IMPLEMENTATION GUIDE

Optimizing NFV Infrastructure for TCP Workloads

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1.0 Introduction

Since 2015, Intel Corporation has cooperated with several communication service providers to define optimal Network Functions Virtualization Infrastructures (NFVIs) that would help virtualize their workloads.

As part of this initiative, Intel helped a prominent video, phone, and cable Internet access provider to build a performant generic infrastructure that could be used for different workloads such as video on demand and high-speed, data-related network functions. This infrastructure had to be capable of supporting edge and access services across technologies such as Data Over Cable Service Interface Specifications (DOCSIS), Ethernet, or passive optical networks.

Network services utilizing such an infrastructure are often based on the TCP/IP communication. An example of such a service is a TCP speed test. Many Internet customers use a speed test server as a tool to compare the actual speed they are experiencing with the speed they signed up for. These speed test servers are also based on the TCP; therefore the TCP performance is critical in such a network infrastructure.

This proof-of-concept (PoC) solution is built from three commercial-off-the-shelf (COTS) Intel® Xeon® processor-based servers and the open source software platform, primarily based on OpenStack that provides the cloud computing environment. New network functions virtualization (NFV) extensions integrated into OpenStack Kilo include the support for non-uniform memory access (NUMA) topology awareness, CPU affinity in virtual machines (VM), and huge pages, to improve overall OpenStack VM performance.

For fast packet processing, we integrated the Open vSwitch* with the Data Plane Development Kit (DPDK) on the host machines. Furthermore, we used features such as multi-queue, and implemented a patch to enable the TCP segmentation offload in DPDK-accelerated Open vSwitch (OVS-DPDK) that helped achieve an additional performance boost.

The primary audience for this document are architects and engineers planning to implement and optimize their TCP-based NFVIs. While this document discusses the solution in detail, it is not a large-scale solution. This guide also provides the installation steps of the software components and the performance optimizations implemented to deliver an optimal virtualized infrastructure capable of handling communications-grade Network Functions Virtualization workloads.

In the Technical Brief companion document (https://builders.intel.com/docs/networkbuilders/implementing_a_TCP_broadband_speed_test_in_the_cloud_for_use_in_an_NFV_infrastructure.pdf) we present three examples of test scenarios that were built on this infrastructure to reflect real-world setups and share the test results. Our findings show that open source software can be successfully used to achieve a reliable and flexible topology that enables delivery of robust and highly efficient virtualized infrastructures.

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2.0 Solution Overview

The NFVI used for this proof-of-concept (PoC) solution consists of three COTS Intel® Xeon® processor-based servers, running the Fedora* 21 Server operating system (OS). OpenStack* Kilo was installed on these servers to provide a cloud computing platform.

One server is configured as the OpenStack controller that also includes the OpenStack Networking* functions, whereas the remaining two servers are configured as OpenStack compute nodes.

Figure 1 shows the physical topology and the software stack of the PoC.

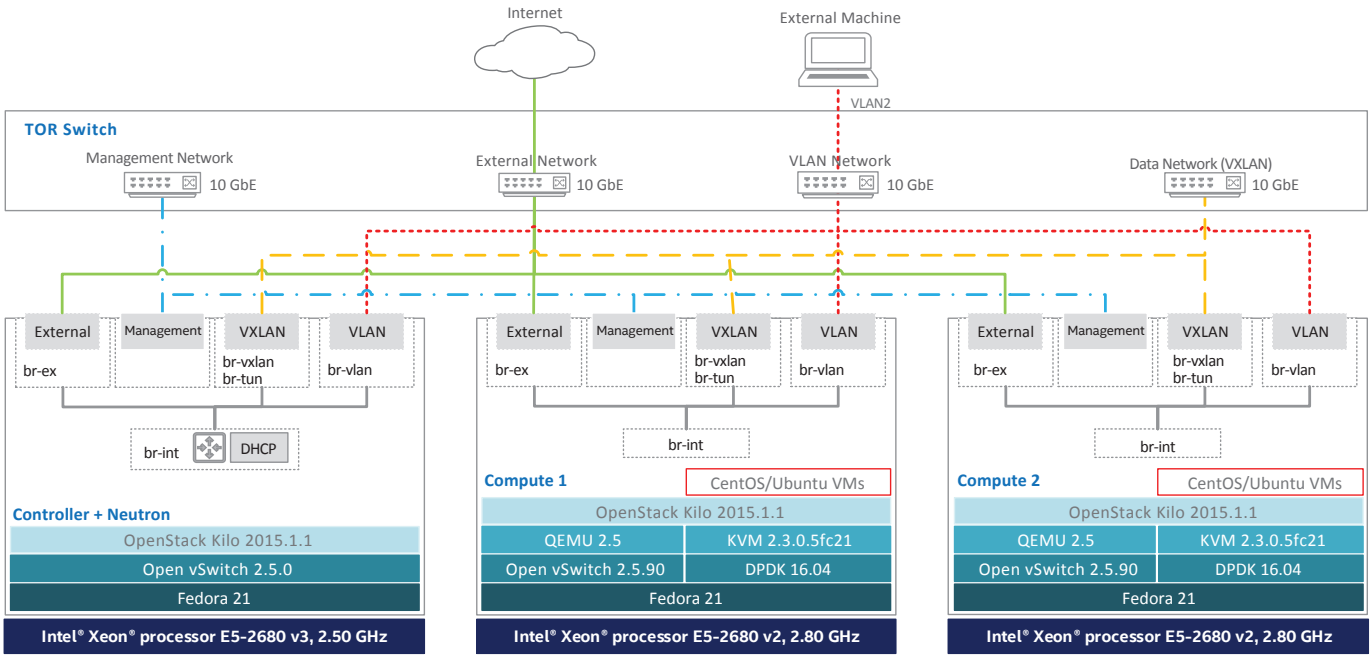


Figure 1. Physical topology of the PoC.

Each server has four network interfaces that, through a top-of-rack switch, provide connectivity to the networks described in Table 1.

Table 1. Networks used in the PoC.

NETWORK	NETWORK DESCRIPTION	COMPUTE NODES NIC	CONTROLLER NODE NIC
External	Flat provider network used for Internet/ remote access to the hosts and OpenStack* virtual machines (VMs).	Intel® Ethernet Server Adapter I350-T4	
VLAN	802.1Q tagged network mapped to the existing physical virtual local area network (VLAN) provider network. This network simulates the subscribers.	Intel® Ethernet Server Adapter X520-DA2	Intel® Ethernet Converged Network Adapter X710-DA4
Management	Management network used for accessing and managing OpenStack services.	Intel Ethernet Server Adapter I350-T4	
Data (VxLAN)	Virtual extensible local area network (VxLAN) tunnel used for east-west traffic between tenant VMs on different hosts.	Intel Ethernet Server Adapter X520-DA2	Intel Ethernet Converged Network Adapter X710-DA4

Table 2 presents the specification of the hardware used in the solution.

Table 2. Specification of the hardware components.

HARDWARE	SPECIFICATION
Controller / Neutron host server	• 2x Intel® Xeon® processor E5-2680 v3, 2.50 GHz, total of 48 logical cores with Intel® Hyper-Threading Technology • 128 GB, DDR4-2133 RAM • Intel® Ethernet Server Adapter I350-T4 (using Intel® Ethernet Controller I350) • Intel® Ethernet Converged Network Adapter X710-DA4 (using Intel® Ethernet Controller XL710-AM1) • 200 GB HDD
Compute 1 host server Compute 2 host server	• 2x Intel® Xeon® processor E5-2680 v2, 2.80 GHz, total of 40 logical cores with Intel Hyper-Threading Technology • 64 GB, DDR3-1600 RAM • Intel Ethernet Server Adapter I350-T4 (using Intel Ethernet Controller I350) • Intel® Ethernet Server Adapter X520-DA2 (using Intel® 82599ES 10 Gigabit Ethernet Controller) • 1 TB HDD
Top-of-rack switch	• Extreme Networks Summit* X670V-48t-BF-AC 10GbE Switch, SFP+ Connections

3.0 Installation Guide

This chapter contains the instructions for installation and configuration of the software stack.

3.1 Enable Hardware Features

Before starting to install the OS, enable the following features in the BIOS of all host machines:

- Intel® Virtualization Technology
- Intel® Hyper-Threading Technology (Intel® HT Technology)
- Intel® Turbo Boost Technology

3.2 Prepare Host Machines for the OpenStack* Installation

Note: The instructions for installing Fedora 21 Server are not within the scope of this document; however, this section contains some information that user needs to follow during OS installation or configuration.

1. Install the following packages while installing the OS.
   - C development tools and libraries
   - Development tools
   - Virtualization
2. Create custom partitioning as presented in Table 3.

Table 3. Solution partitioning schema.

PARTITION	SIZE
Biosboot	2 MB
/boot	2 GB
/swap	Double the size of physical memory
/ (root partition)	Remaining space

3. After the OS is installed, configure the network interfaces on the host machines with the proper IP addresses. On each host machine, eno1, eno2, and eno3 interfaces are used for the External, Management, and VxLAN tunnel networks respectively. These interfaces are assigned with static IP addresses as mentioned in Table 4. On the VLAN interface, no assignment of IP address is required on any node.

Table 4. The IP addresses of the setup.

COMPONENT	EXTERNAL IP ADDRESS	MANAGEMENT IP ADDRESS	VXLAN TUNNEL IP ADDRESS
Controller	10.250.100.101	172.16.101.2	172.16.111.2
Compute 1	10.250.100.102	172.16.101.3	172.16.111.3
Compute 2	10.250.100.126	172.16.101.4	172.16.111.4
OpenStack dashboard	http://10.250.100.101/dashboard/auth/login/?next=/dashboard/		
External Network	10.250.100.0/24, Untagged		
VLAN2 Network	20.20.20.0/24, VLAN ID=2		
Public DNS1	8.8.4.4		
Public DNS2	4.2.2.2		
Public DNS3	4.2.2.1		

In the Fedora 21 OS, the network script files are located in the /etc/sysconfig/network-scripts directory. Since the NetworkManager service is not used, the following line is added into the network script file of each interface.

```
NM_CONTROLLED=no
```

A sample network script file with a static IP address assigned on the management interface on the controller node is shown below.

```
TYPE=Ethernet
BOOTPROTO=static
IPADDR=172.16.101.2
NETMASK=255.255.255.0
DEFROUTE=no
IPV4_FAILURE_FATAL=yes
IPV6INIT=no
IPV6_AUTOCONF=yes
IPV6_DEFROUTE=yes
IPV6_FAILURE_FATAL=no
NAME=eno2
DEVICE=eno2
UUID=58215fc4-845e-4e0d-af51-588beb53f536
ONBOOT=yes
HWADDR=EC:F4:BB:C8:58:7A
PEERDNS=yes
PEERROUTES=yes
IPV6_PEERDNS=yes
IPV6_PEERROUTES=yes
NM_CONTROLLED=no
```

On all the host machines, update the network script file for the interface that provides external connectivity, and set the default route only on that interface. To check the default route, run the following command.

```
#route –n
```

The following listing shows a sample network script file for the external network interface with a static IP address and default route.

```
TYPE=Ethernet
BOOTPROTO=static
IPADDR=10.250.100.101
NETMASK=255.255.255.0
GATEWAY=10.250.100.1
DEFROUTE=yes
IPV4_FAILURE_FATAL=yes
IPV6INIT=no
IPV6_AUTOCONF=yes
IPV6_DEFROUTE=yes
IPV6_FAILURE_FATAL=no
NAME=eno1
DEVICE=eno1
UUID=58215fc4-845e-4e0d-af51-588beb53f536
ONBOOT=yes
HWADDR=EC:F4:BB:C8:58:7A
PEERDNS=yes
PEERROUTES=yes
IPV6_PEERDNS=yes
IPV6_PEERROUTES=yes
NM_CONTROLLED=no
```

4. Once all IP addresses are configured, disable the NetworkManager and enable the network service on all the host machines in the following order.

```
# systemctl disable NetworkManager
# systemctl enable network
# systemctl stop NetworkManager
# systemctl restart network
```

5. Set the host name on all the host machines by editing the /etc/hostname files. Additionally, provide all the host names of the setup with their management IP addresses into the /etc/hosts files on each host machine. An example is shown below.

```
172.16.101.2 controller  controller.
localdomain
172.16.101.3 compute1  compute1.
localdomain
172.16.101.3 compute2 compute2.localdomain
```

6. Update the software packages on each of the host machines.

```
# yum –y update
```

7. Disable Security-Enhanced Linux* (SELinux) and the firewall on all the host machines. Edit the etc/sysconfig/selinux file and set SELINUX=disabled to permanently disable SELinux. The following commands can be used to disable the firewall service and, temporarily, SELinux.

```
# setenforce 0
# sestatus
# systemctl disable firewalld.service
# systemctl stop firewalld.service
```

8. Uncomment the PermitRootLogin line in the /etc/ssh/sshd_config file.

```
PermitRootLogin=yes
```

Note: Remote login as root is not advisable from the security standpoint.

9. Reboot all the host machines.

3.3 Install the OpenStack Using Packstack*

To install the OpenStack Kilo using Packstack, perform the following steps.

1. Set up RDO repositories on all of the nodes.

```
# yum install –y https://repos.
fedorapeople.org/openstack/openstack-
kilo/rdo-release-kilo-1.noarch.rpm
```

2. Install Packstack on the controller node.

```
# yum install openstack-packstack
```

3. Update packages on all of the nodes.

```
# yum –y update
```

4. Run Packstack to generate the answer file. Packstack uses the answer file to install and configure the desired OpenStack services.

```
#packstack --gen-answer-file=answerfile.
txt
```

The answer file used in this setup is presented in Appendix A: The Packstack Answer File. Edit the answer file based on your setup requirements and network configurations.

5. Run Packstack with the edited answer file on the controller node.

```
# packstack --answer-file=./answerfile.txt
```

6. After OpenStack is installed, verify that all of the installed OpenStack services are running.

```
# cd /root
# source keystonerc_admin
# openstack-status
```

Check the openstack-status on the controller node to make sure that the services are active and all the service parameters (for example, both compute nodes, keystone user-list, glance image-list, and so on) are listed.

7. Update the /etc/neutron/l3_agent.ini file on the controller node and remove the br-ex from the line as shown below.

```
external_network_bridge =
```

8. Update /etc/neutron/plugins/ml2/ml2_conf.ini file on the controller node as shown below.

```
[ml2]
type_drivers = vxlan,flat,gre,vlan,local
tenant_network_types =
vxlan,flat,gre,vlan,local
mechanism_drivers =openvswitch,linuxbridg
e,l2population
extension_drivers = port_security

[ml2_type_flat]
flat_networks = external
network_vlan_ranges = physnet1:2:1000

[ovs]
bridge_mappings = external:br-
ex,physnet1:br-vlan
```

9. Restart the neutron-server and neutron-l3-agent services on the controller node.

10. Update the /etc/httpd/conf.d/15-horizon_vhost.conf file on the controller node so that the external IP address can be used to access the OpenStack dashboard.

```
ServerAlias 172.16.101.2
ServerAlias *
```

11. Reload the httpd service on the controller node.

```
# service httpd reload
```

12. Log in to verify that the OpenStack dashboard is accessible. The credentials set in the answer file are admin/password. In the PoC example, the URL to access the dashboard is http://10.250.100.101/dashboard/auth/login/?next=/dashboard/.

Figure 2. The OpenStack* login screen.

13. In the OpenStack dashboard, click **Project→Access & Security**, and then modify the default security group to add new rules for ingress and egress traffic types such as transmission control protocol (TCP), Internet Control Message Protocol (ICMP), and User Datagram Protocol (UDP). The final set of rules should be similar to the sample security rules shown below.

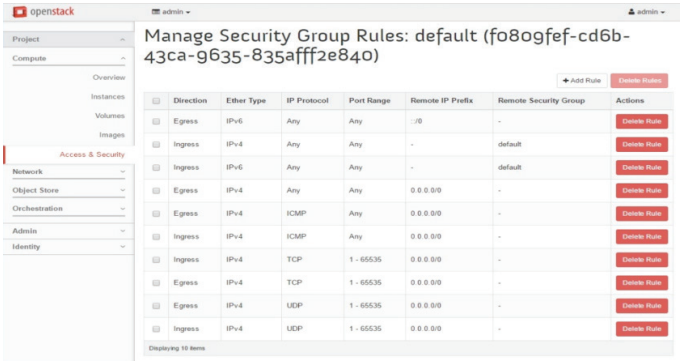


Figure 3. Managing security group rules in the OpenStack* dashboard.

Execute the following steps to verify the networking and connectivity within the OpenStack cloud setup.

14. Create the public and private networks in OpenStack. Refer to the Appendix B: Create OpenStack Networks and Router for commands used to create different types of OpenStack networks.

15. Download the CirrOS* image from http://docs.openstack.org/image-guide/content/ch_obtaining_images.html, and import it to the OpenStack Image Service*.

    In the following example, the CirrOS image is downloaded into the `/etc/demouser/Downloads` directory.

```
# cd /home/demouser/Downloads/
# glance image-create --name="cirros"
--is-public=true --container-format=bare
--disk-format=qcow2--progress < cirros-
0.3.4-x86_64-disk.img
```

16. Launch two VMs on the private network, and then check whether the VMs are getting IP addresses through the Dynamic Host Configuration Protocol (DHCP). Check whether the VMs can ping each other. The credentials for the CirrOS image are `cirros/cubswin:`).

17. Create another private network, and spawn a new CirrOS VM on this new subnet.

18. Create the OpenStack router as presented in Appendix B: Create OpenStack Networks and Router or by using OpenStack dashboard, and attach it to both the private networks and the public network. Create a floating IP address within the public network and associate it to one of the VMs previously spawned on the private network.

    Alternatively, you may want to install the Brocade 5600 vRouter*. The respective configuration steps are presented in Appendix C: Basic Configuration of Brocade 5600 vRouter.

    Note: Floating IP address can be created through the OpenStack dashboard following **Compute→ Access & Security→Floating IPs→ Allocate IP to project;** select **Public network** from a drop-down menu.

19. Ping the associated floating IP address from the host machine and any other machine connected to the same public network.

20. Check whether the VMs on different private networks can ping each other and any IP address on the Internet.

21. To create an OpenStack virtual local area network (VLAN) with a specific VLAN ID and a classless inter-domain routing (CIDR), use the commands provided in the Appendix B: Create OpenStack Networks and Router.

3.4 Enable the networking-ovs-dpdk Plug-In

3.4.1 Prepare the OpenStack Nodes

Perform the following steps on the controller node.

1. Install missing packages.

```
# yum install openstack-neutron
openstack-neutron-ml2 python-
neutronclient openstack-neutron-
openvswitch
```

Note: The packages mentioned above may already be installed by Packstack.

2. Edit the following parameters in the `/etc/sysctl.conf` file as presented below.

```
net.ipv4.ip_forward=1
net.ipv4.conf.all.rp_filter=0
net.ipv4.conf.default.rp_filter=0
```

3. Commit the changes.

```
# sysctl -p
```

4. Recreate the MySQL* database for the OpenStack Networking services. Enter the MySQL shell.

```
# mysql -u root -p
```

   Execute the following set of MySQL commands.

```
DROP DATABASE neutron;
CREATE DATABASE neutron;
GRANT ALL PRIVILEGES ON neutron.* TO
'neutron'@'localhost' IDENTIFIED BY
'intel';
GRANT ALL PRIVILEGES ON neutron.* TO
'neutron'@'%' IDENTIFIED BY 'intel';
```

5. Edit the following parameters in the `/etc/neutron/plugins/ml2/ml2_conf.ini` file as presented below.

```
[ml2]
...
type_drivers = flat,vlan,gre,vxlan
tenant_network_types = vxlan, vlan
mechanism_drivers = openvswitch

[ml2_type_flat]
...
```

```
flat_networks = external

[ml2_type_vlan]
...
vlan_ranges = physnet1:2:1000

[ml2_type_vxlan]
...
vni_ranges = 1001:2000

[securitygroup]
...
enable_security_group = True
firewall_driver = neutron.
agent.linux.iptables_firewall.
OVSHybridIptablesFirewallDriver
enable_ipset = True

[ovs]
...
local_ip = 172.16.111.2
bridge_mappings = external:br-ex,
physnet1:br-vlan

[agent]
...
tunnel_types = vxlan
```

6. Create a symbolic link.

```
# ln -s /etc/neutron/plugins/ml2/ml2_
conf.ini /etc/neutron/plugin.ini
```

7. Edit the `/usr/lib/systemd/system/neutron-openvswitch-agent.service` file and replace the following entry

```
ExecStart=/usr/bin/neutron-openvswitch-
agent --config-file /usr/share/neutron/
neutron-dist.conf --config-file /etc/
neutron/neutron.conf --config-file /etc/
neutron/plugins/openvswitch/ovs_neutron_
plugin.ini --config-dir /etc/neutron/
conf.d/neutron-openvswitch-agent --log-
file /var/log/neutron/openvswitch-agent.
log
```

with the line below.

```
ExecStart=/usr/bin/neutron-openvswitch-
agent --config-file /usr/share/neutron/
neutron-dist.conf --config-file /etc/
neutron/neutron.conf --config-dir /etc/
neutron/conf.d/neutron-openvswitch-agent
--log-file /var/log/neutron/openvswitch-
agent.log --config-file /etc/neutron/
plugins/ml2/ml2_conf.ini
```

8. Populate the database with the new configuration.

```
# su -s /bin/sh -c "neutron-db-manage
--config-file /etc/neutron/neutron.conf
--config-file /etc/neutron/plugins/ml2/ml2_
conf.ini upgrade head" neutron
```

9. Verify that all the Open vSwitch bridges exist before restarting the OpenStack Networking services.

```
# systemctl daemon-reload
# systemctl restart neutron*
```

Perform the following steps on each compute node.

10. Edit the following parameters in the `/etc/sysctl.conf` file as presented below.

```
net.ipv4.conf.all.rp_filter=0
net.ipv4.conf.default.rp_filter=0
net.bridge.bridge-nf-call-iptables=1
net.bridge.bridge-nf-call-ip6tables=1
```

11. Apply the changes.

```
# sysctl -p
```

12. Install networking components.

```
# yum install openstack-neutron
openstack-neutron-ml2 openstack-neutron-
openvswitch
```

Note: The packages mentioned above may already be installed by Packstack.

13. Edit the `/etc/neutron/plugins/ml2/ml2_conf.ini` file as presented below.

```
[ml2]
...
type_drivers = vxlan,vlan,flat
tenant_network_types = vxlan,vlan,flat
mechanism_drivers = openvswitch

[ml2_type_flat]
...
flat_networks = external

[ml2_type_vlan]
...
network_vlan_ranges = physnet1:2:1000

[ml2_type_vxlan]
...
vni_ranges = 1001:2000

[securitygroup]
...
enable_security_group = True
enable_ipset = True
firewall_driver = neutron.agent.firewall.
NoopFirewallDriver

[ovs]
...
bridge_mappings = external:br-
ex,physnet1:br-vlan
local_ip = 172.16.111.3
tunnel_types = vxlan
tunnel_id_ranges = 32769:34000
enable_tunneling = True

[agent]
...
tunnel_types = vxlan
```

14. Create a symbolic link.

```
# ln -s /etc/neutron/plugins/ml2/ml2_
conf.ini /etc/neutron/plugin.ini
```

15. Edit the /usr/lib/systemd/system/neutron-openvswitch-agent.service file and replace the following entry

```
ExecStart=/usr/bin/neutron-openvswitch-
agent --config-file /usr/share/neutron/
neutron-dist.conf --config-file /etc/
neutron/neutron.conf --config-file /etc/
neutron/plugins/openvswitch/ovs_neutron_
plugin.ini --config-dir /etc/neutron/
conf.d/neutron-openvswitch-agent --log-
file /var/log/neutron/openvswitch-agent.
log
```

with the line below.

```
ExecStart=/usr/bin/neutron-openvswitch-
agent --config-file /usr/share/neutron/
neutron-dist.conf --config-file /etc/
neutron/neutron.conf --config-dir /etc/
neutron/conf.d/neutron-openvswitch-agent
--log-file /var/log/neutron/openvswitch-
agent.log --config-file /etc/neutron/
plugins/ml2/ml2_conf.ini
```

16. Restart all the OpenStack Networking services.

```
# systemctl daemon-reload
# systemctl restart neutron*
```

Perform the following step on the controller node.

17. Recreate all the OpenStack networks as given in Appendix B: Create OpenStack Networks and Router.

3.4.2 Clone the Required Repositories

1. Clone the networking-ovs-dpdk git repository on both the compute and controller nodes.

```
# git clone https://github.com/openstack/
networking-ovs-dpdk.git
# cd networking-ovs-dpdk
# git checkout origin/stable/kilo
```

2. Clone the dpdk repository only on the compute nodes.

```
# git clone http://dpdk.org/git/dpdk
# cd dpdk
# git checkout v2.2.0
```

Note: You can check out the v16.04 tag of dpdk repository to enable some of the performance optimizations. Refer to the section 4.0 Performance Optimizations for more information.

3. Clone the ovs repository only on compute nodes.

```
# git clone https://github.com/
openvswitch/ovs.git
# cd ovs
# git checkout v2.5.0
```

Note: You can check out the newer Open vSwitch version to enable some of the performance optimizations. Refer to the section 4.0 Performance Optimizations for more information and detailed instructions.

3.4.3 Install the OVS-DPDK

1. Change the directory to the DPDK directory, and then edit the following lines in the config/common_linuxapp file.

```
CONFIG_RTE_BUILD_COMBINE_LIBS=y
CONFIG_RTE_LIBRTE_VHOST=y
```

2. Build the DPDK.

```
# export RTE_TARGET=x86_64-native-
linuxapp-gcc
# make install T=$RTE_TARGET
DESTDIR=install
```

3. Change the directory to the Open vSwitch directory, and then build the Open vSwitch with DPDK.

```
# ./boot.sh
# ./configure --with-dpdk=<DPDK_
DIR>/<TARGET> --prefix=/usr --with-
rundir=/var/run/openvswitch
# make CFLAGS='-O3 -march-native'
# make install
```

4. Change the directory to the networking-ovs-dpdk directory, and install the ovs-dpdk agent.

```
# yum install python-pip
# python setup.py install
```

5. Stop the native openvswitch service.

```
# systemctl stop openvswitch
```

6. Stop the native neutron-openvswitch-agent.service.

```
# systemctl stop neutron-openvswitch-
agent.service
```

7. Change the directory to the networking-ovs-dpdk directory, and then copy the files as shown below.

```
# cd ~/networking-ovs-dpdk
# cp devstack/ovs-dpdk/ovs-dpdk-init /
etc/init.d/ovs-dpdk
# cp devstack/ovs-dpdk/ovs-dpdk-conf /
etc/default/ovs-dpdk
```

8. Edit the /etc/default/ovs-dpdk file to match your environment. Use the content below as an example, and adjust paths, huge pages, and other settings.

```
RTE_SDK=/root/source/dpdk
RTE_TARGET=x86_64-native-linuxapp-gcc

OVS_INSTALL_DIR=/usr
OVS_DB_CONF_DIR=/etc/openvswitch
OVS_DB_SOCKET_DIR=/var/run/openvswitch
OVS_DB_CONF=/etc/openvswitch/conf.db
OVS_DB_SOCKET=/var/run/openvswitch/
db.sock

OVS_SOCKET_MEM=2048
OVS_MEM_CHANNELS=4
OVS_CORE_MASK=2
OVS_PMD_CORE_MASK=C
OVS_LOG_DIR=/var/log/openvswitch
OVS_LOCK_DIR=''
OVS_SRC_DIR=/root/source/ovs
```

```
OVS_DIR=/root/source/ovs
OVS_UTILS=/root/source/ovs/utilities/
OVS_DB_UTILS=/root/source/ovs/ovsdb/
OVS_DPDK_DIR=/root/source/dpdk
OVS_NUM_HUGEPAGES=60
OVS_HUGEPAGE_MOUNT=/mnt/huge
OVS_HUGEPAGE_MOUNT_PAGESIZE='1G'
OVS_BRIDGE_MAPPINGS=eno3
OVS_ALLOCATE_HUGEPAGES=True
OVS_INTERFACE_DRIVER='igb_uio'
OVS_DATAPATH_TYPE='netdev'
```

9. Create a backup of the `qemu-kvm` executable file.

```
# mv /usr/bin/qemu-kvm /usr/bin/qemu-kvm.
orig
```

10. Create a new `qemu-kvm` executable script that includes the support for DPDK vhost-user ports for newly created VMs on this node. To do so, create a new qemu-kvm file

```
# touch /usr/bin/qemu-kvm
```

Open the newly created `/usr/bin/qemu-kvm` file, paste the following code, and then save it.

```
#!/bin/bash -
VIRTIO_OPTIONS="csum=off,gso=off,guest_
tso4=off,guest_tso6=off,guest_ecn=off,guest_
ufo=off"
VHOST_FORCE="vhostforce=on"
SHARE="share=on"
add_mem=False
i=0
while [ $# -gt 0 ]; do
     case "$1" in
     -netdev)
        args[i]="$1"
        (( i++ ))
        shift
        if [[ $1 =~ "vhost-user" ]]
        then
                args[i]=${1},${VHOST_
FORCE}
                (( i++))
                shift
        fi
        ;;
     -device)
        args[i]="$1"
        (( i++ ))
        shift
        if [[ $1 == virtio-net-pci* ]];
then
                args[i]=${1},${VIRTIO_
OPTIONS}
                (( i++))
                shift
        fi
        ;;
    -object)
        args[i]="$1"
        (( i++ ))
        shift
        if [[ $1 =~ "memory-backend-file"
]]
        then
                args[i]=${1},${SHARE}
                (( i++))
                shift

        fi
        ;;

     *)
          args[i]="$1"
          (( i++ ))
          shift ;;
     esac
done
if [ -e /usr/local/bin/qemu-system-x86_64
]; then
    exec /usr/local/bin/qemu-
system-x86_64   "${args[@]}"
elif [ -e /usr/libexec/qemu-kvm.orig ];
then
    exec /usr/libexec/qemu-kvm.orig
"${args[@]}"
fi
```

11. Add execution permissions to the `qemu-kvm` file and the networking-ovs-dpdk plug-in executable files.

```
# chmod +x /usr/bin/qemu-kvm
# chmod +x /usr/bin/networking-ovs-dpdk-
agent
```

12. Edit the OpenStack Networking neutron ml2 agent settings.

On the compute node, open the `/etc/neutron/plugins/ml2/ml2_conf.ini` file, and then edit the `mechanism_drivers` parameter as shown below.

```
[DEFAULT]
…
mechanism_drivers = ovsdpdk

[securitygroup]
…
firewall_driver = neutron.agent.firewall.
NoopFirewallDriver
```

On the controller node, open the `/etc/neutron/plugins/ml2/ml2_conf.ini` file, and then add the `ovsdpdk` entry to the `mechanism_drivers` parameter as shown below.

```
[DEFAULT]
…
mechanism_drivers = openvswitch, ovsdpdk

[securitygroup]
…
firewall_driver = neutron.agent.firewall.
NoopFirewallDriver
```

In the same file on both the compute and controller nodes, configure the VxLAN tunnel settings.

```
[ovs]
…
local_ip = IP_OF_THE_INTERFACE_USED_FOR_TUNNEL

[agent]
…
tunnel_types = vxlan
```

13. Edit the /etc/libvirt/qemu.conf file, and then change the user and group parameters to qemu.

```
user = "qemu"
group = "qemu"
```

Set the hugetlbfs_mount location to match your system settings.

```
hugetlbfs_mount = "/mnt/huge"
```

14. Due to errors in the ovs-dpdk script, edit the /etc/init.d/ovs-dpdk file.

At line 191, change:

```
sudo ip link $nic 0 down
```

to:

```
sudo ip link set dev $nic down
```

At line 376, change:

```
while [ ! $(grep "unix.*connected" ${OVS_LOG_DIR}/ovs-vswitchd.log) ]; do
```

to:

```
while [ ! "$(grep 'unix.*connected' ${OVS_LOG_DIR}/ovs-vswitchd.log)" ]; do
```

Insert the following lines after line 410:

```
echo "vhostuser sockets cleanup"
rm -f $OVS_DB_SOCKET_DIR/vhu*
```

Save the file, and then exit.

15. Initialize the ovs-dpdk service.

At this point, it is recommended that you remove and recreate manually the Open vSwitch database file conf.db to avoid any issues with configuration of the Open vSwitch in the next steps.

Kill any Open vSwitch-related process running in your system, such as ovs-vswitchd and ovsdb-server.

```
# rm /usr/local/etc/openvswitch/conf.db
# ovsdb-tool create /etc/openvswitch/conf.db \
    /usr/share/openvswitch/vswitch.ovsschema
```

Run the service initialization.

```
# service ovs-dpdk init
```

16. Run the ovs-dpdk service.

```
# service ovs-dpdk start
```

Note: To identify possible issues, pay attention to the output of this command, and check also the ovs-vswitchd logs located in the /etc/default/ovs-dpdk directory.

Check the status of the ovs-dpdk with the following command.

```
# systemctl status ovs-dpdk
```

Note: Automatic binding of igb_uio to the interfaces by the ovs-dpdk service was not fully tested and might not be working. If this happens, a solution is to disable this feature by commenting out the following parts of the /etc/init.d/ovs-dpdk script.

```
319     #       bind_nics
[...]
403             #if uio diver is not loaded load
404     #       echo "loading OVS_INTERFACE_DRIVER diver"
405     #       if [[ "$OVS_INTERFACE_DRIVER" == "igb_uio" ]]; then
406     #               load_igb_uio_module
407     #       elif [[ "$OVS_INTERFACE_DRIVER" == "vfio-pci" ]]; then
408     #               load_vfio_pci_module
409     #       fi
[...]
427     #       echo "binding nics to linux_dirver"
428     #       unbind_nics
429     #
430     #       echo "unloading OVS_INTERFACE_DRIVER"
431     #       if [[ "$OVS_INTERFACE_DRIVER" == "igb_uio" ]]; then
432     #               remove_igb_uio_module
433     #       elif [[ "$OVS_INTERFACE_DRIVER" =~ "vfio-pci" ]]; then
434     #               remove_vfio_pci_module
435     #       fi
```

17. Bind the DPDK interfaces to the igb_uio driver, and manually create the Open vSwitch bridges for these interfaces.

Execute the following commands to bind the interface to the igb_uio driver.

```
# modprobe uio
# modprobe cuse
# modprobe fuse
```

Change the directory to the DPDK directory, and then load the DPDK igb_uio driver.

```
# insmod x86_64-native-linuxapp-gcc/kmod/igb_uio.ko
```

Note: For a different DPDK target, replace the x86_64-native-linuxapp-gcc in the above command with the respective one.

18. Execute the following command to check the current binding status of all the interfaces.

```
# ./tools/dpdk_nic_bind.py --status
```

19. Bind the interfaces to the DPDK driver if needed. The interfaces must be in down status; otherwise, binding will fail. To bring the interfaces down execute the following command.

```
# ip l s dev <Interface-Name> down
```

20. The following command brings down the eno4 interface.

```
# ip l s dev eno4 down
```

To bind the interface to the DPDK driver, execute the command below.

```
# /root/dpdk/dpdk-nic-bind.py -b igb_iuo
\
          <PCI_ADDRESS_OF_NIC_TO_BIND>
# /root/dpdk/tools/dpdk_nic_bind.py -b
igb_uio 0000:04:00.0
To bind the interface back to the
regular Linux driver, execute the
command below.
# /root/dpdk/tools/dpdk-nic-bind.py -b
<DRIVER_NAME> \
          <PCI_ADDRESS_OF_NIC_TO_BIND>
```

21. Run the ovs-dpdk service.

```
# service ovs-dpdk start
```

3.5 Post-Installation Configuration

1. To create the Open vSwitch bridges with DPDK interfaces use the following commands. Table 5 shows the mapping of DPDK interfaces.

```
# ovs-vsctl add-br br-ex -- set bridge
br-ex datapath_type=netdev
# ovs-vsctl add-port br-ex dpdk0 -- set
Interface dpdk0 type=dpdk
# ovs-vsctl add-br br-vxlan -- set bridge
br-vxlan datapath_type=netdev
# ovs-vsctl add-port br-vxlan dpdk1 --
set Interface dpdk1 type=dpdk
# ovs-vsctl add-br br-vlan -- set bridge
br-vlan datapath_type=netdev
# ovs-vsctl add-port br-vlan dpdk2 --
set Interface dpdk2 type=dpdk
```

Table 5. Mapping of DPDK interfaces.

DPDK INTERFACE NAME	PREVIOUS NAME	PURPOSE
dpdk0	eno1	External network
dpdk1	eno3	VxLAN network
dpdk2	eno4	VLAN network

Note: The DPDK interfaces are sorted by the Peripheral Component Interconnect* (PCI*) address—the higher value of a PCI address results in a higher interface number.

Check the status of the Open vSwitch.

```
# ovs-vsctl show
```

If there are issues with adding the DPDK port to the bridge, restart the ovs-dpdk service after binding the DPDK interfaces using the command below.

```
# systemctl restart ovs-dpdk
```

2. Set the administrative status to up on all the Open vSwitch bridges except for the br-int.

Note: This step may be required after creating new Open vSwitch bridges and restarting the ovs-dpdk service.

The following sample command brings the br-vlan bridge up.

```
# ip link set dev br-vlan up
```

Use the following commands to assign an IP address to the VxLAN bridge.

```
# ip address add 172.16.111.3/24 dev br-
vxlan
```

3. Once all the bridges are created and configured, start the networking-ovs-dpdk-agent.

```
# screen /usr/bin/networking-ovs-dpdk-
agent \
       --config-file /etc/neutron/neutron.
conf \
       --config-file /etc/neutron/plugins/
ml2/ml2_conf.ini
```

4. It is recommended that you run networking-ovs-dpdk-agent in the nohup, screen (as provided in the example above), or tmux session.

5. Restart the openstack-nova-compute service on the compute nodes.

```
# systemctl restart openstack-nova-
compute
```

6. On the controller node, restart all the OpenStack Networking services.

```
# systemctl restart neutron*
```

7. On the controller node, check whether all of the OpenStack Networking and Compute services are running.

```
# neutron agent-list
# cd /root
# source keystonerc_admin
# openstack-status
```

There might also be an old Open vSwitch agent visible on the compute nodes. Make sure to delete manually all the entries with the agent_type as Open vSwitch agent. To delete the old agent, execute the following command.

```
# neutron agent-delete <id-of-the-non-
dpdk-agent>
```

8. On the controller node, create a new flavor or update an already existing one, and set the extra_specs parameter as shown below. These updated flavors will be used for all OpenStack VMs.

```
# nova flavor-key <flavor-id> set "hw:mem_
page_size"="large"
```

3.6 Enable Traffic Monitoring on the vHost-user and DPDK Interfaces

3.6.1 Configure the sFlow* in OVS-DPDK

Traffic monitoring using sFlow* was not supported on physical DPDK and vHost-user interfaces. To enable this feature, we implemented a patch and published it to the ovs-dev mailing list. To enable sFlow on DPDK interfaces, perform following steps.

1. Download the patch from the ovs-dev mailing list: https://mail.openvswitch.org/pipermail/ovs-dev/2016-April/070317.html, and then apply the patch on the Open vSwitch sources.

```
# git am 0001-netdev-dpdk-add-sflow-support-for-vhost-user-ports.patch
```

   Alternatively, use the command below.

```
# git apply 0001-netdev-dpdk-add-sflow-support-for-vhost-user-ports.patch
```

2. Recompile and reinstall the Open vSwitch.

```
# ./boot.sh
# ./configure --with-dpdk=<DPDK_DIR>/<TARGET> --prefix=/usr --with-rundir=/var/run/openvswitch CFLAGS='-O3 -march-native'
# make
# make install
```

3. Restart the `ovs-dpdk` service, and then start the `networking-ovs-dpdk-agent`.

```
# service ovs-dpdk restart
# screen /usr/bin/networking-ovs-dpdk-agent \
        --config-file /etc/neutron/neutron.conf \
        --config-file /etc/neutron/plugins/ml2/ml2_conf.ini
```

On all of the nodes, configure the Open vSwitch with the following commands.

4. Define the following variables in the shell environment.

```
COLLECTOR_IP=172.16.101.2
COLLECTOR_PORT=6343
AGENT_IP=eno2
HEADER_BYTES=128
SAMPLING_N=64
POLLING_SECS=10
```

   Note: `COLLECTOR_IP` is the IP address of the management interface on the controller node. `AGENT_IP` is the name of the management interface of the currently configured node.

5. Enable the sFlow agent on all the Open vSwitch bridges. The following command creates the sFlow agent and assigns it to the `br-int` bridge. This command also returns the universally unique identifier (UUID) of the sFlow agent, which may be reused for other Open vSwitch bridges.

```
# ovs-vsctl -- --id=@sflow create sflow agent=${AGENT_IP} \
target=\"${COLLECTOR_IP}:${COLLECTOR_PORT}\" header=${HEADER_BYTES} \
sampling=${SAMPLING_N} polling=${POLLING_SECS} -- set bridge br-int sflow=@sflow

a733c94f-0364-43f2-9c14-a5a163b4add8
```

6. Use the following command to enable the sFlow agent on all the remaining bridges.

```
# ovs-vsctl set bridge BR_NAME sflow=RETURNED_SFLOW_UUID
```

   The commands below present the exemplary executions.

```
# ovs-vsctl set bridge br-ex sflow=a733c94f-0364-43f2-9c14-a5a163b4add8
# ovs-vsctl set bridge br-vlan sflow=a733c94f-0364-43f2-9c14-a5a163b4add8
```

   Note: Repeat the above steps on each host where the sFlow Open vSwitch agent must be enabled.

3.6.2 Install the InMon sFlowTrend* Data Collector

Perform the following steps on the controller node.

1. Download the installation script.

```
# wget http://www.inmon.com/products/sFlowTrend/downloads/sFlowTrend-unix-6_2.sh
```

2. Set the execution permissions, and then run the script.

```
# chmod +x sFlowTrend-unix-6_2.sh
# ./sFlowTrend-unix-6_2.sh
```

3. Follow the installation steps displayed on the screen.

4. Once the installation is completed, use the web browser to navigate to the InMon sFlowTrend* dashboard at http://CONTROLLER_IP:8087/sflowtrend.

5. The InMon sFlowTrend dashboard should be accessible and show all the collected network statistics from the Open vSwitch bridges and interfaces, as shown in Figure 4.

Figure 4. InMon sFlowTrend* monitor dashboard.

4.0 Performance Optimizations

This chapter provides the optimization instructions that enable the NFVI to operate with optimal performance.

4.1 Optimize the Host

4.1.1 Isolate the CPU Cores

First, isolate the CPU cores from the Linux scheduler so that the OS cannot use it for housekeeping or other OS-related tasks. These isolated cores can then be dedicated to the Open vSwitch, DPDK poll mode drivers (PMDs), and OpenStack VMs.

Optimal performance is achieved when CPU cores that are isolated and assigned to the Open vSwitch, PMD threads, OpenStack VMs, memory banks, and the NIC, are connected to the same NUMA node. This helps avoid the usage of costly cross-NUMA node links and therefore boosts the performance.

To check what NUMA node the NIC is connected to, execute the following command.

```
# cat /sys/class/net/<interface_name>/
device/numa_node
```

The output of this command indicates the NUMA node number, 0 or 1, in case of a two-socket system.

To list the associations between the CPU cores and NUMA nodes, execute the following commands.

```
# yum install numactl
# numactl –hardware
available: 2 nodes (0-1)
node 0 cpus: 0 1 2 3 4 5 6 7 8 9 20 21
22 23 24 25 26 27 28 29
node 0 size: 32083 MB
node 0 free: 42 MB
node 1 cpus: 10 11 12 13 14 15 16 17 18
19 30 31 32 33 34 35 36 37 38 39
node 1 size: 32237 MB
node 1 free: 1 MB
node distances:
node   0   1
  0:  10  21
  1:  21  10
```

The output of the command shows that cores 0–9 and 20–29 belong to the NUMA node 0, and cores 10–19 and 30–39 belong to the NUMA node 1.

All the NICs used in this PoC setup are connected to the NUMA node 0. Hence, the CPU cores belonging to the NUMA node 0 are assigned to the Open vSwitch, DPDK PMD threads, and VMs. Table 6 shows the assignment of the CPU cores from NUMA node 0.

Note: The CPU cores belonging to the NUMA node 1 are not listed in the Table 6 as these cores were not used in the PoC. However, these cores can be assigned to the OpenStack Compute service in order to allocate more resources to OpenStack VMs.

Intel HT Technology increases the number of independent instructions in the CPU pipeline, because when it is enabled, every single physical CPU core appears as two virtual processors in the OS. These virtual processors are referred to as hyper-threaded or logical cores (LCs). Two hyper-threaded cores that belong to the same physical core are called sibling cores. In this setup, there is an offset of 20 between each of the sibling cores, as presented in Figure 5.

To achieve the optimal performance of DPDK PMD threads, three CPU pinning alternatives were tested:

- Two LCs (LC2 and LC22) on same physical core assigned to DPDK PMD threads (0x400004).
- One LC (LC2) assigned to one PMD thread (0x4).
- Two LCs (LC2 and LC3) on different physical cores assigned to PMD threads (0xC).

Figure 5 shows the graphical interpretation of these alternatives. The hexadecimal values are the masks that denote which virtual cores were assigned to PMD threads. This notation is often used as a parameter passed to a configuration file or a command. Table 6 shows that physical cores 2 and 3 were selected due to the best performance achieved.

Table 6. Sample usage of CPU cores.

NUMA NODE 0 CPU CORES	ASSIGNED TO	CONFIGURATION SETTINGS
0, 20	Housekeeping	Set the parameters below in the `/etc/default/grub` file. `GRUB_CMDLINE_LINUX = … isolcpus=1-19,21-39`

2, 3	OVS-DPDK PMD threads	Set the mask below in the `/etc/default/ovs-dpdk` file.
		`OVS_PMD_CORE_MASK=C`
		Alternatively, execute the following command.
		`ovs-vsctl set Open_vSwitch . other_config:pmd-cpu-mask=C`

1	ovs-vswitchd daemon	Set the mask below in the `/etc/default/ovs-dpdk` file. `OVS_CORE_MASK=2`
4-9, 24-29	OpenStack VMs	Set the CPU core numbers in the `/etc/nova/nova.conf` file. `vcpu_pin_set = 4-9,24-29`

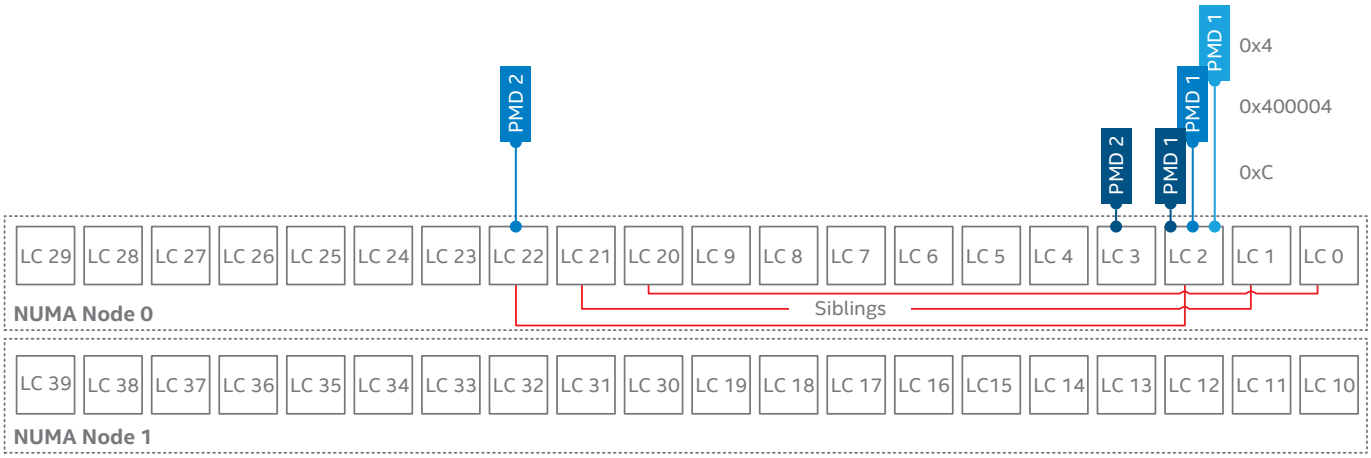


Figure 5. Three different assignments of logical cores to DPDK PMD threads.

4.1.2 Enable 1 GB Huge Pages

1 GB huge pages were used for OpenStack VMs to reduce translation lookaside buffer (TLB) misses by the memory management hardware and the CPU on x86_64 architectures. To enable 1 GB huge pages, execute the following steps on all the compute nodes.

1. Add the following line to the `/etc/libvirt/qemu.conf` file.

```
hugetlbfs_mount="/mnt/huge"
```

2. Add the following line in the `/etc/fstab` file.

```
hugetlbfs /mnt/huge hugetlbfs defaults 0 0
```

3. Create the mount directory for huge pages.

```
# mkdir -p /mnt/huge
```

4. Add the following line to the `/etc/sysctl.conf` file.

```
vm.nr_hugepages = 60
```

5. Edit the `/etc/default/grub` file to set the huge pages.

```
GRUB_CMDLINE_LINUX="… hugepagesz=1G
hugepages=60 default_hugepagesz=1G"
```

6. Update the GRUB2 configuration.

```
# grub2-mkconfig -o /boot/grub2/grub.cfg
```

Note: The `grub.cfg` file location may vary. You can use the following command to locate it.

```
# locate grub.cfg
```

7. Reboot the host machine.

```
# reboot
```

8. Verify the settings.

```
# cat /proc/meinfo | grep Huge
AnonHugePages:           0 kB
HugePages_Total:        60
HugePages_Free:         44
HugePages_Rsvd:          0
HugePages_Surp:          0
Hugepagesize:      1048576 kB
```

```
# dmesg | grep –o "isolcpus.*"
isolcpus=2-19,22-39 iommu=on
isolcpus=2-19,22-39 iommu=on
```

4.1.3 Enable the TCP Segmentation Offload in OVS-DPDK

We implemented and published a patch to enable TCP segmentation offload (TSO) support in OVS-DPDK. The patch enables successful feature negotiation of TSO (and implicitly, transmit checksum offloading) between the hypervisor and the OVS-DPDK vHost-user back end so that TSO may be enabled on a per-port basis in the VM using the standard Linux ethtool* utility. Furthermore, the patch also increases the maximum permitted frame length for OVS-DPDK-netdevs to 64 KB—a necessity to accommodate oversized frames received—and introduces the support for handling "offload" frames.

Note that the TSO feature in OVS-DPDK is experimental. It is only validated on OpenStack-deployed flat and VLAN networks. The guest may only take advantage of TSO if OVS is connected to a NIC that supports that functionality. The mechanism by which offloading was achieved works as follows: When OVS dequeues a frame from a TSO-enabled guest port using the DPDK vHost library, the library sets specific offload flags in the metadata that DPDK uses to represent a frame (known as 'mbuf'). Upon receipt of an offload mbuf, Open vSwitch sets additional offload flags and attribute values in the mbuf before passing it to the DPDK NIC driver for transmission. The driver examines and interprets the mbuf's offload flags and corresponding attributes to facilitate TCP segmentation on the NIC.

With the enablement of TSO for OVS-DPDK-netdevs in Open vSwitch, the segmentation of guest-originated, oversized TCP frames moves from the guest operating system's software TCP/IP stack to the NIC hardware. The benefits of this approach are many. First, offloading segmentation of a guest's TCP frames to hardware significantly reduces the compute burden on the VM's virtual CPU. Consequently, when the guest does not need to segment frames itself, its virtual CPU can take advantage of the additionally available computational cycles to perform more meaningful work.

Second, with TSO enabled, Open vSwitch does not need to receive, process, and transmit a large number of smaller frame segments, but rather a smaller amount of significantly larger frames. In other words, the same amount of data can be handled with significantly reduced overhead. Finally, the reduction in the number of small packets, which are sent to the NIC for transmission, results in the reduction of PCI bandwidth usage. The cumulative effect of these enhancements is a massive improvement in TCP throughput for DPDK-accelerated Open vSwitch.

To enable TSO in OVS-DPDK, execute the following steps.

1. Stop the `ovs-dpdk` service.

```
# service ovs-dpdk stop
```

2. Unload the `igb_uio module`.

```
# rmmod igb_uio
```

3. Change the directory to the source directory of Open vSwitch.

```
# cd ~/ovs
```

4. Check out the TSO patch with a compatible commit.

```
# git checkout
cae7529c16e312524bc6b76182e080c97428e2e0
```

Note: This will change the Open vSwitch version to 2.5.90.

5. Download the TCP segmentation patch from the ovs-dev mailing list at https://mail.openvswitch.org/pipermail/ovs-dev/2016-June/316414.html, and then apply the patch.

```
# git am 0001-netdev-dpdk-add-TSO-
support-for-vhostuser-ports.patch
```

Alternatively, use the command below.

```
# git apply 0001-netdev-dpdk-add-TSO-
support-for-vhostuser-ports.patch
```

6. Check out the DPDK v16.04, which is required to use the TSO feature.

```
# cd ~/dpdk
# git checkout v16.04
```

7. Recompile the DPDK libraries.

```
# make install T=x86_64-native-linuxapp-
gcc DESTDIR=install
```

8. Recompile, and then reinstall the Open vSwitch.

```
# cd ~/ovs
# ./boot.sh
# ./configure --with-dpdk=<DPDK_
DIR>/<TARGET> --prefix=/usr --with-
rundir=/var/run/openvswitch CFLAGS='-O3
-march-native'
# make
# make install
```

9. Load the `igb_uio` driver.

```
# insmod ~/dpdk/x86_64-native-linuxapp-
gcc/kmod/igb_uio.ko
```

10. Bind the network interfaces to the `igb_uio` driver as described in section 3.4.3 Install the OVS-DPDK.

11. Restart the `ovs-dpdk` service, and then run the `networking-ovs-dpdk agent`.

```
# service ovs-dpdk restart
# screen /usr/bin/networking-ovs-dpdk-
agent \

      --config-file /etc/neutron/neutron.
conf \

      --config-file /etc/neutron/plugins/
ml2/ml2_conf.ini
```

12. Enable the offload features in qemu-kvm wrapper. Edit the `/usr/bin/qemu-kvm` file, and change the following line

```
VIRTIO_OPTIONS="csum=off,gso=off,guest_
tso4=off,guest_tso6=off,guest_ecn=off,guest_
ufo=off"
```

with the line below.

```
VIRTIO_OPTIONS="csum=on,gso=on,guest_
tso4=on,guest_tso6=on,guest_ecn=on,guest_
ufo=on"
```

4.1.4 Enable the Multiqueue Feature for vHost-user and Physical DPDK Interfaces

1. Enable multiple queues in the qemu-kvm wrapper. Edit the `/usr/bin/qemu-kvm` file on both compute nodes. Add multiqueue settings in the following lines.

```
...
VIRTIO_OPTIONS="...,mq=on,vectors=18"
VHOST_FORCE="...,queues=8"
...
```

Note: The value of `vectors` parameter must be equal to 2 × `queues` + 2.

2. Configure the number of DPDK queues in the Open vSwitch to increase the network performance. In the Open vSwitch 2.5.0 and older, this option is set globally with the command below.

```
# ovs-vsctl set Open_vSwitch . other_
config:n-dpdk-rxqs=8
```

In the Open vSwitch 2.5.90 or newer, this option is configured on a per-port basis.

It was reported that the multiqueues feature used with OpenStack Kilo and Open vSwitch 2.5.90 or newer is not working properly. The issue appears when the number of queues specified in Quick Emulator* (QEMU*) is higher than the default value, 1.

To work around the problem, identify the VM's port ID with the following commands.

```
# nova list
# neutron port-list | grep –e
"20.20.20.105"
```

Make sure to note the first 10 characters of port-id for your desired VM. This string will be used to identify the interface on OVS-DPDK.

Once the port is identified, use the Open vSwitch command line interface and set the options:n_rxq parameter manually on the Open vSwitch interface in order to set a specific number of queues on that interface.

```
# ovs-vsctl set interface vhu9fbcbc75-30 options:n_rxq=8
```

To apply the changes, execute the soft reboot of the instance.

4.1.5 Enable Core Pinning and NUMA Awareness in the OpenStack Compute

1. On all of the compute nodes, edit the `/etc/nova/nova.conf` file, and then update the vcpu_pin_set setting.

```
vcpu_pin_set = 4-9,24-29
```

2. Restart the `openstack-nova-compute.service`.

```
# systemctl restart openstack-nova-compute.service
```

3. On the controller node, create the optimized NUMA-aware OpenStack flavor by specifying the number of CPU cores, memory size, and storage capacity.

```
# nova flavor-create <flavor-name> <id> <mb-of-ram> <gb-of-storage> <cpus-number>
```

4. Set the following `extra_specs` to use the resources from the selected NUMA node.

```
# nova flavor-key <id> set hw:numa_mem.0=<mb-of-ram>
# nova flavor-key <id> set hw:mem_page_size="large"
# nova flavor-key <id> set hw:cpu_policy="dedicated"
# nova flavor-key <id> set hw:numa_mempolicy="strict"
# nova flavor-key <id> set hw:numa_nodes=1
# nova flavor-key <id> set hw:numa_cpus.0="0,1,…,<cpus-number>"
# nova flavor-key <id> set hw:cpu_threads_policy="prefer"
```

Note: The above commands create a flavor utilizing NUMA node 0 resources only. To use the NUMA node 1, set the `hw:numa_cpus.1` and `hw:numa_mem.1` keys instead of `hw:numa_cpus.0` and `hw:numa_mem.0` respectively.

4.2 Optimize the Guest

4.2.1 The 'extra_specs' Properties for OpenStack VMs

To make use of features like CPU affinity, huge pages, and single NUMA node topology in VMs, we set the 'extra_specs' property applicable to OpenStack Compute* flavors. Table 7 shows the extra_specs parameters that were used to instantiate VMs in this setup.

4.2.2 Enable Multiqueue for VirtIO Interfaces

After enabling the multiqueue feature on the host machine, the same number of queues need to be set inside the VM with the command below.

```
# ethtool -L eth0 combined NR_OF_QUEUES
```

Note: The interface name on the virtual machine may be different.

4.2.3 Upgrade the CentOS* 7 Kernel to version 4.5.5 on the Guest

1. Install dependencies.

```
# yum install wget
# yum install linux-firmware
```

2. Download the RPM package of the kernel.

```
# wget http://mirrors.coreix.net/elrepo-archive-archive/kernel/el7/x86_64/RPMS/kernel-ml-4.5.4-1.el7.elrepo.x86_64.rpm
```

3. Install the new kernel.

```
# rpm -i kernel-ml-4.5.4-1.el7.elrepo.x86_64.rpm
```

4. Optionally, uninstall the old kernel.

```
# rpm -e <kernel-package-name>
```

The package name of an old kernel can be obtained with the command below.

```
# rpm -qa kernel command.
```

5. Reboot the VM, and then select the 4.5.4 kernel in the GRUB boot menu if more than one entry is available.

4.2.4 Additional TCP Performance Tunings on the CentOS* 7 Guest

1. Set the tuned-adm profile that can bring further TCP performance improvements.

```
# tuned-adm profile latency-performance
# tuned-adm profile network-throughput
# tuned-adm profile throughput-performance
```

Table 7. The extra_specs settings for OpenStack Compute flavors.

EXTRA_SPECS PARAMETER	VALUE	NOTES
hw:cpu_policy	dedicated	Guest virtual CPUs will be strictly pinned to a set of host physical CPUs.
hw:mem_page_size	large	Guest will use 1 GB HugePages.
hw:numa_mempolicy	preferred	Memory resources will be provided according to extra_specs, but if more resources are needed, these will be taken from the other NUMA node.
hw:numa_mem.0	4096	Mapping memory size to the NUMA node 0.
hw:numa_nodes	1	Number of NUMA nodes to expose to the guest.
hw_numa_cpus.0	0,1,2,3	Mapping of virtual CPUs list to the NUMA node 0.
hw:cpu_threads_policy	prefer	If the host has threads, the virtual CPU will be placed on the same core as a sibling core.

Appendix A: The Packstack Answer File

The following is the Packstack answer file that is used in the PoC.

```
[general]

CONFIG_SSH_KEY=/root/.ssh/id_rsa.pub
CONFIG_DEFAULT_PASSWORD=password
CONFIG_MARIADB_INSTALL=y
CONFIG_GLANCE_INSTALL=y
CONFIG_CINDER_INSTALL=y
CONFIG_MANILA_INSTALL=n
CONFIG_NOVA_INSTALL=y
CONFIG_NEUTRON_INSTALL=y
CONFIG_HORIZON_INSTALL=y
CONFIG_SWIFT_INSTALL=y
CONFIG_CEILOMETER_INSTALL=y
CONFIG_HEAT_INSTALL=y
CONFIG_SAHARA_INSTALL=n
CONFIG_TROVE_INSTALL=n
CONFIG_IRONIC_INSTALL=n
CONFIG_CLIENT_INSTALL=y
CONFIG_NTP_SERVERS=
CONFIG_NAGIOS_INSTALL=y
EXCLUDE_SERVERS=
CONFIG_DEBUG_MODE=n
CONFIG_CONTROLLER_HOST=172.16.101.2
CONFIG_COMPUTE_
HOSTS=172.16.101.3,172.16.101.4
CONFIG_NETWORK_HOSTS=172.16.101.2
CONFIG_VMWARE_BACKEND=n
CONFIG_UNSUPPORTED=n
CONFIG_USE_SUBNETS=n
CONFIG_VCENTER_HOST=
CONFIG_VCENTER_USER=
CONFIG_VCENTER_PASSWORD=
CONFIG_VCENTER_CLUSTER_NAME=
CONFIG_STORAGE_HOST=172.16.101.2
CONFIG_SAHARA_HOST=
CONFIG_USE_EPEL=n
CONFIG_REPO=
CONFIG_ENABLE_RDO_TESTING=n
CONFIG_RH_USER=
CONFIG_SATELLITE_URL=
CONFIG_RH_PW=
CONFIG_RH_OPTIONAL=y
CONFIG_RH_PROXY=
CONFIG_RH_PROXY_PORT=
CONFIG_RH_PROXY_USER=
CONFIG_RH_PROXY_PW=
CONFIG_SATELLITE_USER=
CONFIG_SATELLITE_PW=
CONFIG_SATELLITE_AKEY=
CONFIG_SATELLITE_CACERT=
CONFIG_SATELLITE_PROFILE=
CONFIG_SATELLITE_FLAGS=
CONFIG_SATELLITE_PROXY=
CONFIG_SATELLITE_PROXY_USER=
CONFIG_SATELLITE_PROXY_PW=
CONFIG_SSL_CACERT_FILE=/etc/pki/tls/
certs/selfcert.crt
CONFIG_SSL_CACERT_KEY_FILE=/etc/pki/tls/
private/selfkey.key
CONFIG_SSL_CERT_DIR=~/packstackca/
CONFIG_SSL_CACERT_SELFSIGN=y
CONFIG_SELFSIGN_CACERT_SUBJECT_C=--
CONFIG_SELFSIGN_CACERT_SUBJECT_ST=State
CONFIG_SELFSIGN_CACERT_SUBJECT_L=City
CONFIG_SELFSIGN_CACERT_SUBJECT_
O=openstack
CONFIG_SELFSIGN_CACERT_SUBJECT_
OU=packstack
CONFIG_SELFSIGN_CACERT_SUBJECT_
CN=localhost.localdomain
CONFIG_SELFSIGN_CACERT_SUBJECT_
MAIL=admin@localhost.localdomain
CONFIG_AMQP_BACKEND=rabbitmq
CONFIG_AMQP_HOST=172.16.101.2
CONFIG_AMQP_ENABLE_SSL=n
CONFIG_AMQP_ENABLE_AUTH=n
CONFIG_AMQP_NSS_CERTDB_PW=password
CONFIG_AMQP_AUTH_USER=amqp_user
CONFIG_AMQP_AUTH_PASSWORD=password
CONFIG_MARIADB_HOST=172.16.101.2
CONFIG_MARIADB_USER=root
CONFIG_MARIADB_PW=password
CONFIG_KEYSTONE_DB_PW=password
CONFIG_KEYSTONE_REGION=RegionOne
CONFIG_KEYSTONE_ADMIN_TOKEN=9b45b4987ca04
d889203287691c11f1e
CONFIG_KEYSTONE_ADMIN_EMAIL=root@
localhost
CONFIG_KEYSTONE_ADMIN_USERNAME=admin
CONFIG_KEYSTONE_ADMIN_PW=password
CONFIG_KEYSTONE_DEMO_PW=password
CONFIG_KEYSTONE_API_VERSION=v2.0
CONFIG_KEYSTONE_TOKEN_FORMAT=UUID
CONFIG_KEYSTONE_SERVICE_NAME=keystone
CONFIG_KEYSTONE_IDENTITY_BACKEND=sql
CONFIG_KEYSTONE_LDAP_
URL=ldap://172.16.101.2
CONFIG_KEYSTONE_LDAP_USER_DN=
CONFIG_KEYSTONE_LDAP_USER_PASSWORD=
CONFIG_KEYSTONE_LDAP_SUFFIX=
CONFIG_KEYSTONE_LDAP_QUERY_SCOPE=one
CONFIG_KEYSTONE_LDAP_PAGE_SIZE=-1
CONFIG_KEYSTONE_LDAP_USER_SUBTREE=
CONFIG_KEYSTONE_LDAP_USER_FILTER=
CONFIG_KEYSTONE_LDAP_USER_OBJECTCLASS=
CONFIG_KEYSTONE_LDAP_USER_ID_ATTRIBUTE=
CONFIG_KEYSTONE_LDAP_USER_NAME_
ATTRIBUTE=
CONFIG_KEYSTONE_LDAP_USER_MAIL_
ATTRIBUTE=
CONFIG_KEYSTONE_LDAP_USER_ENABLED_
ATTRIBUTE=
CONFIG_KEYSTONE_LDAP_USER_ENABLED_MASK=-
1
CONFIG_KEYSTONE_LDAP_USER_ENABLED_
DEFAULT=TRUE
```

```
CONFIG_KEYSTONE_LDAP_USER_ENABLED_
INVERT=n
CONFIG_KEYSTONE_LDAP_USER_ATTRIBUTE_
IGNORE=
CONFIG_KEYSTONE_LDAP_USER_DEFAULT_
PROJECT_ID_ATTRIBUTE=
CONFIG_KEYSTONE_LDAP_USER_ALLOW_CREATE=n
CONFIG_KEYSTONE_LDAP_USER_ALLOW_UPDATE=n
CONFIG_KEYSTONE_LDAP_USER_ALLOW_DELETE=n
CONFIG_KEYSTONE_LDAP_USER_PASS_
ATTRIBUTE=
CONFIG_KEYSTONE_LDAP_USER_ENABLED_
EMULATION_DN=
CONFIG_KEYSTONE_LDAP_USER_ADDITIONAL_
ATTRIBUTE_MAPPING=
CONFIG_KEYSTONE_LDAP_GROUP_SUBTREE=
CONFIG_KEYSTONE_LDAP_GROUP_FILTER=
CONFIG_KEYSTONE_LDAP_GROUP_OBJECTCLASS=
CONFIG_KEYSTONE_LDAP_GROUP_ID_ATTRIBUTE=
CONFIG_KEYSTONE_LDAP_GROUP_NAME_
ATTRIBUTE=
CONFIG_KEYSTONE_LDAP_GROUP_MEMBER_
ATTRIBUTE=
CONFIG_KEYSTONE_LDAP_GROUP_DESC_
ATTRIBUTE=
CONFIG_KEYSTONE_LDAP_GROUP_ATTRIBUTE_
IGNORE=
CONFIG_KEYSTONE_LDAP_GROUP_ALLOW_
CREATE=n
CONFIG_KEYSTONE_LDAP_GROUP_ALLOW_
UPDATE=n
CONFIG_KEYSTONE_LDAP_GROUP_ALLOW_
DELETE=n
CONFIG_KEYSTONE_LDAP_GROUP_ADDITIONAL_
ATTRIBUTE_MAPPING=
CONFIG_KEYSTONE_LDAP_USE_TLS=n
CONFIG_KEYSTONE_LDAP_TLS_CACERTDIR=
CONFIG_KEYSTONE_LDAP_TLS_CACERTFILE=
CONFIG_KEYSTONE_LDAP_TLS_REQ_CERT=demand
CONFIG_GLANCE_DB_PW=password
CONFIG_GLANCE_KS_PW=password
CONFIG_GLANCE_BACKEND=file
CONFIG_CINDER_DB_PW=2e6edd7b3d834fe1
CONFIG_CINDER_KS_PW=b7c18d9ac44d4f67
CONFIG_CINDER_BACKEND=lvm
CONFIG_CINDER_VOLUMES_CREATE=y
CONFIG_CINDER_VOLUMES_SIZE=20G
CONFIG_CINDER_GLUSTER_MOUNTS=
CONFIG_CINDER_NFS_MOUNTS=
CONFIG_CINDER_NETAPP_LOGIN=
CONFIG_CINDER_NETAPP_PASSWORD=
CONFIG_CINDER_NETAPP_HOSTNAME=
CONFIG_CINDER_NETAPP_SERVER_PORT=80
CONFIG_CINDER_NETAPP_STORAGE_
FAMILY=ontap_cluster
CONFIG_CINDER_NETAPP_TRANSPORT_TYPE=http
CONFIG_CINDER_NETAPP_STORAGE_
PROTOCOL=nfs
CONFIG_CINDER_NETAPP_SIZE_MULTIPLIER=1.0
CONFIG_CINDER_NETAPP_EXPIRY_THRES_
MINUTES=720
CONFIG_CINDER_NETAPP_THRES_AVL_SIZE_
PERC_START=20
CONFIG_CINDER_NETAPP_THRES_AVL_SIZE_
PERC_STOP=60
CONFIG_CINDER_NETAPP_NFS_SHARES=
CONFIG_CINDER_NETAPP_NFS_SHARES_CONFIG=/
etc/cinder/shares.conf
CONFIG_CINDER_NETAPP_VOLUME_LIST=
CONFIG_CINDER_NETAPP_VFILER=
CONFIG_CINDER_NETAPP_PARTNER_BACKEND_
NAME=
CONFIG_CINDER_NETAPP_VSERVER=
CONFIG_CINDER_NETAPP_CONTROLLER_IPS=
CONFIG_CINDER_NETAPP_SA_PASSWORD=
CONFIG_CINDER_NETAPP_ESERIES_HOST_
TYPE=linux_dm_mp
CONFIG_CINDER_NETAPP_WEBSERVICE_PATH=/
devmgr/v2
CONFIG_CINDER_NETAPP_STORAGE_POOLS=
CONFIG_MANILA_DB_PW=password
CONFIG_MANILA_KS_PW=password
CONFIG_MANILA_BACKEND=generic
CONFIG_MANILA_NETAPP_DRV_HANDLES_SHARE_
SERVERS=false
CONFIG_MANILA_NETAPP_TRANSPORT_
TYPE=https
CONFIG_MANILA_NETAPP_LOGIN=admin
CONFIG_MANILA_NETAPP_PASSWORD=
CONFIG_MANILA_NETAPP_SERVER_HOSTNAME=
CONFIG_MANILA_NETAPP_STORAGE_
FAMILY=ontap_cluster
CONFIG_MANILA_NETAPP_SERVER_PORT=443
CONFIG_MANILA_NETAPP_AGGREGATE_NAME_
SEARCH_PATTERN=(.*)
CONFIG_MANILA_NETAPP_ROOT_VOLUME_
AGGREGATE=
CONFIG_MANILA_NETAPP_ROOT_VOLUME_
NAME=root
CONFIG_MANILA_NETAPP_VSERVER=
CONFIG_MANILA_GENERIC_DRV_HANDLES_SHARE_
SERVERS=true
CONFIG_MANILA_GENERIC_VOLUME_NAME_
TEMPLATE=manila-share-%s
CONFIG_MANILA_GENERIC_SHARE_MOUNT_PATH=/
shares
CONFIG_MANILA_SERVICE_IMAGE_
LOCATION=https://www.dropbox.com/s/
vi5oeh10q1qkckh/ubuntu_1204_nfs_cifs.
qcow2
CONFIG_MANILA_SERVICE_INSTANCE_
USER=ubuntu
CONFIG_MANILA_SERVICE_INSTANCE_
PASSWORD=ubuntu
CONFIG_MANILA_NETWORK_TYPE=neutron
CONFIG_MANILA_NETWORK_STANDALONE_
GATEWAY=
CONFIG_MANILA_NETWORK_STANDALONE_
NETMASK=
CONFIG_MANILA_NETWORK_STANDALONE_SEG_ID=
CONFIG_MANILA_NETWORK_STANDALONE_IP_
RANGE=
CONFIG_MANILA_NETWORK_STANDALONE_IP_
VERSION=4
CONFIG_IRONIC_DB_PW=password
CONFIG_IRONIC_KS_PW=password
```

```
CONFIG_NOVA_DB_PW=password
CONFIG_NOVA_KS_PW=password
CONFIG_NOVA_SCHED_CPU_ALLOC_RATIO=16.0
CONFIG_NOVA_SCHED_RAM_ALLOC_RATIO=1.5
CONFIG_NOVA_COMPUTE_MIGRATE_PROTOCOL=tcp
CONFIG_NOVA_COMPUTE_MANAGER=nova.
compute.manager.ComputeManager
CONFIG_VNC_SSL_CERT=
CONFIG_VNC_SSL_KEY=
CONFIG_NOVA_COMPUTE_PRIVIF=eno2
CONFIG_NOVA_NETWORK_MANAGER=nova.
network.manager.FlatDHCPManager
CONFIG_NOVA_NETWORK_PUBIF=eno1
CONFIG_NOVA_NETWORK_PRIVIF=eno2
CONFIG_NOVA_NETWORK_
FIXEDRANGE=192.168.32.0/22
CONFIG_NOVA_NETWORK_
FLOATRANGE=10.3.4.0/22
CONFIG_NOVA_NETWORK_
AUTOASSIGNFLOATINGIP=n
CONFIG_NOVA_NETWORK_VLAN_START=100
CONFIG_NOVA_NETWORK_NUMBER=1
CONFIG_NOVA_NETWORK_SIZE=255
CONFIG_NEUTRON_KS_PW=password
CONFIG_NEUTRON_DB_PW=password
CONFIG_NEUTRON_L3_EXT_BRIDGE=br-ex
CONFIG_NEUTRON_METADATA_PW=password
CONFIG_LBAAS_INSTALL=n
CONFIG_NEUTRON_METERING_AGENT_INSTALL=n
CONFIG_NEUTRON_FWAAS=n
CONFIG_NEUTRON_ML2_TYPE_DRIVERS=vxlan
CONFIG_NEUTRON_ML2_TENANT_NETWORK_
TYPES=vxlan
CONFIG_NEUTRON_ML2_MECHANISM_
DRIVERS=openvswitch
CONFIG_NEUTRON_ML2_FLAT_
NETWORKS=external
CONFIG_NEUTRON_ML2_VLAN_
RANGES=physnet1:2:1000
CONFIG_NEUTRON_ML2_TUNNEL_ID_RANGES=
CONFIG_NEUTRON_ML2_VXLAN_
GROUP=239.1.1.100
CONFIG_NEUTRON_ML2_VNI_RANGES=1001:2000
CONFIG_NEUTRON_L2_AGENT=openvswitch
CONFIG_NEUTRON_LB_INTERFACE_MAPPINGS=
CONFIG_NEUTRON_OVS_BRIDGE_
MAPPINGS=external:br-ex,physnet1:br-vlan
CONFIG_NEUTRON_OVS_BRIDGE_IFACES=br-
ex:eno1,br-vlan:eno4
CONFIG_NEUTRON_OVS_TUNNEL_IF=eno3
CONFIG_NEUTRON_OVS_VXLAN_UDP_PORT=4789
CONFIG_HORIZON_SSL=n
CONFIG_HORIZON_SECRET_KEY=989819e547564b0
ba3fc1b4a6778ebdf
CONFIG_HORIZON_SSL_CERT=
CONFIG_HORIZON_SSL_KEY=
CONFIG_HORIZON_SSL_CACERT=
CONFIG_SWIFT_KS_PW=password
CONFIG_SWIFT_STORAGES=
CONFIG_SWIFT_STORAGE_ZONES=1
CONFIG_SWIFT_STORAGE_REPLICAS=1
CONFIG_SWIFT_STORAGE_FSTYPE=ext4
CONFIG_SWIFT_HASH=6ec5f52beb214f4a
CONFIG_SWIFT_STORAGE_SIZE=2G
CONFIG_HEAT_DB_PW=password
CONFIG_HEAT_AUTH_ENC_KEY=2fffb5d89b5947a7
CONFIG_HEAT_KS_PW=password
CONFIG_HEAT_CLOUDWATCH_INSTALL=n
CONFIG_HEAT_CFN_INSTALL=n
CONFIG_HEAT_DOMAIN=heat
CONFIG_HEAT_DOMAIN_ADMIN=heat_admin
CONFIG_HEAT_DOMAIN_PASSWORD=password
CONFIG_PROVISION_DEMO=n
CONFIG_PROVISION_TEMPEST=n
CONFIG_PROVISION_DEMO_
FLOATRANGE=172.24.4.224/28
CONFIG_PROVISION_IMAGE_NAME=cirros
CONFIG_PROVISION_IMAGE_URL=http://
download.cirros-cloud.net/0.3.3/cirros-
0.3.3-x86_64-disk.img
CONFIG_PROVISION_IMAGE_FORMAT=qcow2
CONFIG_PROVISION_IMAGE_SSH_USER=cirros
CONFIG_PROVISION_TEMPEST_USER=
CONFIG_PROVISION_TEMPEST_USER_PW=PW_
PLACEHOLDER
CONFIG_PROVISION_TEMPEST_
FLOATRANGE=172.24.4.224/28
CONFIG_PROVISION_TEMPEST_REPO_URI=https://
github.com/openstack/tempest.git
CONFIG_PROVISION_TEMPEST_REPO_
REVISION=master
CONFIG_PROVISION_ALL_IN_ONE_OVS_BRIDGE=n
CONFIG_CEILOMETER_SECRET=3bd14fee29614097
CONFIG_CEILOMETER_KS_PW=c7836c856272421a
CONFIG_CEILOMETER_COORDINATION_
BACKEND=redis
CONFIG_MONGODB_HOST=172.16.101.2
CONFIG_REDIS_MASTER_HOST=172.16.101.2
CONFIG_REDIS_PORT=6379
CONFIG_REDIS_HA=n
CONFIG_REDIS_SLAVE_HOSTS=
CONFIG_REDIS_SENTINEL_HOSTS=
CONFIG_REDIS_SENTINEL_CONTACT_HOST=
CONFIG_REDIS_SENTINEL_PORT=26379
CONFIG_REDIS_SENTINEL_QUORUM=2
CONFIG_REDIS_MASTER_NAME=mymaster
CONFIG_SAHARA_DB_PW=PW_PLACEHOLDER
CONFIG_SAHARA_KS_PW=PW_PLACEHOLDER
CONFIG_TROVE_DB_PW=PW_PLACEHOLDER
CONFIG_TROVE_KS_PW=PW_PLACEHOLDER
CONFIG_TROVE_NOVA_USER=trove
CONFIG_TROVE_NOVA_TENANT=services
CONFIG_TROVE_NOVA_PW=PW_PLACEHOLDER
CONFIG_NAGIOS_PW=password
```

Appendix B: Create OpenStack Networks and Router

Execute the following commands to create the OpenStack public network.

```
# neutron net-create public
--provider:network_type flat \
      --provider:physical_network
external --router:external=True
# neutron subnet-create public
10.2.125.0/24 --name public_subnet \
      --gateway 10.2.125.1 --allocation-
pool \
      start=10.2.125.236,end=10.2.125.240
--enable-dhcp=False
```

Execute the following commands to create the OpenStack private network.

```
# neutron net-create private
# neutron subnet-create private
172.16.111.0/24 \
      --name private_subnet
```

Execute the following commands to create the OpenStack router, add an interface to the private subnet, and set the default gateway.

```
# neutron router-create myrouter
# neutron router-gateway-set myrouter
public
# neutron router-interface-add myrouter
private_subnet
```

Execute the following commands to create the VLAN network with the VLAN identifier set to 2.

```
# neutron net-create net-vlan-2
--provider:network_type vlan \
      --provider:physical_network
physnet1 \
            --provider:segmentation_id 2
--router:external —shared
# neutron subnet-create net-vlan-2
20.20.20.0/24 \
      —name net-vlan2-subnet —no-gateway
—allocation-pool \
      start=20.20.20.10,end=20.20.20.100 —
enable-dhcp=False
```

The following table explains the values of parameters used in the commands above.

ABBREVIATION	DESCRIPTION
public	Name of the external/public network
flat	Network type for the public network
external	Physical network for the public network
10.2.125.0/24	CIDR of the public network
public_subnet	Name of the public subnet
10.2.125.1	IP address of the gateway for the public subnet
10.2.125.236	Starting IP address in the allocation pool for the public subnet
10.2.125.240	The last IP address in the allocation pool for the public subnet
private	Name of the private network
172.16.111.0/24	CIDR of the private network
private_subnet	Name of the private subnet
myrouter	Name of the OpenStack router
net-vlan-2	Name of the VLAN network
physnet1	Physical network for the VLAN type network
2	VLAN identifier of VLAN network
net-vlan2-subnet	Name of the VLAN subnet
20.20.20.0/24	CIDR of the VLAN subnet
20.20.20.10	Starting IP in the allocation pool for the VLAN subnet
20.20.20.100	The last IP address in the allocation pool for the VLAN subnet

Appendix C: Basic Configuration of Brocade 5600 vRouter

The following steps describe how to configure the Brocade 5600 vRouter VM.

1. Download the Brocade 5600 vRouter qcow2 image file. The command below can be used to import this image to the OpenStack Image Service.

```
# glance image-create --name="Brocade
5600 vRouter" --is-public=true
--container-format=bare --disk-
format=qcow2--progress < vyatta_vrouter.
qcow2
```

2. Use the OpenStack dashboard to spawn the Brocade 5600 vRouter VM on all the desired subnets.

3. Once the Brocade 5600 vRouter VM is booted, connect to its console using the OpenStack dashboard. Use the credentials `vyatta/vyatta` to log in to the router VM.

   In the following example, the Brocade 5600 vRouter VM is spawned on VLAN2 and public networks, and have two interfaces, `dp0s4` and `dp0s6`. The interface dp0s4 is directly connected to the VLAN 2 subnet with an IP address of `20.20.20.10/24`. The interface `dp0s6` is directly connected to the public network and have an IP address of `10.250.100.236`.

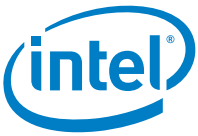
```
vyatta@R1# set system name-server 8.8.4.4
vyatta@R1# set system name-server 4.2.2.2
vyatta@R1# set system name-server 4.2.2.1
vyatta@R1# set interfaces dataplane dp0s6
address 10.250.100.236/24
vyatta@R1# set service nat source rule 10
source address 20.20.20.0/24
[edit]
vyatta@R1# set service nat source rule 10
outbound-interface dp0s6
[edit]
vyatta@R1# set service nat source rule 10
translation address masquerade
[edit]
vyatta@R1# commit
[edit]
vyatta@R1# set protocols static route
0.0.0.0/0 next-hop 10.250.100.1 interace
dp0s6
vyatta@R1# commit
[edit]
```

The commands above set:

- Public DNS, that is, `8.8.4.4`, `4.2.2.2`, and `4.2.2.1`, in the router VM
- Network address translation rules for the VLAN2 network
- Default gateway in the router to `10.250.100.1` to provide Internet access to the VMs spawned on VLAN2 network

Appendix D: Abbreviations

PARAMETER VALUE	DESCRIPTION
BIOS	Basic Input/Output System
CIDR	Classless Inter-Domain Routing
COTS	Commercial Off-the-Shelf
CPU	Central Processing Unit
DHCP	Dynamic Host Configuration Protocol
DPDK	Data Plane Development Kit
ICMP	Internet Control Message Protocol
IP	Internet Protocol
LC	Logical Core
netdev	Network Device
NFV	Network Functions Virtualization
NFVI	NFV Infrastructure
NIC	Network Interface Card
NUMA	Non-Uniform Memory Architecture
OS	Operating System
OVS-DPDK	DPDK-Accelerated Open vSwitch
PCI	Peripheral Component Interconnect
PMD	Poll Mode Driver
PoC	Proof-of-Concept
QEMU	Quick Emulator
TCP	Transmission Control Protocol
TLB	Transaction Lookaside Buffer
TSO	TCP Segmentation Offload
UDP	User Datagram Protocol
URL	Uniform Resource Locator
UUID	Universally Unique Identifier
VLAN	Virtual Local Area Network
VM	Virtual Machine
VNF	Virtual Network Function
vSwitch	Virtual Switch
VxLAN	Virtual eXtensible LAN



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