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Benchmarking Virtual Switches in OPNFV
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Abstract

This memo describes the progress of the Open Platform for NFV (OPNFV) project on virtual switch performance "VSWITCHPERF". This project intends to build on the current and completed work of the Benchmarking Methodology Working Group in IETF, by referencing existing literature. The Benchmarking Methodology Working Group has traditionally conducted laboratory characterization of dedicated physical implementations of internetworking functions. Therefore, this memo begins to describe the additional considerations when virtual switches are implemented in general-purpose hardware. The expanded tests and benchmarks are also influenced by the OPNFV mission to support virtualization of the "telco" infrastructure.

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

Benchmarking Methodology Working Group (BMWG) has traditionally conducted laboratory characterization of dedicated physical implementations of internetworking functions. The Black-box Benchmarks of Throughput, Latency, Forwarding Rates and others have served our industry for many years. Now, Network Function Virtualization (NFV) has the goal to transform how internetwork functions are implemented, and therefore has garnered much attention.

This memo summarizes the progress of the Open Platform for NFV (OPNFV) project on virtual switch performance characterization, "VSWITCHPERF", through the Brahmaputra (second) release [BrahRel]. This project intends to build on the current and completed work of the Benchmarking Methodology Working Group in IETF, by referencing existing literature. For example, currently the most often referenced RFC is [RFC2544] (which depends on [RFC1242]) and foundation of the benchmarking work in OPNFV is common and strong.

See [VSPERFhome] for more background, and the OPNFV website for general information [OPNFV].

The authors note that OPNFV distinguishes itself from other open source compute and networking projects through its emphasis on existing "telco" services as opposed to cloud-computing. There are many ways in which telco requirements have different emphasis on performance dimensions when compared to cloud computing: support for and transfer of isochronous media streams is one example.

Note also that the move to NFV Infrastructure has resulted in many new benchmarking initiatives across the industry. The authors are currently doing their best to maintain alignment with many other projects, and this Internet Draft is one part of the efforts. We acknowledge the early work in [I-D.huang-bmwg-virtual-network-performance], and useful discussion with the authors.

2. Scope

The primary purpose and scope of the memo is to inform the industry of work-in-progress that builds on the body of extensive BMWG literature and experience, and describe the extensions needed for benchmarking virtual switches. Inital feedback indicates that many of these extensions may be applicable beyond the current scope (to hardware switches in the NFV Infrastructure and to virtual routers, for example). Additionally, this memo serves as a vehicle to include more detail and commentary from BMWG and other Open Source communities, under BMWG's chartered work to characterize the NFV

Infrastructure (a virtual switch is an important aspect of that infrastructure).

The benchmarking covered in this memo should be applicable to many types of vswitches, and remain vswitch-agnostic to great degree. There has been no attempt to track and test all features of any specific vswitch implementation.

3. Benchmarking Considerations

This section highlights some specific considerations (from [I-D.ietf-bmwg-virtual-net])related to Benchmarks for virtual switches. The OPNFV project is sharing its present view on these areas, as they develop their specifications in the Level Test Design (LTD) document.

3.1. Comparison with Physical Network Functions

To compare the performance of virtual designs and implementations with their physical counterparts, identical benchmarks are needed. BMWG has developed specifications for many network functions this memo re-uses existing benchmarks through references, and expands them during development of new methods. A key configuration aspect is the number of parallel cores required to achieve comparable performance with a given physical device, or whether some limit of scale was reached before the cores could achieve the comparable level.

It's unlikely that the virtual switch will be the only application running on the SUT, so CPU utilization, Cache utilization, and Memory footprint should also be recorded for the virtual implementations of internetworking functions.

3.2. Continued Emphasis on Black-Box Benchmarks

External observations remain essential as the basis for Benchmarks. Internal observations with fixed specification and interpretation will be provided in parallel to assist the development of operations procedures when the technology is deployed.

3.3. New Configuration Parameters

A key consideration when conducting any sort of benchmark is trying to ensure the consistency and repeatability of test results. When benchmarking the performance of a vSwitch there are many factors that can affect the consistency of results, one key factor is matching the various hardware and software details of the SUT. This section lists some of the many new parameters which this project believes are critical to report in order to achieve repeatability.

Hardware details including:

- o Platform details
- o Processor details
- o Memory information (type and size)
- o Number of enabled cores
- o Number of cores used for the test
- o Number of physical NICs, as well as their details (manufacturer, versions, type and the PCI slot they are plugged into)
- o NIC interrupt configuration
- o BIOS version, release date and any configurations that were modified
- o CPU microcode level
- o Memory DIMM configurations (quad rank performance may not be the same as dual rank) in size, freq and slot locations
- o PCI configuration parameters (payload size, early ack option...)
- o Power management at all levels (ACPI sleep states, processor package, OS...)

Software details including:

- o OS parameters and behavior (text vs graphical no one typing at the console on one system)
- o OS version (for host and VNF)
- o Kernel version (for host and VNF)
- o GRUB boot parameters (for host and VNF)
- o Hypervisor details (Type and version)
- o Selected vSwitch, version number or commit id used
- o vSwitch launch command line if it has been parameterised
- o Memory allocation to the vSwitch

- o which NUMA node it is using, and how many memory channels

- o DPDK or any other SW dependency version number or commit id used

- o Memory allocation to a VM - if it's from Hugpages/elsewhere

- o VM storage type: snapshot/independent persistent/independent non-persistent

- o Number of VMs

- o Number of Virtual NICs (vNICs), versions, type and driver

- o Number of virtual CPUs and their core affinity on the host

- o Number vNIC interrupt configuration

- o Thread affinitization for the applications (including the vSwitch itself) on the host

- o Details of Resource isolation, such as CPUs designated for Host/Kernel (isolcpu) and CPUs designated for specific processes (taskset). - Test duration. - Number of flows.

Test Traffic Information:

- o Traffic type - UDP, TCP, IMIX / Other

- o Packet Sizes

- o Deployment Scenario

3.4. Flow classification

Virtual switches group packets into flows by processing and matching particular packet or frame header information, or by matching packets based on the input ports. Thus a flow can be thought of a sequence of packets that have the same set of header field values (5-tuple) or have arrived on the same port. Performance results can vary based on the parameters the vSwitch uses to match for a flow. The recommended flow classification parameters for any vSwitch performance tests are: the input port, the source IP address, the destination IP address and the Ethernet protocol type field. It is essential to increase the flow timeout time on a vSwitch before conducting any performance tests that do not measure the flow setup time. Normally the first packet of a particular stream will install the flow in the virtual switch which adds an additional latency, subsequent packets of the

same flow are not subject to this latency if the flow is already installed on the vSwitch.

3.5. Benchmarks using Baselines with Resource Isolation

This outline describes measurement of baseline with isolated resources at a high level, which is the intended approach at this time.

1. Baselines:

   * Optional: Benchmark platform forwarding capability without a vswitch or VNF for at least 72 hours (serves as a means of platform validation and a means to obtain the base performance for the platform in terms of its maximum forwarding rate and latency).

Benchmark platform forwarding capability

```
                                                      __
   +---------------------------------------------------+  |
   |   +--------------------------------------------+   |  |
   |   |                                            |   |  |
   |   |          Simple Forwarding App             |   |  Host
   |   |                                            |   |  |
   |   +--------------------------------------------+   |  |
   |   |                 NIC                        |   |  |
   +---+--------------------------------------------+---+ __|
              ^                           :
              |                           |
              :                           v
   +---------------------------------------------------+
   |                                                   |
   |                traffic generator                  |
   |                                                   |
   +---------------------------------------------------+
```

   * Benchmark VNF forwarding capability with direct connectivity (vSwitch bypass, e.g., SR/IOV) for at least 72 hours (serves as a means of VNF validation and a means to obtain the base performance for the VNF in terms of its maximum forwarding rate and latency). The metrics gathered from this test will serve as a key comparison point for vSwitch bypass technologies performance and vSwitch performance.

                        Benchmark VNF forwarding capability

```
                                                            __
      +--------------------------------------------------+   |
      |   +--------------------------------------------+  |   |
      |   |                                            |  |   |
      |   |                 VNF                        |  |   |
      |   |                                            |  |   |
      |   +--------------------------------------------+  |   |
      |   |          Passthrough/SR-IOV                |  |  Host
      |   +--------------------------------------------+  |   |
      |   |                 NIC                        |  |   |
      +---+--------------------------------------------+---+ __|
                ^                           :
                |                           |
                :                           v
      +--------------------------------------------------+
      |                                                  |
      |              traffic generator                   |
      |                                                  |
      +--------------------------------------------------+
```

* Benchmarking with isolated resources alone, with other resources (both HW&SW) disabled Example, vSw and VM are SUT

* Benchmarking with isolated resources alone, leaving some resources unused

* Benchmark with isolated resources and all resources occupied

2. Next Steps

   * Limited sharing

   * Production scenarios

   * Stressful scenarios

4. VSWITCHPERF Specification Summary

The overall specification in preparation is referred to as a Level Test Design (LTD) document, which will contain a suite of performance tests. The base performance tests in the LTD are based on the pre-existing specifications developed by BMWG to test the performance of physical switches. These specifications include:

o [RFC2544] Benchmarking Methodology for Network Interconnect Devices

- [RFC2889] Benchmarking Methodology for LAN Switching

- [RFC6201] Device Reset Characterization

- [RFC5481] Packet Delay Variation Applicability Statement

Some of the above/newer RFCs are being applied in benchmarking for the first time, and represent a development challenge for test equipment developers. Fortunately, many members of the testing system community have engaged on the VSPERF project, including an open source test system.

In addition to this, the LTD also re-uses the terminology defined by:

- [RFC2285] Benchmarking Terminology for LAN Switching Devices

- [RFC5481] Packet Delay Variation Applicability Statement

Specifications to be included in future updates of the LTD include:

- [RFC3918] Methodology for IP Multicast Benchmarking

- [RFC4737] Packet Reordering Metrics

As one might expect, the most fundamental internetworking characteristics of Throughput and Latency remain important when the switch is virtualized, and these benchmarks figure prominently in the specification.

When considering characteristics important to "telco" network functions, we must begin to consider additional performance metrics. In this case, the project specifications have referenced metrics from the IETF IP Performance Metrics (IPPM) literature. This means that the [RFC2544] test of Latency is replaced by measurement of a metric derived from IPPM's [RFC2679], where a set of statistical summaries will be provided (mean, max, min, etc.). Further metrics planned to be benchmarked include packet delay variation as defined by [RFC5481] , reordering, burst behaviour, DUT availability, DUT capacity and packet loss in long term testing at Throughput level, where some low-level of background loss may be present and characterized.

Tests have been (or will be) designed to collect the metrics below:

- Throughput Tests to measure the maximum forwarding rate (in frames per second or fps) and bit rate (in Mbps) for a constant load (as defined by [RFC1242]) without traffic loss.

- o Packet and Frame Delay Distribution Tests to measure average, min and max packet and frame delay for constant loads.

- o Packet Delay Tests to understand latency distribution for different packet sizes and over an extended test run to uncover outliers.

- o Scalability Tests to understand how the virtual switch performs as the number of flows, active ports, complexity of the forwarding logic's configuration... it has to deal with increases.

- o Stream Performance Tests (TCP, UDP) to measure bulk data transfer performance, i.e. how fast systems can send and receive data through the switch.

- o Control Path and Datapath Coupling Tests, to understand how closely coupled the datapath and the control path are as well as the effect of this coupling on the performance of the DUT (example: delay of the initial packet of a flow).

- o CPU and Memory Consumption Tests to understand the virtual switch's footprint on the system, usually conducted as auxiliary measurements with benchmarks above. They include: CPU utilization, Cache utilization and Memory footprint.

- o The so-called "Soak" tests, where the selected test is conducted over a long period of time (with an ideal duration of 24 hours, but only long enough to determine that stability issues exist when found; there is no requirement to continue a test when a DUT exhibits instability over time). The key performance characteristics and benchmarks for a DUT are determined (using short duration tests) prior to conducting soak tests. The purpose of soak tests is to capture transient changes in performance which may occur due to infrequent processes, memory leaks, or the low probability coincidence of two or more processes. The stability of the DUT is the paramount consideration, so performance must be evaluated periodically during continuous testing, and this results in use of [RFC2889] Frame Rate metrics instead of [RFC2544] Throughput (which requires stopping traffic to allow time for all traffic to exit internal queues), for example.

Future/planned test specs include:

- o Request/Response Performance Tests (TCP, UDP) which measure the transaction rate through the switch.

- o Noisy Neighbour Tests, to understand the effects of resource sharing on the performance of a virtual switch.

o Tests derived from examination of ETSI NFV Draft GS IFA003
   requirements [IFA003] on characterization of acceleration
   technologies applied to vswitches.

The flexibility of deployment of a virtual switch within a network means that the BMWG IETF existing literature needs to be used to characterize the performance of a switch in various deployment scenarios. The deployment scenarios under consideration include:

Physical port to virtual switch to physical port

```
                                                         __
    +--------------------------------------------------+   |
    |              +--------------------+               |   |
    |              |                    |               |   |
    |              |                    v               |   |  Host
    |   +--------------+            +--------------+   |   |
    |   |   phy port   |  vSwitch   |   phy port   |   |   |
    +---+--------------+------------+--------------+---+ __|
               ^                           :
               |                           |
               :                           v
    +--------------------------------------------------+
    |                                                  |
    |                traffic generator                 |
    |                                                  |
    +--------------------------------------------------+
```

Physical port to virtual switch to VNF to virtual switch to physical
port

```
                                                         __
    +---------------------------------------------------+   |
    |                                                   |   |
    |   +-------------------------------------------+   |   |
    |   |                 Application               |   |   |
    |   +-------------------------------------------+   |   |
    |       ^                                  :        |   |
    |       |                                  |        |   |  Guest
    |       :                                  v        |   |
    |   +---------------+           +---------------+   |   |
    |   | logical port 0|           | logical port 1|   |   |
    +---+---------------+-----------+---------------+---+ __|
            ^                                  :
            |                                  |
            :                                  v         __
    +---+---------------+----------+---------------+---+   |
    |   | logical port 0|          | logical port 1|   |   |
    |   +---------------+          +---------------+   |   |
    |       ^                                  :       |   |
    |       |                                  |       |   |  Host
    |       :                                  v       |   |
    |   +--------------+            +--------------+   |   |
    |   |   phy port   |  vSwitch   |   phy port   |   |   |
    +---+--------------+------------+--------------+---+ __|
               ^                           :
               |                           |
               :                           v
    +--------------------------------------------------+
    |                                                  |
    |                traffic generator                 |
    |                                                  |
    +--------------------------------------------------+
```

Physical port to virtual switch to VNF to virtual switch to VNF to
virtual switch to physical port

```
                                                      __
    +----------------------+  +----------------------+  |
    |   Guest 1            |  |   Guest 2            |  |
    |   +---------------+  |  |   +---------------+  |  |
    |   |  Application  |  |  |   |  Application  |  |  |
    |   +---------------+  |  |   +---------------+  |  |
    |       ^       |      |  |       ^       |      |  |
    |       |       v      |  |       |       v      |  |  Guests
    |   +---------------+  |  |   +---------------+  |  |
    |   | logical ports |  |  |   | logical ports |  |  |
    |   |   0       1   |  |  |   |   0       1   |  |  |
    +---+---------------+--+  +---+---------------+--+__|
            ^       :                 ^       :
            |       |                 |       |
            :       v                 :       v       _
    +---+---------------+---------+---------------+--+ |
    |   |   0       1   |         |   3       4   |  | |
    |   | logical ports |         | logical ports |  | |
    |   +---------------+         +---------------+  | |
    |       ^       |                 ^       |      | |  Host
    |       |       |-----------------|       v      | |
    |   +--------------+          +--------------+   | |
    |   |   phy ports  | vSwitch  |   phy ports  |   | |
    +---+--------------+----------+--------------+---+_|
            ^                                 :
            |                                 |
            :                                 v
    +--------------------------------------------------+
    |                                                  |
    |                traffic generator                 |
    |                                                  |
    +--------------------------------------------------+
```

   Physical port to virtual switch to VNF

```
                                                          __
    +---------------------------------------------------+   |
    |                                                   |   |
    |   +-------------------------------------------+   |   |
    |   |                 Application               |   |   |
    |   +-------------------------------------------+   |   |
    |       ^                                           |   |
    |       |                                           |   |  Guest
    |       :                                           |   |
    |   +---------------+                               |   |
    |   | logical port 0|                               |   |
    +---+---------------+-------------------------------+ __|
            ^
            |
            :                                           __
    +---+---------------+------------------------------+   |
    |   | logical port 0|                              |   |
    |   +---------------+                              |   |
    |       ^                                          |   |
    |       |                                          |   |  Host
    |       :                                          |   |
    |   +--------------+                               |   |
    |   |   phy port   |  vSwitch                      |   |
    +---+--------------+------------ -------------- ---+ __|
               ^
               |
               :
    +--------------------------------------------------+
    |                                                  |
    |                traffic generator                 |
    |                                                  |
    +--------------------------------------------------+
```

   VNF to virtual switch to physical port

```
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    +---------------------------------------------------+   |
    |                                                   |   |
    |   +-------------------------------------------+   |   |
    |   |                 Application               |   |   |
    |   +-------------------------------------------+   |   |
    |                                          :        |   |
    |                                          |        |   |  Guest
    |                                          v        |   |
    |                               +---------------+   |   |
    |                               | logical port  |   |   |
    +-------------------------------+---------------+---+ __|
                                               :
                                               |
                                               v         __
    +------------------------------+---------------+---+   |
    |                              | logical port  |   |   |
    |                              +---------------+   |   |
    |                                          :       |   |
    |                                          |       |   |  Host
    |                                          v       |   |
    |                               +--------------+   |   |
    |                     vSwitch   |   phy port   |   |   |
    +-------------------------------+--------------+---+ __|
                                           :
                                           |
                                           v
    +--------------------------------------------------+
    |                                                  |
    |                traffic generator                 |
    |                                                  |
    +--------------------------------------------------+
```

VNF to virtual switch to VNF

```
                                                  __
+----------------------+  +----------------------+  |
|   Guest 1            |  |   Guest 2            |  |
|   +---------------+  |  |   +---------------+  |  |
|   |  Application  |  |  |   |  Application  |  |  |
|   +---------------+  |  |   +---------------+  |  |
|              |       |  |       ^              |  |
|              v       |  |       |              |  |  Guests
|   +---------------+  |  |   +---------------+  |  |
|   | logical ports |  |  |   | logical ports |  |  |
|   |           0   |  |  |   |   0           |  |  |
+---+---------------+--+  +---+---------------+--+__|
                :                 ^
                |                 |
                v                 :               _
+---+---------------+---------+---------------+--+ |
|   |           1   |         |   1           |  | |
|   | logical ports |         | logical ports |  | |
|   +---------------+         +---------------+  | |
|               |                 ^              | |  Host
|               L-----------------+              | |
|                                                | |
|                    vSwitch                     | |
+------------------------------------------------+_|
```

A set of Deployment Scenario figures is available on the VSPERF Test Methodology Wiki page [TestTopo].

5. 3x3 Matrix Coverage

This section organizes the many existing test specifications into the "3x3" matrix (introduced in [I-D.ietf-bmwg-virtual-net]). Because the LTD specification ID names are quite long, this section is organized into lists for each occupied cell of the matrix (not all are occupied, also the matrix has grown to 3x4 to accommodate scale metrics when displaying the coverage of many metrics/benchmarks). The current version of the LTD specification is available [LTD].

The tests listed below assess the activation of paths in the data plane, rather than the control plane.

A complete list of tests with short summaries is available on the VSPERF "LTD Test Spec Overview" Wiki page [LTDoverV].

5.1. Speed of Activation

- Activation.RFC2889.AddressLearningRate
- PacketLatency.InitialPacketProcessingLatency

5.2. Accuracy of Activation section

- CPDP.Coupling.Flow.Addition

5.3. Reliability of Activation

- Throughput.RFC2544.SystemRecoveryTime
- Throughput.RFC2544.ResetTime

5.4. Scale of Activation

- Activation.RFC2889.AddressCachingCapacity

5.5. Speed of Operation

- Throughput.RFC2544.PacketLossRate
- CPU.RFC2544.0PacketLoss
- Throughput.RFC2544.PacketLossRateFrameModification
- Throughput.RFC2544.BackToBackFrames
- Throughput.RFC2889.MaxForwardingRate
- Throughput.RFC2889.ForwardPressure
- Throughput.RFC2889.BroadcastFrameForwarding

5.6. Accuracy of Operation

- Throughput.RFC2889.ErrorFramesFiltering
- Throughput.RFC2544.Profile

5.7. Reliability of Operation

- Throughput.RFC2889.Soak
- Throughput.RFC2889.SoakFrameModification

o PacketDelayVariation.RFC3393.Soak

5.8. Scalability of Operation

o Scalability.RFC2544.0PacketLoss

o MemoryBandwidth.RFC2544.0PacketLoss.Scalability

5.9. Summary

	SPEED	ACCURACY	RELIABILITY	SCALE
Activation	X	X	X	X
Operation	X	X	X	X
De-activation				

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. Acknowledgements

The authors appreciate and acknowledge comments from Scott Bradner, Marius Georgescu, Ramki Krishnan, Doug Montgomery, Martin Klozik, Christian Trautman, and others for their reviews.

9. References

9.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <http://www.rfc-editor.org/info/rfc2119>.

[RFC2285] Mandeville, R., "Benchmarking Terminology for LAN Switching Devices", RFC 2285, DOI 10.17487/RFC2285, February 1998, <http://www.rfc-editor.org/info/rfc2285>.

[RFC2544] Bradner, S. and J. McQuaid, "Benchmarking Methodology for Network Interconnect Devices", RFC 2544, DOI 10.17487/RFC2544, March 1999, <http://www.rfc-editor.org/info/rfc2544>.

[RFC2679] Almes, G., Kalidindi, S., and M. Zekauskas, "A One-way Delay Metric for IPPM", RFC 2679, DOI 10.17487/RFC2679, September 1999, <http://www.rfc-editor.org/info/rfc2679>.

[RFC2889] Mandeville, R. and J. Perser, "Benchmarking Methodology for LAN Switching Devices", RFC 2889, DOI 10.17487/RFC2889, August 2000, <http://www.rfc-editor.org/info/rfc2889>.

[RFC3918] Stopp, D. and B. Hickman, "Methodology for IP Multicast Benchmarking", RFC 3918, DOI 10.17487/RFC3918, October 2004, <http://www.rfc-editor.org/info/rfc3918>.

[RFC4737] Morton, A., Ciavattone, L., Ramachandran, G., Shalunov, S., and J. Perser, "Packet Reordering Metrics", RFC 4737, DOI 10.17487/RFC4737, November 2006, <http://www.rfc-editor.org/info/rfc4737>.

[RFC6201] Asati, R., Pignataro, C., Calabria, F., and C. Olvera, "Device Reset Characterization", RFC 6201, DOI 10.17487/RFC6201, March 2011, <http://www.rfc-editor.org/info/rfc6201>.

9.2. Informative References

[BrahRel] "Brahmaputra, Second OPNFV Release https://wiki.opnfv.org/display/SWREL/Brahmaputra".

[I-D.huang-bmwg-virtual-network-performance]
Huang, L., Rong, G., Mandeville, B., and B. Hickman, "Benchmarking Methodology for Virtualization Network Performance", draft-huang-bmwg-virtual-network-performance-02 (work in progress), March 2017.

[I-D.ietf-bmwg-virtual-net]
Morton, A., "Considerations for Benchmarking Virtual Network Functions and Their Infrastructure", draft-ietf-bmwg-virtual-net-05 (work in progress), March 2017.

[IFA003] "https://docbox.etsi.org/ISG/NFV/Open/Drafts/IFA003_Acceleration_-_vSwitch_Spec/".

[LTD] "LTD Test Specification http://artifacts.opnfv.org/vswitchperf/brahmaputra/docs/requirements/index.html".

[LTDoverV]
"LTD Test Spec Overview https://wiki.opnfv.org/display/vsperf/LTD+Test+Spec+Overview".

[OPNFV] "OPNFV Home https://www.opnfv.org/".

[RFC1242] Bradner, S., "Benchmarking Terminology for Network Interconnection Devices", RFC 1242, DOI 10.17487/RFC1242, July 1991, <http://www.rfc-editor.org/info/rfc1242>.

[RFC5481] Morton, A. and B. Claise, "Packet Delay Variation Applicability Statement", RFC 5481, DOI 10.17487/RFC5481, March 2009, <http://www.rfc-editor.org/info/rfc5481>.

[TestTopo]
"Test Topologies https://wiki.opnfv.org/display/vsperf/Test+Methodology".

[VSPERFhome]
"VSPERF Home https://wiki.opnfv.org/display/vsperf/
VSperf+Home".

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