1.0 Introduction

For the past years, many organizations have been adopting Network Functions Virtualization (NFV) to improve their business agility and reduce operational costs. Virtual Network Functions (VNF), NFV Infrastructure (NFVI), and NFV Management and Orchestration (MANO), are the main components of an NFV architecture. Together, they enable Communication Service Providers (CoSPs), Enterprises and Cloud Service Providers to consolidate and manage specialized network equipment onto industry standard, high-volume servers (SHVS). At the same time, virtualization technology and hardware advancements continue to evolve, allowing deployment of more VNFs on a single server. One of the key NFV benefits is that it enables service flexibility and scalability at lower operational costs. This can be more readily achieved if the underlying infrastructure is utilized effectively.

The rich variety of hardware features makes the SHVS based on the Intel® architecture a favorable choice for NFV deployments; however, network administrators and architects may not always know how to take full advantage of the underlying platform capabilities. One option to achieve efficient infrastructure utilization is Enhanced Platform Awareness (EPA). EPA represents a methodology and a related suite of changes across multiple layers of the orchestration stack targeting intelligent platform capability, configuration & capacity consumption. EPA features include Huge page support, NUMA topology awareness, CPU pinning, integration with OVS-DPDK, support for I/O Passthrough via SR-IOV, and many others.

This Technical Brief focuses on performance benchmarking and flavor verification steps and shows how leveraging even a few EPA features can lead to significantly improved and more predictable performance, and therefore better utilization of the underlying infrastructure.

This paper presents performance improvements achieved with several EPA features enabled while onboarding VNFs within an OpenStack* environment deployed on Intel architecture-based SHVS. The document summarizes two typical VNF onboarding test cases:

- Palo Alto Networks® VM-Series Next-Generation Firewall* VNF spawned as a stand-alone VM
- Three VNFs—a Commercial vRouter*, a Sandvine* Policy Traffic Switch Virtual Series*, and a Palo Alto Networks® VM-Series Next-Generation Firewall VNF spawned to form a static service chain.

The results show an approximate 5x throughput improvement for the platform with a single VM, and 9x throughput gain for the platform with a service chain.
2.0 Accelerating OpenStack® Environments on Intel® Architecture

OpenStack is a leading open-source suite for cloud computing. It is capable of managing large pools of compute, storage, and networking resources throughout a data center. It provides administrators with a convenient web interface used to control and provision resources and run virtualized software.

OpenStack has an active community of users and contributors. Intel contributes to OpenStack with EPA features, enabling a better view of the underlying hardware and offering an advanced selection of tuning capabilities. EPA allows OpenStack administrators to filter platforms with specific capabilities that match particular workload requirements and to deploy NFV solutions with optimal performance and predictable characteristics.

This paper presents a use case example of a few EPA features and platform technologies selected to optimize NFV infrastructure driven by two Intel® Xeon® processors E5-2680 v3. The Intel® Xeon® processor E5 product family helps address requirements of virtualized data centers and clouds by offering leading-edge performance and advanced hardware virtualization features.

2.1 Demonstrating Platform Capabilities

As part of this demonstration, Intel engineers set up two identical single-server platforms, each running an all-in-one OpenStack Newton Installation with the same hardware configuration. To demonstrate the potential of the Intel architecture, each server was configured with a set of hardware virtualization features.

The following two VNF onboarding test cases demonstrate performance capabilities of Intel architecture platforms:

- A commercial VNF spawned as a stand-alone VM (described in section 2.3)
- Three commercial VNFs spawned to form a static service chain (described in section 2.4)

These two deployments were setup on dedicated servers with Intel® Hyper-Threading Technology (Intel® HT Technology) enabled. More information on the hardware and software configurations of these two deployments is presented in sections 2.3 and 2.4.

The following networks compose the OpenStack network topology in both setups:

- The public flat provider network is used to reach the Internet.
- The ixnet1 and ixnet2 flat provider networks are directly associated with the two ports of the Intel 82599 ES 10 gigabit Ethernet Controller on system under test (SUT). They are connected to two corresponding IxVM Virtual Load Modules on the traffic generator host (described in section 2.2). The port on the ixnet1 network acts as a "client port," sending HTTP requests to the "server port" on the ixnet2 network.
- The management network is used to manage the OpenStack services and instances. It is mapped to one of the Intel® Ethernet Controller X540-AT2 interfaces on the OpenStack node.

Figure 1 shows the setup for the test case with a single VM which was a Palo Alto Networks® VM-Series Next-Generation firewall VNF spawned in an OpenStack environment, while Figure 2 depicts the test setup with three chained VNFs.
**Figure 1.** Test setup for the platform with a standalone virtual firewall.

**Figure 2.** Test setup for the platform with three chained VNFs.
2.2 Traffic Generation

Ixia* IxLoad Virtual Edition* Tier-3 10G was deployed on a separate server for HTTP traffic generation. IxLoad Virtual Edition is released in the form of IxVVM Virtual Chassis and IxVM Virtual Load Module VMs running over QEMU-KVM and CentOS* 7.0.

In this test setup, the traffic generator consists of three VMs: an IxVVM Linux Chassis and two IxVM Virtual Modules, as depicted in Figure 3. Each VM is allocated 4,096 MB of RAM and two virtual CPUs pinned to physical cores on the host.

The IxVVM Linux Chassis connects to the management network for external access, and internally with the two IxVM Virtual Load Modules for backplane communication between the VMs.

Both IxVM Virtual Load Modules have two virtual ports connected via a test virtual switch. Ports denoted as eth0 are used to send traffic, while eth1 ports receive traffic. Thus, each of the VMs participates in traffic generation.

On the host, the two ports (NIC 0 and NIC 1) connect to the system-under-test (SUT). The NIC 0 sends the traffic via the ixnet1 network, whereas NIC 1 on the ixnet2 network is used for traffic reception.

2.3 Test Setup #1: Standalone VNF

Figure 1 shows a setup for the test case with a single VM, which is a Palo Alto Networks VM-Series Next-Generation firewall VNF spawned in an OpenStack environment. OpenStack Newton was installed on the same server using Packstack*'s all-in-one deployment option with both controller and compute nodes in the same server. The figure also presents the hardware and software configuration of the platform. The baseline configuration includes the Open vSwitch and Palo Alto Networks Next-Generation Firewall VNF (without DPDK integration). The software components (DPDK versions) in the best performing configuration are indicated in parentheses, which includes DPDK optimized Palo Alto Networks Next-Generation Firewall VNF.

In the standalone VM setup, the firewall VNF connects to the ixnet1, ixnet2 and the management networks. The HTTP traffic from the client port on the traffic generator enters the virtual firewall on ixnet1 and reaches the server port on the traffic generator on ixnet2. The HTTP reply traffic flows in the opposite direction, reaching the virtual firewall on ixnet2 and then returning to the traffic generator on the client port on ixnet1.

2.4 Test Setup #2: VNFs in a Static Service Chain

Figure 2 presents the setup for the second scenario configured in the same way as the previous one. The setup includes three VNFs, a virtual router from a 3rd party vendor, virtual network policy controller from Sandvine, and virtual next-generation firewall from Palo Alto Networks, manually configured to forward traffic within the service chain in the given order.

In the chained setup, the flow becomes more complex because apart from the Host-VM communication, there is also inter-VM communication. The HTTP traffic from the client port on the traffic generator enters the virtual router on ixnet1. Then, the router forwards the traffic to the virtual DPI, which consequently forwards the traffic to the virtual firewall. The Firewall VNF forwards the traffic to the traffic generator on ixnet2 network. The HTTP reply traffic flows in the opposite direction, from the virtual firewall on ixnet2, then reaching the virtual DPI and virtual router, and finally returning to the traffic generator on the client port on ixnet1.

3.0 Test Methodology

We have considered the benchmarking methodology for firewall performance as given in RFC3511.

We have benchmarked the two setups using HTTP traffic of the following configuration:

- Content-type field of the HTTP header: text/html
- Transaction sizes: 1MB for the Throughput metric, and 1B for the other 2 metrics

The performance metrics have been gathered at the traffic generator to characterize end-to-end performance of each deployment. Table 1 presents these metrics and the corresponding workload characteristics configured in the traffic generator.
Performance Optimizations using Enhanced Platform Awareness

Table 1. Configuration of testing workload in the traffic generator.

### 3.1 Optimizations

The two presented deployments were optimized by enabling specific EPA features incrementally, and the measurements were gathered after a tuning method was applied. Although multiple tuning variants were tested, this technical brief focuses only on the two particular configuration profiles (see Table 2 for configuration details):

- **Baseline Configuration**: Initial configuration of the setup (i.e., without EPA features or platform technologies enabled)
- **Best Configuration**: Final configuration of the setup (i.e., resulting in the highest obtained dataplane performance)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Objective</th>
<th>Workload Configuration in the Traffic Generator</th>
</tr>
</thead>
</table>
| Throughput                      | To measure throughput performance of the deployment                      | • HTTP 1.1  
• Maximal possible transactions per second  
• 21 concurrent connections per user  
• 1048576-byte GET  
• 1048576-byte TCP Send/Receive Buffer |
| Connections per second          | To measure how well the deployment can accept and service new connections  | • HTTP 1.0  
• 21 concurrent connections per user  
• 1-byte GET |
| Maximum Concurrent connections   | To measure deployment scalability via number of sustained TCP connections | • HTTP 1.1  
• Maximum possible transactions per second  
• 21 concurrent connections per user  
• 1-byte GET |

Table 2. Details of the baseline and best configuration profiles.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Baseline Configuration</th>
<th>Best Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intel® Hyper-Threading Technology (Intel® HT Technology)</td>
<td>Enabled</td>
<td>Enabled</td>
</tr>
<tr>
<td>CPU Core Isolation</td>
<td>No</td>
<td>Yes, isolated cores were allocated to Open vSwitch, PMD threads, and VMs.</td>
</tr>
<tr>
<td>CPU Pinning</td>
<td>No</td>
<td>Yes, isolated cores were pinned to specific VMs. Note the sibling threads were not used for scheduling VMs</td>
</tr>
<tr>
<td>Memory Page Size</td>
<td>4 KB</td>
<td>1 GB (huge pages)</td>
</tr>
<tr>
<td>Virtual Switch</td>
<td>Open vSwitch</td>
<td>OVS-DPDK (i.e., DPDK at NFVI level)</td>
</tr>
</tbody>
</table>
| Number of poll mode driver (PMD) Threads   | N/A                    | Setup #1: 1 PMD thread pinned to a physical core  
Setup #2: 4 PMD threads pinned to four physical cores                                |
| DPDK Support at VNF Layer                  | No                     | Yes (see Table 3 for DPDK versions used)                                           |
Table 3 shows the resources allocated to each VNF as well as the DPDK versions used by each VNF (this is separate from the DPDK used at the NFVI layer). Figure 4 shows the CPU layout of the host machines. Sibling cores exist since Hyperthreading was enabled.

<table>
<thead>
<tr>
<th>VNF</th>
<th>Virtual CPUs</th>
<th>NUMA Node</th>
<th>Memory</th>
<th>DPDK version</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Setup #1: Standalone VM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palo Alto Networks® VM-Series Next-Gen Firewall 8.0</td>
<td>8 (Cores 0-7)</td>
<td>0</td>
<td>16 GB</td>
<td>2.2</td>
</tr>
<tr>
<td><strong>Setup #2: Chained VNFs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial vRouter</td>
<td>2 (Cores 12-13)</td>
<td>1</td>
<td>4 GB</td>
<td>2.2</td>
</tr>
<tr>
<td>Sandvine® Policy Traffic Switch Virtual Series 7.40.00</td>
<td>4 (Cores 14-17)</td>
<td>1</td>
<td>8 GB</td>
<td>16.07</td>
</tr>
<tr>
<td>Palo Alto Networks® VM-Series Next-Gen Firewall 8.0</td>
<td>8 (Cores 0-7)</td>
<td>0</td>
<td>16 GB</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Table 3. Resources allocated to VNFs in the best configuration profiles.

3.2 Optimizations with SR-IOV

An alternative optimization method uses Single-Root Input-Output Virtualization (SR-IOV). In this case, the firewall VNF is spawned in OpenStack with an SR-IOV interface that enables the allocation of VFs to the VM from the PCIe* device, such as a network adapter. In this configuration the VM does not have a virtio interface, and a virtual switch is not used for communication.

To use SR-IOV, the Input-Output Memory Management Unit (IOMMU) and Intel® Virtualization Technology for Directed I/O (Intel® VT-d) must be enabled in the kernel. To learn more about enabling SR-IOV technology, refer to the Enabling Enhanced Platform Awareness for Superior Packet Processing in OpenStack document.

In this configuration, the device drivers for the NICs are configured to enable the NIC VFs on the host. OpenStack Networking requires the SR-IOV modular layer 2 (ML2) mechanism driver to be enabled. Since the firewall VNF used supports only the MacVTap interface instead of direct port, it is necessary to create the SR-IOV port with vnic_type as macvtap and to boot the instance with that port assigned.
4.0 Results

The throughput performance with standalone VM (Setup #1) is presented in Figure 5. Compared to the baseline profile (solid blue line), the throughput is 2x higher when applying 1 GB huge pages, isolating and pinning CPU cores to virtual cores at VM, and enabling DPDK-accelerated Open vSwitch (dashed grey line).

Even better performance is possible when DPDK is enabled in the virtual firewall; this configuration (upper solid black line) achieves approximately five times greater performance compared to the baseline configuration profile. This demonstrates the advantage of DPDK’s polling technique of packet processing in the user space. The VNF is able to process more packets this way, in turn yielding higher throughput.

Figure 5. Impact of performance optimizations on the throughput at the platform with a standalone VNF (Setup #1).

Figure 6. Impact of performance optimizations on consistency and stability of the performance at the platform with a standalone VNF (Setup #1).
In Figure 6, the baseline profile (solid blue line) was not stable. This was because CPU pinning was not enabled. Later, when CPU pinning was enabled (black line), performance was a lot more consistent and stable.

Figure 7 shows throughput of the Setup #1 with an SR-IOV interface enabled in the VNF yielding a ~3x improvement over the baseline. In this case, the packets are directed from the physical network interface to the virtual function in the VM without the overhead of a virtual switch in between but through the MacVTap abstraction layer.

![Performance gain on the platform with a standalone VNF](image)

**Figure 7.** Impact of SR-IOV and core pinning and isolation on the throughput at the platform with a standalone VNF (Setup #1).

Figure 8 shows the performance difference between the baseline profile (solid blue line) and the best profile (solid grey line). This was on Setup #2 which contained a static chain of three VNFs. When allocating four PMD threads to the OVS-DPDK at the NFVI layer, a performance boost of about nine times was measured.

![Performance gain on the platform with three chained VNFS](image)

**Figure 8.** Impact of performance optimizations on the throughput at the platform with three chained VNFS (Setup #2).
5.0 Summary

Enabling EPA features and other platform technologies significantly improves performance. In the presented platform configurations, the maximum performance was achieved by enabling DPDK in both NFVI and VNFs along with enabling 1 GB huge pages and pinning virtual CPUs on the guest to physical cores on the host. The achieved gain was approximately equal to 5x in the case of a standalone VNF setup, and approximately 9x for the platform with three chained VNFs.

The enabled EPA features and platform technologies also increased the number of connections per second. In case of the standalone VNF deployment, this number increased by up to 15%. However, the maximum concurrent connections measurement was found to be a function of memory that was allotted to the VNF. Hence, there was no impact of EPA features and platform technologies on that KPI.

Apart from offering performance gains, EPA also offers increased efficiency by delivering more capabilities with existing resources leading to better total cost of ownership. EPA ensures that the intended workload runs on the right hardware with matching compute, storage, network, and security capabilities.

The performance results presented in this paper do not represent the absolute maximum possible and better performance can be achieved by enabling other relevant EPA features based on the requirement of the VNF or the Network Service. For example, in order to improve security, cloud subscribers may want their workloads to be executed on verified compute platforms. In OpenStack, it is possible to designate groups of trusted hosts to form pools of trusted computes which is an EPA feature. The trusted hosts are supported with hardware-based security features, such as Intel® TXT, and 3rd party attestation servers.

With EPA in OpenStack, operators have additional levels of control and configuration available to them. EPA features are systematically added to OpenStack, exposing new platform capabilities to build powerful and deterministic network performance on industry standard, high-volume servers.

6.0 Next Steps

- To learn more about the technologies mentioned in this paper, please follow the links in the document.
- To learn more about Intel’s technology for NFV, attend the courses available in the Intel® Network Builders University at https://networkbuilders.intel.com/university.
- To learn more about Intel® Network Builders partners for NFV products, visit https://networkbuilders.intel.com/solutionscatalog.
- To get a higher performance from your NFV systems, consider using DPDK in both your NFVI and VNF layers.
- To get a higher return on investment from your NFV systems, consider leveraging Enhanced Platform Awareness throughout the 3 elements of your NFV architecture: your orchestration layer, your VNF layer and your NFVI layer.
## Appendix A: References

<table>
<thead>
<tr>
<th>Title</th>
<th>Reference</th>
</tr>
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<tr>
<td>Considerations for SR-IOV and NFV Solutions</td>
<td><a href="https://www.youtube.com/watch?v=6UUFWZs-Sck">https://www.youtube.com/watch?v=6UUFWZs-Sck</a></td>
</tr>
<tr>
<td>DPDK</td>
<td><a href="http://dpdk.org/doc/guides/">http://dpdk.org/doc/guides/</a></td>
</tr>
<tr>
<td>OVS-DPDK</td>
<td><a href="https://01.org/openstack/blogs/stephenfin/2016/enabling-ovs-dpdk-openstack">https://01.org/openstack/blogs/stephenfin/2016/enabling-ovs-dpdk-openstack</a></td>
</tr>
</tbody>
</table>
## Appendix B: Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>DPDK</td>
<td>Data Plane Development Kit</td>
</tr>
<tr>
<td>DPI</td>
<td>Deep Packet Inspection</td>
</tr>
<tr>
<td>EPA</td>
<td>Enhanced Platform Awareness</td>
</tr>
<tr>
<td>Intel® HT Technology</td>
<td>Intel® Hyper-Threading Technology</td>
</tr>
<tr>
<td>Intel® TXT</td>
<td>Intel® Trusted Execution Technology</td>
</tr>
<tr>
<td>IOMMU</td>
<td>Input-Output Memory Management Unit</td>
</tr>
<tr>
<td>MANO</td>
<td>Management and Orchestration</td>
</tr>
<tr>
<td>NFV</td>
<td>Network Functions Virtualization</td>
</tr>
<tr>
<td>NFVI</td>
<td>NFV Infrastructure</td>
</tr>
<tr>
<td>NGFW</td>
<td>Next-Generation Firewall</td>
</tr>
<tr>
<td>NIC</td>
<td>Network Interface Controller</td>
</tr>
<tr>
<td>OVS-DPDK</td>
<td>DPDK-Accelerated Open vSwitch</td>
</tr>
<tr>
<td>PCIe</td>
<td>Peripheral Component Interconnect Express</td>
</tr>
<tr>
<td>PF</td>
<td>Physical Function</td>
</tr>
<tr>
<td>PMD</td>
<td>Poll Mode Driver</td>
</tr>
<tr>
<td>SHVS</td>
<td>Standard High Volume Server</td>
</tr>
<tr>
<td>SR-IOV</td>
<td>Single-Root Input-Output Virtualization</td>
</tr>
<tr>
<td>SUT</td>
<td>System-under-Test</td>
</tr>
<tr>
<td>VF</td>
<td>Virtual Function</td>
</tr>
<tr>
<td>VM</td>
<td>Virtual Machine</td>
</tr>
<tr>
<td>VNF</td>
<td>Virtual Network Function</td>
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