other hand, are closer to the application layer and are able to work with not only L2/L3

packets but also segments that leverage TCP optimizations such as Large Segment Offload (LSO).

NVPs leverage TCP stack optimizations such as TCP Segmentation Offload (TSO) and Large Receive Offload (LRO) that enables NVPs to work with much larger payloads of up to 64K unlike their counterparts such as NFVs.

Because of the difference in the payload, which translates into one operation per 64K of payload in NVP verses ~40 operations for the same amount of payload in NFV because of having to divide it to MTU sized packets, results in considerable difference in performance between NFV and NVP.

Please refer to figure 1 for a pictorial representation of this primary difference between NPV and NFV for a 64K payload segment/packet running on network set to 1500 bytes MTU.

Note: Payload sizes in figure 1 are approximates.



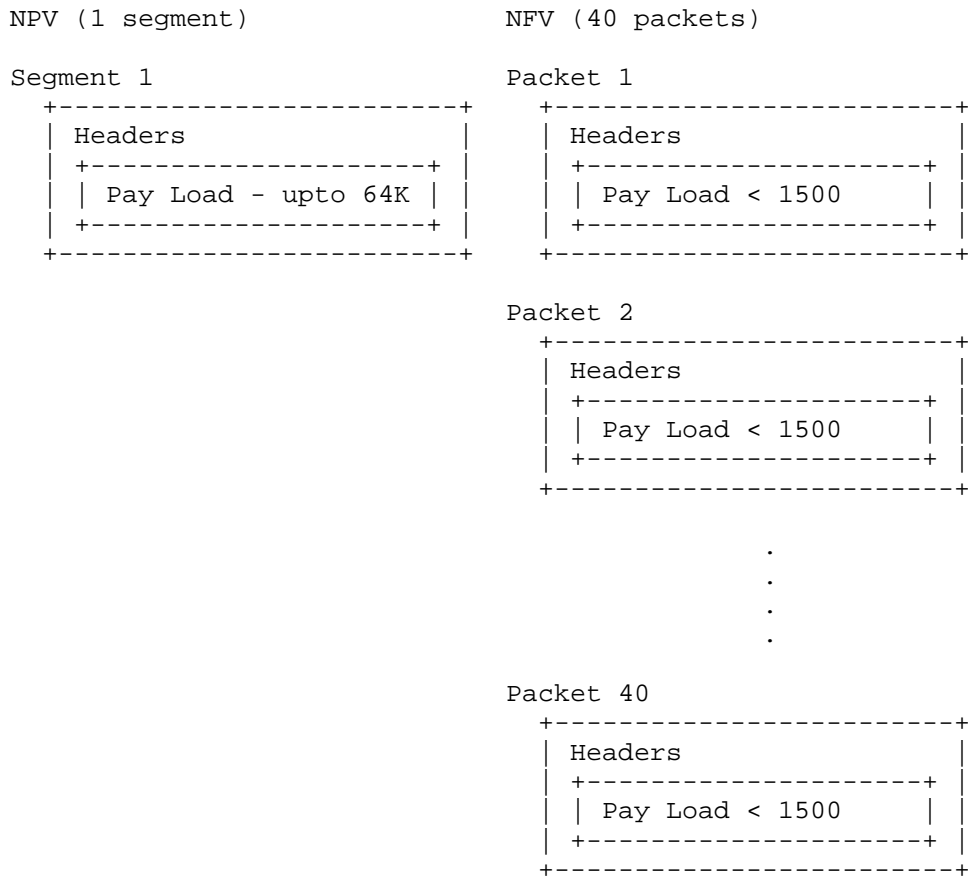


Figure 1 Payload NPV vs NFV

Hence, normal benchmarking methods are not relevant to the NVPs.

Instead, newer methods that take into account the built in advantages of TCP provided optimizations MUST be used for testing Network Virtualization Platforms.

### 3.3. Micro-services

Traditional monolithic application architectures such as the three tier web, app and db architectures are hitting scale and deployment limits for the modern use cases.

Micro-services make use of classic unix style of small app with single responsibility.

These small apps are designed with the following characteristics:

Each application only does one thing - like unix tools

Small enough that you could rewrite instead of maintain

Embedded with a simple web container

Packaged as a single executable

Installed as daemons

Each of these applications are completely separate

Interact via uniform interface

REST (over HTTP/HTTPS) being the most common

With Micro-services architecture, a single web app of the three tier application model could now have 100s of smaller apps dedicated to do just one job.

These 100s of small one responsibility only services will MUST be secured into their own segment - hence pushing the scale boundaries of the overlay from both simple segmentation perspective and also from a security perspective

#### 4. Scope

This document does not address Network Function Virtualization has been covered already by previous IETF documents ([https://datatracker.ietf.org/doc/draft-ietf-bmwg-virtual-net/?include\\_text=1](https://datatracker.ietf.org/doc/draft-ietf-bmwg-virtual-net/?include_text=1)) the focus of this document is Network Virtualization Platform where the network functions are an intrinsic part of the hypervisor's TCP stack, working closer to the application layer and leveraging performance optimizations such TSO/RSS provided by the TCP stack and the underlying hardware.

##### 4.1. Virtual Networking for Datacenter Applications

While virtualization is growing beyond the datacenter, this document focuses on the virtual networking for east-west traffic within the datacenter applications only. For example, in a three tier app such web, app and db, this document focuses on the east-west traffic between web and app. It does not address north-south web traffic accessed from outside the datacenter. A future document would address north-south traffic flows.

This document addresses scale requirements for modern application architectures such as Micro-services to consider whether the proposed solution is able to scale up to the demands of micro-services application models that basically have 100s of small services communicating on some standard ports such as http/https using protocols such as REST

#### 4.2. Interaction with Physical Devices

Virtual network components cannot be tested independent of other components within the system. Example, unlike a physical router or a firewall, where the tests can be focused directly solely on the device, when testing a virtual router or firewall, multiple other devices may become part of the system under test. Hence the characteristics of these other traditional networking switches and routers, LB, FW etc. MUST be considered.

- ! Hashing method used
- ! Over-subscription rate
- ! Throughput available
- ! Latency characteristics

#### 5. Interaction with Physical Devices

In virtual environments, System Under Test (SUT) may often share resources and reside on the same Physical hardware with other components involved in the tests. Hence SUT MUST be clearly defined. In this tests, a single hypervisor may host multiple servers, switches, routers, firewalls etc.,

Intra host testing: Intra host testing helps in reducing the number of components involved in a test. For example, intra host testing would help focus on the System Under Test, logical switch and the hardware that is running the hypervisor that hosts the logical switch, and eliminate other components. Because of the nature of virtual infrastructures and multiple elements being hosted on the same physical infrastructure, influence from other components cannot be completely ruled out. For example, unlike in physical infrastructures, logical routing or distributed firewall MUST NOT be benchmarked independent of logical switching. System Under Test definition MUST include all components involved with that particular test.



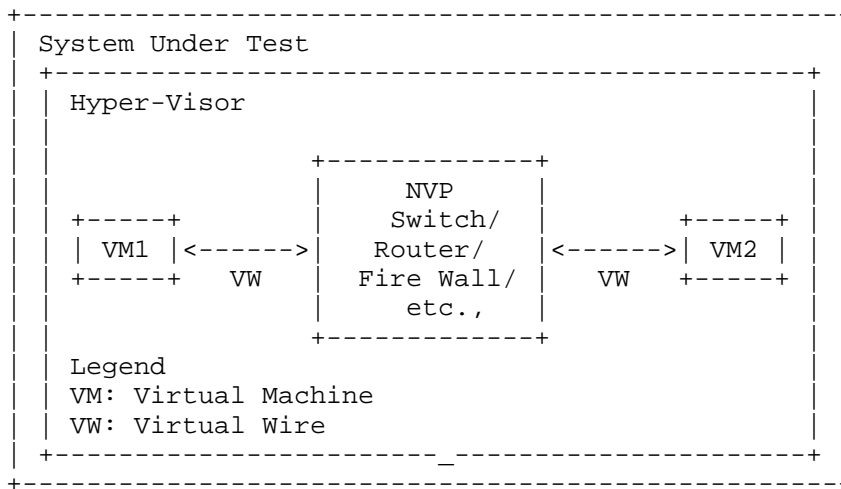


Figure 2 Intra-Host System Under Test

Inter host testing: Inter host testing helps in profiling the underlying network interconnect performance. For example, when testing Logical Switching, inter host testing would not only test the logical switch component but also any other devices that are part of the physical data center fabric that connects the two hypervisors. System Under Test MUST be well defined to help with repeatability of tests. System Under Test definition in the case of inter host testing, MUST include all components, including the underlying network fabric.

Figure 2 is a visual representation of system under test for inter-host testing

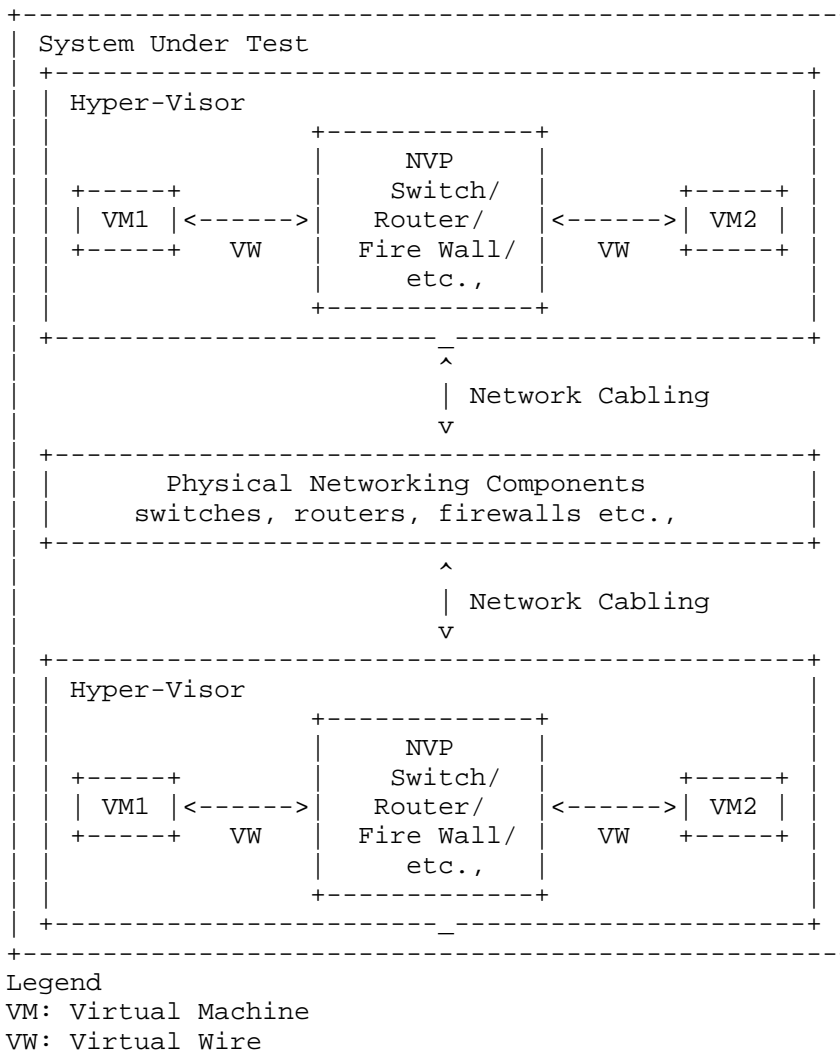


Figure 3 Inter-Host System Under Test

Virtual components have a direct dependency on the physical infrastructure that is hosting these resources. Hardware characteristics of the physical host impact the performance of the virtual components. The components that are being tested and the impact of the other hardware components within the hypervisor on the performance of the SUT MUST be documented. Virtual component performance is influenced by the physical hardware components within the hypervisor. Access to various offloads such as TCP segmentation

offload, may have significant impact on performance. Firmware and driver differences may also significantly impact results based on whether the specific driver leverages any hardware level offloads offered. Hence, all physical components of the physical server running the hypervisor that hosts the virtual components MUST be documented along with the firmware and driver versions of all the components used to help ensure repeatability of test results. For example, BIOS configuration of the server MUST be documented as some of those changes are designed to improve performance. Please refer to Appendix A for a partial list of parameters to document.

## 5.1. Server Architecture Considerations

When testing physical networking components, the approach taken is to consider the device as a black-box. With virtual infrastructure, this approach would no longer help as the virtual networking components are an intrinsic part of the hypervisor they are running on and are directly impacted by the server architecture used. Server hardware components define the capabilities of the virtual networking components. Hence, server architecture MUST be documented in detail to help with repeatability of tests. And the entire hardware and software components become the SUT.

### 5.1.1. Frame format/sizes within the Hypervisor

Maximum Transmission Unit (MTU) limits physical network component's frame sizes. The most common max supported MTU for physical devices is 9000. However, 1500 MTU is the standard. Physical network testing and NFV uses these MTU sizes for testing. However, the virtual networking components that live inside a hypervisor, may work with much larger segments because of the availability of hardware and software based offloads. Hence, the normal smaller packets based testing is not relevant for performance testing of virtual networking components. All the TCP related configuration such as TSO size, number of RSS queues MUST be documented along with any other physical NIC related configuration.

Virtual network components work closer to the application layer than the physical networking components. Hence virtual network components work with type and size of segments that are often not the same type and size that the physical network works with. Hence, testing virtual network components MUST be done with application layer segments instead of the physical network layer packets.

### 5.1.2. Baseline testing with Logical Switch

Logical switch is often an intrinsic component of the test system along with any other hardware and software components used for

testing. Also, other logical components cannot be tested independent of the Logical Switch.

#### 5.1.3. Repeatability

To ensure repeatability of the results, in the physical network component testing, much care is taken to ensure the tests are conducted with exactly the same parameters. Parameters such as MAC addresses used etc.,

When testing NPV components with an application layer test tool, there may be a number of components within the system that may not be available to tune or to ensure they maintain a desired state. Example: housekeeping functions of the underlying Operating System.

Hence, tests MUST be repeated a number of times and each test case MUST be run for at least 2 minutes if test tool provides such an option. Results SHOULD be derived from multiple test runs. Variance between the tests SHOULD be documented.

#### 5.1.4. Tunnel encap/decap outside the hypervisor

Logical network components may also have performance impact based on the functionality available within the physical fabric. Physical fabric that supports NVO encap/decap is one such case that has considerable impact on the performance. Any such functionality that exists on the physical fabric MUST be part of the test result documentation to ensure repeatability of tests. In this case SUT MUST include the physical fabric

#### 5.1.5. SUT Hypervisor Profile

Physical networking equipment has well defined physical resource characteristics such as type and number of ASICs/SoCs used, amount of memory, type and number of processors etc., Virtual networking components' performance is dependent on the physical hardware that hosts the hypervisor. Hence the physical hardware usage, which is part of SUT, for a given test MUST be documented. Example, CPU usage when running logical router.

CPU usage changes based on the type of hardware available within the physical server. For example, TCP Segmentation Offload greatly reduces CPU usage by offloading the segmentation process to the NIC card on the sender side. Receive side scaling offers similar benefit on the receive side. Hence, availability and status of such hardware MUST be documented along with actual CPU/Memory usage when the virtual networking components have access to such offload capable hardware.

Following is a partial list of components that MUST be documented - both in terms of what's available and also what's used by the SUT -

- o CPU - type, speed, available instruction sets (e.g. AES-NI)
- o Memory - type, amount
- o Storage - type, amount
- o NIC Cards - type, number of ports, offloads available/used, drivers, firmware (if applicable), HW revision
- o Libraries such as DPDK if available and used
- o Number and type of VMs used for testing and
  - o vCPUs
  - o RAM
  - o Storage
  - o Network Driver
  - o Any prioritization of VM resources
  - o Operating System type, version and kernel if applicable
  - o TCP Configuration Changes - if any
  - o MTU
- o Test tool
  - o Workload type
  - o Protocol being tested
  - o Number of threads
  - o Version of tool
- o For inter-hypervisor tests,
  - o Physical network devices that are part of the test

! Note: For inter-hypervisor tests, system under test is no longer only the virtual component that is being tested but the entire fabric that connects the

virtual components become part of the system under test.

## 6. Security Considerations

Benchmarking activities as described in this memo are limited to technology characterization of a Device Under Test/System Under Test (DUT/SUT) using controlled stimuli in a laboratory environment, with dedicated address space and the constraints specified in the sections above.

The benchmarking network topology will be an independent test setup and MUST NOT be connected to devices that may forward the test traffic into a production network, or misroute traffic to the test management network.

Further, benchmarking is performed on a "black-box" basis, relying solely on measurements observable external to the DUT/SUT.

Special capabilities SHOULD NOT exist in the DUT/SUT specifically for benchmarking purposes. Any implications for network security arising from the DUT/SUT SHOULD be identical in the lab and in production networks.

## 7. IANA Considerations

No IANA Action is requested at this time.

## 8. Conclusions

Network Virtualization Platforms, because of their proximity to the application layer and since they can take advantage of TCP stack optimizations, do not function on packets/sec basis. Hence, traditional benchmarking methods, while still relevant for Network Function Virtualization, are not designed to test Network Virtualization Platforms. Also, advances in application architectures such as micro-services, bring new challenges and need benchmarking not just around throughput and latency but also around scale. New benchmarking methods that are designed to take advantage of the TCP optimizations or needed to accurately benchmark performance of the Network Virtualization Platforms

## 9. References

### 9.1. Normative References

[RFC7364] T. Narten, E. Gray, D. Black, L. Fang, L. Kreeger, M. Napierala, "Problem Statement: Overlays for Network Virtualization", RFC 7364, October 2014, <https://datatracker.ietf.org/doc/rfc7364/>

[nv03] IETF, WG, Network Virtualization Overlays, <  
<https://datatracker.ietf.org/wg/nvo3/documents/>>

## 9.2. Informative References

- [1] A. Morton " Considerations for Benchmarking Virtual Network Functions and Their Infrastructure", draft-ietf-bmwg-virtual-net-03, < [https://datatracker.ietf.org/doc/draft-ietf-bmwg-virtual-net/?include\\_text=1](https://datatracker.ietf.org/doc/draft-ietf-bmwg-virtual-net/?include_text=1)>





Appendix A. Partial List of Parameters to Document

A.1. CPU

CPU Vendor

CPU Number

CPU Architecture

# of Sockets (CPUs)

# of Cores

Clock Speed (GHz)

Max Turbo Freq. (GHz)

Cache per CPU (MB)

# of Memory Channels

Chipset

Hyperthreading (BIOS Setting)

Power Management (BIOS Setting)

VT-d

A.2. Memory

Memory Speed (MHz)

DIMM Capacity (GB)

# of DIMMs

DIMM configuration

Total DRAM (GB)

A.3. NIC

Vendor

Model

Port Speed (Gbps)

Ports

PCIe Version

PCIe Lanes

Bonded

Bonding Driver

Kernel Module Name

Driver Version

VXLAN TSO Capable

VXLAN RSS Capable

Ring Buffer Size RX

Ring Buffer Size TX

#### A.4. Hypervisor

Hypervisor Name

Version/Build

Based on

Hotfixes/Patches

OVS Version/Build

IRQ balancing

vCPUs per VM

Modifications to HV

Modifications to HV TCP stack

Number of VMs

IP MTU

Flow control TX (send pause)

Flow control RX (honor pause)

Encapsulation Type

A.5. Guest VM

Guest OS & Version

Modifications to VM

IP MTU Guest VM (Bytes)

Test tool used

Number of NetPerf Instances

Total Number of Streams

Guest RAM (GB)

A.6. Overlay Network Physical Fabric

Vendor

Model

# and Type of Ports

Software Release

Interface Configuration

Interface/Ethernet MTU (Bytes)

Flow control TX (send pause)

Flow control RX (honor pause)

A.7. Gateway Network Physical Fabric

Vendor

Model

# and Type of Ports

Software Release

Interface Configuration

Interface/Ethernet MTU (Bytes)

Flow control TX (send pause)

Flow control RX (honor pause)



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