Using Intel VMD Direct Assign with VMware ESXi on Lenovo ThinkSystem Servers

Introduces the features of VMD Direct Assign

Explains which Lenovo servers support the feature

Provides instructions on how to configure VMD Direct Assign in VMware ESXi

Describes how to verify operation of VMD Direct Assign in a virtual machine

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Abstract

Intel VMD Direct Assign is a specific application of Intel VMD that aims to improve the storage experience in Hyperconverged Infrastructure (HCI) architecture. It takes the isolated storage subsystem and bypasses the hypervisor to assign Intel VMD controller directly to a virtual machine running on the host.

This document provides a brief overview of the Intel VMD direct assign and describes how to configure and use VMD direct assign in VMware ESXi 7.0 on Lenovo® ThinkSystem™ servers. This document is intended for IT specialists and IT managers who are familiar with VMware vSphere products.

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Contents

Introduction

Intel VMD (Volume Management Device) is a feature introduced with the Intel Xeon Scalable processor family to help manage NVMe drives and provides features such as surprise hot plug, LED management, error isolation and bootable RAID. VMD is for NVMe drives directly connected to the processor or PCH PCIe lanes and allows direct control and management from PCIe bus without additional hardware adaptors.

VMD maps the entire PCIe subtree into its own address space, enabling it to setup and manage the domain controlled by VMD driver and is enabled in UEFI. As Figure 1 shows, each root port consists of a x16 grouping of PCIe lanes that create a single VMD Domain. Root Ports act like an integrated HBA to provide a robust foundation to support the NVMe ecosystem.

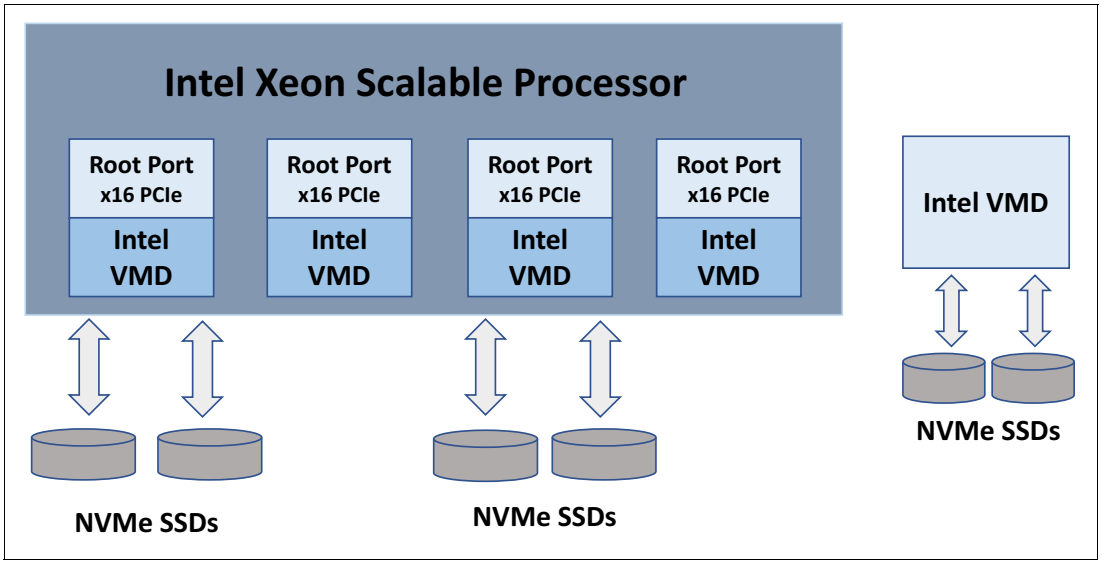

Figure 1 Intel VMD

Hypervisor technology has evolved to functionally divide bare metal server resources into virtual machines for increased IT flexibility and maximize hardware utilization. However, the resource management can cause increased latency and decreased performance for certain components.

Intel VMD Direct Assign is a specific application of VMD that aims to improve the storage experience in Hyperconverged Infrastructure (HCI) architecture. As Figure 2 on page 4 shows, VMD Direct Assign takes the isolated storage subsystem and bypasses the hypervisor to assign a VMD controller directly to a virtual machine running on the host.

Each Intel VMD controller can be assigned to a maximum of 1 VM and the VM inherits the functionality of Intel VMD and the performance of the NVMe drives, without the storage bottleneck of the hypervisor.

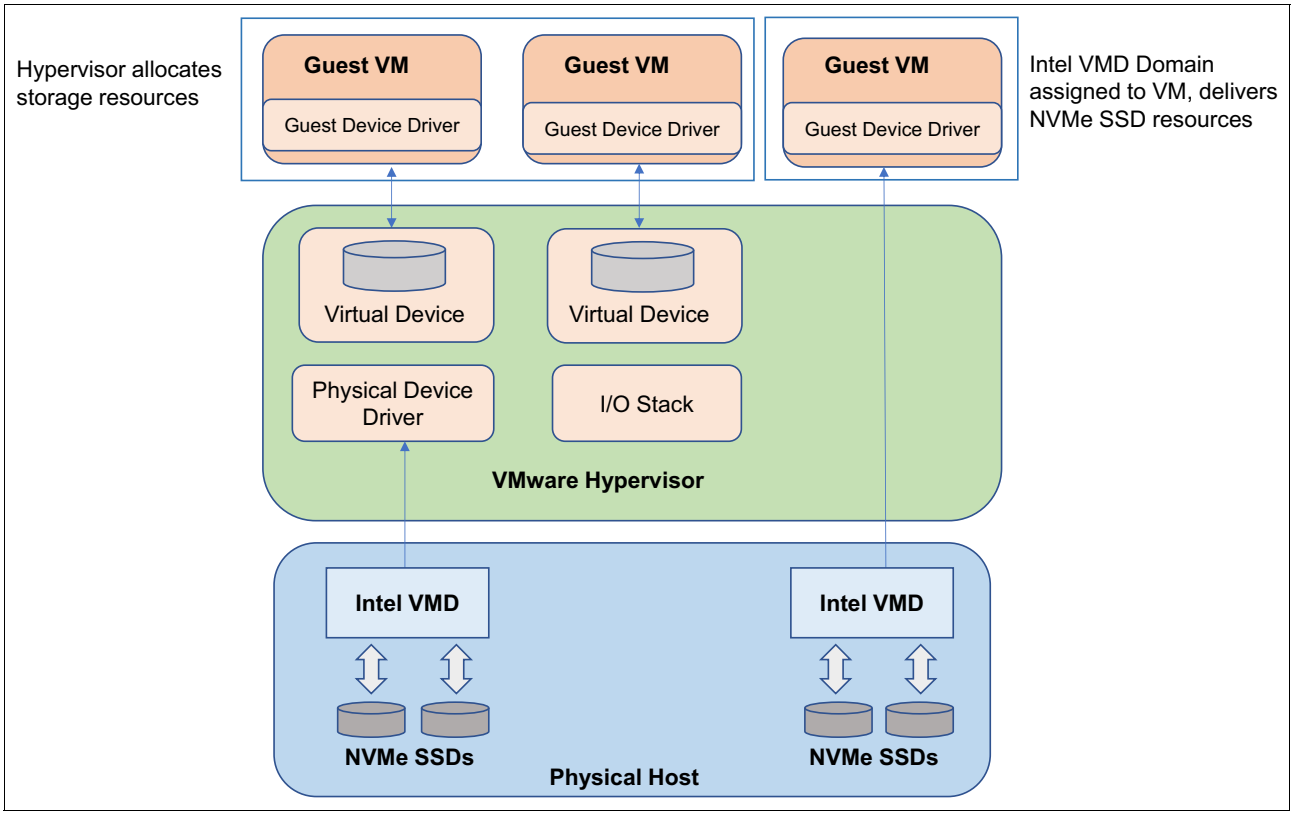

Figure 2 Intel VMD Direct Assign

For more details about the Intel VMD, visit:

https://www.intel.com/content/www/us/en/architecture-and-technology/intel-volume-management-device-overview.html

Table 1 lists the Lenovo ThinkSystem servers with third-generation Intel Xeon scalable processor (codename: IceLake) and minimum version fo UEFI firmware that supports the Intel VMD Direct Assign function.

Table 1 UEFI version support Intel VMD direct assign

Lenovo ThinkSystem Servers with third-gen Intel Xeon Scalable Processor (Ice Lake)	VMD Direct Assign function with VMware	Supported UEFI version
Lenovo ST650 V2 Server	Supported	1.02 or later
Lenovo SR630 V2 Server	Supported	1.02 or later
Lenovo SR650 V2 Server	Supported	1.02 or later
Lenovo SR670 V2 Server	Supported	1.02 or later
Lenovo SD630 V2 Server	Supported	1.02 or later
Lenovo SD650 V2 Server	No Support[a]	N/A
Lenovo SD650-N V2 Server	No Support[a]	N/A

Lenovo ThinkSystem Servers with third-gen Intel Xeon Scalable Processor (Ice Lake)	VMD Direct Assign function with VMware	Supported UEFI version
Lenovo SN550 V2 Server	Supported	1.02 or later

a. Lenovo SD650 V2 and SD650-N V2 servers do not support VMware ESXi

For more information about how to update firmware in Lenovo ThinkSystem servers, refer to the following Lenovo support page:

https://datacentersupport.lenovo.com/us/en/solutions/ht511325

While VMware ESXi allows virtual machine access to physical PCI functions on platform with an I/O memory management unit, some features such as suspend and resume, fault tolerance, snapshots become unavailable to the VM. Refer to VMware KB article for more information:

https://kb.vmware.com/s/article/2142307

In this paper, we will demonstrate Intel VMD Direct Assign on a ThinkSystem SD630 V2 server. As shown in Figure 3, the SD630 V2 supports either 2x 7mm 2.5-inch NVMe drives or 1x 15mm 2.5-inch NVMe drive directly connected to the PCIe ports on the system board.

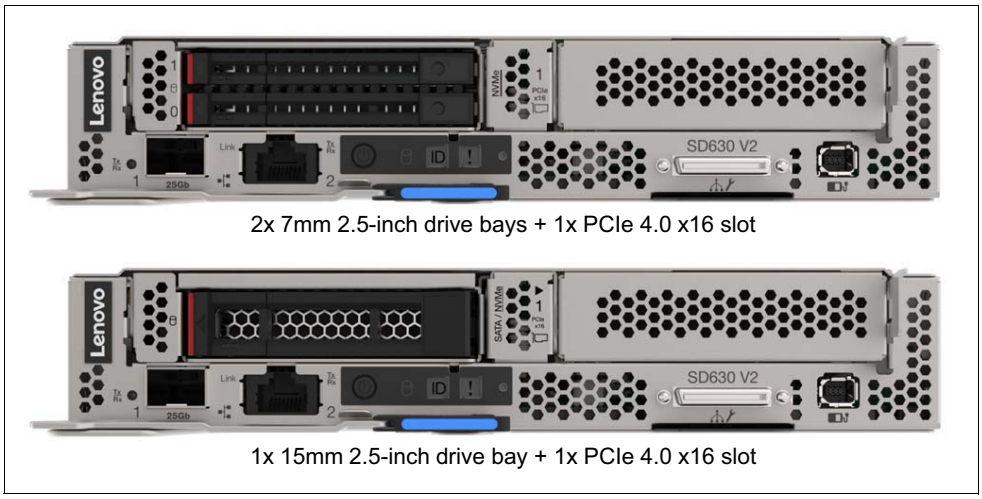

Figure 3 Front panel view of Lenovo ThinkSystem SD630 V2 server

Table 2 lists the supported versions of VMware ESXi and guest operating systems.

Table 2 Supported versions for VMD Direct Assign

Supported VMware ESXi OS	Supported Guest OS
VMware ESXi 6.7 U3 VMware ESXi 7.0 U2 and newer	RHEL 8.0 and newer SLES 15 SP2 and newer

How to use VMD Direct Assign in VMware ESXi

This section describes the steps we took to configure and enable Intel VMD Direct Assign with VMware ESXi 7.0 U2. The configuration of our SD630 V2 test server is listed in Table 3 on page 6. The host OS was installed on the M.2 SATA SSD.

OS boot drive: The NVMe drive can't be the host OS installation device because it's under the VMD domain that will be assigned to the guest OS.

Table 3 ThinkSystem SD630 V2 server configuration

Component	Configuration
Server	ThinkSystem SD630 V2 Server
CPU	2x Intel Xeon Scalable Processors 3rd Generation Platinum 8352V CPU @2.10 GHz
Memory	2x DDR4 3200 MHz 16GB RDIMM
M.2 SATA	1x M.2 240GB SATA 6Gbps SSD
NVMe drive	1x Intel P4510 1.0 TB 2.5-inch 15mm NVMe
Host hypervisor OS	ESXi 7.0 U2 Custom Image for Lenovo ThinkSystem
Guest VM OS	RHEL 8 U2

Step 1: Determine VMD controller PCI address in the system

First, we have to enable VMD function in UEFI setup menu and find out the PCI address of VMD controller in the system.

1. Power on the system and enter UEFI setup menu by pressing F1 key during system boot.
2. Select **System Settings** → **Devices and I/O Ports** → **Intel VT for Directed I/O (VT-d)** and make sure the option is set to Enabled as shown in Figure 4.

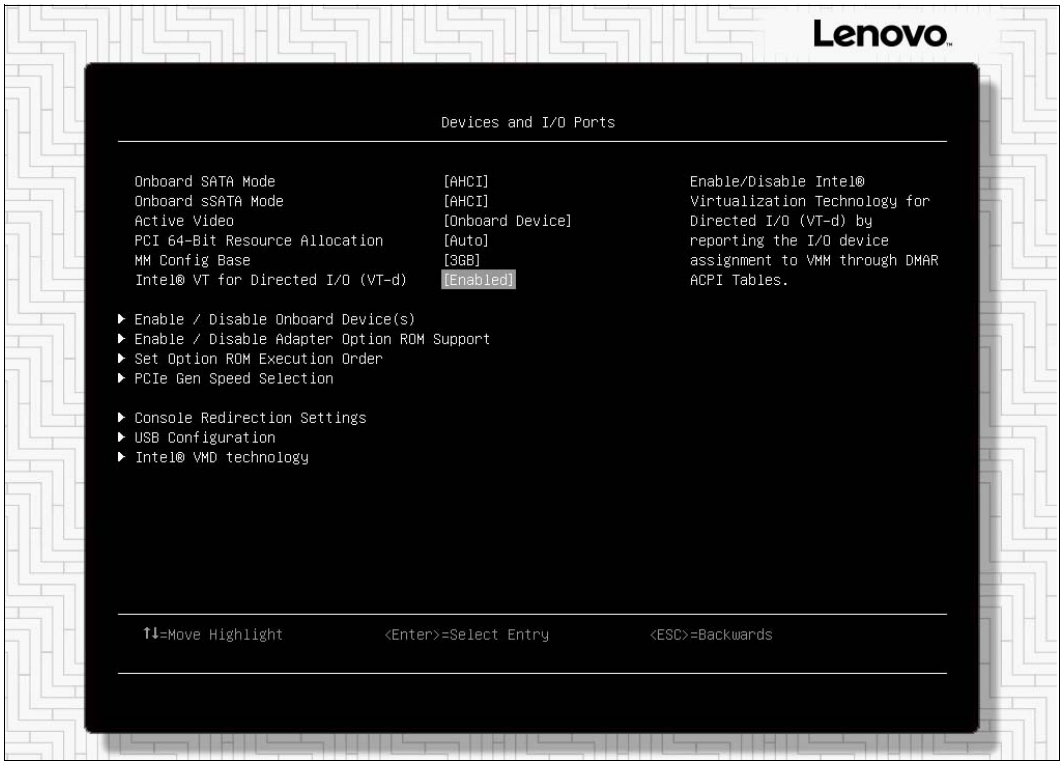

Figure 4 Intel VT-d option set to Enabled

3. Select Intel VMD Technology setting and set the option **Enable/Disable Intel VMD** to Enabled as shown in Figure 5.

Figure 5 Intel VMD option set to Enabled

4. Reboot the system to take effect, and then enter UEFI setup menu by pressing F1 key.
5. Go to **System Settings** → **Storage** → **Intel Virtual RAID on CPU** → **All Intel VMD Controllers**, select the Non-RAID Physical Disk and the Physical Disk Info window will appear. VMD controller PCI address is listed as “C2:00.5” as shown in Figure 6.

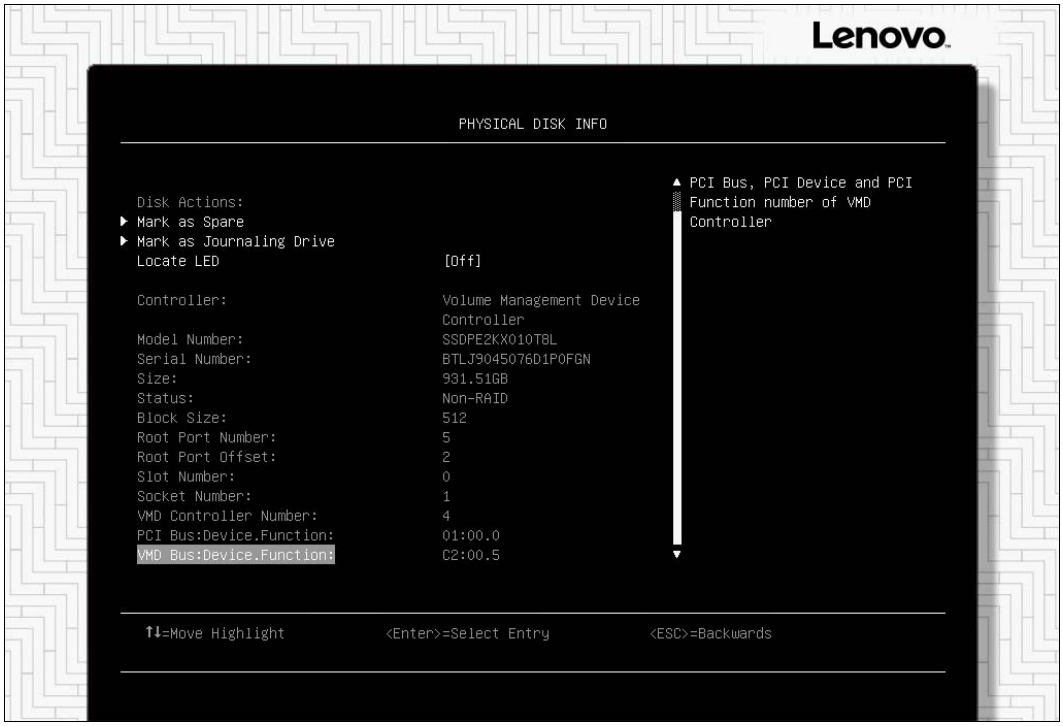

Figure 6 VMD PCI address from UEFI menu

We can also find out the VMD controller PCI address by running the following command on the ESXi host from the shell:

```
~# lspci | grep -i “Volume Management Device”
```

The output of this command is shown in Figure 7.

```
[root@localhost:~] lspci|grep -i "Volume Management Device"
0000:c2:00.5 RAID bus controller: Intel Corporation Intel Volume Management Device [vmhba0]
[root@localhost:~]
```

Figure 7 VMD PCI address from shell

Step 2: Use OneCLI tool to enable uEFI VMD direct assign option

The UEFI option **VMD for Direct Assign** can be enabled by using the Lenovo XClarity™ Essentials OneCLI tool. Download the tool from the Lenovo Support site:

https://datacentersupport.lenovo.com/us/en/solutions/ht116433

Follows the steps below to enable UEFI setting VMD Direct Assign option from the operating system remotely:

1. Run the following OneCLI command to enable VMD direct assign:

   ~# ./OneCli config set DevicesandIOPorts.VMDforDirectAssign Enabled --imm <USERID>:<PASSWORD>@<IP>

   Figure 8 shows how to enable VMD direct assign option from operating system.

```
[root@alpus Onecli]# ./OneCli config set DevicesandIOPorts.VMDforDirectAssign Enabled --imm USERID:p@ssw0rd123@192.168.100.144

Lenovo XClarity Essentials OneCLI lxce_onecli01g-3.3.0
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OneCLI License Agreement and OneCLI Legal Information can be found at the following location:
    "/root/Desktop/Ultron/OneCLI/Onecli/Lic"

[1s]Certificate check finished [100%][=============================================================================================>]

Invoking SET command ...
Connected to BMC at IP address 192.168.100.144 by IPMI
DevicesandIOPorts.VMDforDirectAssign=Enabled
Changes completed successfully, but these changes will not take effect until next reboot.
Succeed.
[root@alpus Onecli]#
```

Figure 8 Enable VMD direct assign option via OneCLI command

2. Reboot the system
3. Run the following OneCLI command to make sure that VMD direct assign option is enabled in the system.

   ~# ./OneCli config show DevicesandIOPorts.VMDforDirectAssign --imm <USERID>:<PASSWORD>@<IP>

   Figure 9 shows VMD direct assign option is enabled in the system

```
[root@alpus Onecli]# ./OneCli config show DevicesandIOPorts.VMDforDirectAssign --imm USERID:p@ssw0rd123@192.168.100.144

Lenovo XClarity Essentials OneCLI lxce_onecli01g-3.3.0
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OneCLI License Agreement and OneCLI Legal Information can be found at the following location:
    "/root/Desktop/Ultron/OneCLI/Onecli/Lic"

[1s]Certificate check finished [100%][=============================================================================================>]

Invoking SHOW command ...
Connected to BMC at IP address 192.168.100.144 by IPMI
DevicesandIOPorts.VMDforDirectAssign=Enabled
Succeed.
[root@alpus Onecli]#
```

Figure 9 Check VMD direct assign option via OneCLI command

Step 3: Toggle VMD passthrough in VMware ESXi OS

1. Boot the system to VMware ESXi 7.0 U2 OS, and add the following lines to the ESXi config file (/etc/vmware/passthru.map) of passthrough attributes for devices, where 8086 is VMD controller vendor ID and 28C0 is VMD controller device ID in the Intel IceLake platform.

   ```
   8086 28C0 d3d0 default
   ```

   The passthru.map file is shown in Figure 10.

```
#
# - resetMethod: override for the type of reset to apply to a PCI device.
#   Bus reset and link reset prevent functions in a multi-function
#   device from being assigned to different virtual machines, or from
#   being assigned between the VMkernel and virtual machines. In
#   some devices it's possible to use PCI power management capability
#   D3->D0 transitions to reset the device. In the absence of the
#   override, the VMkernel decides the type of PCI reset to apply
#   based on the device's capabilities. The VMkernel prioritizes
#   function level reset (flr).
#
# Restrictions:
#
# - PCI SR-IOV physical and virtual functions (PFs/VFs) are not allowed
#   in the list below. Those must support function-level-reset and
#   must be shareable.
#

# Intel 82579LM Gig NIC can be reset with d3d0
8086  1502  d3d0     default
# Intel 82598 10Gig cards can be reset with d3d0
8086  10b6  d3d0     default
8086  10c6  d3d0     default
8086  10c7  d3d0     default
8086  10c8  d3d0     default
8086  10dd  d3d0     default
# Broadcom 57710/57711/57712 10Gig cards are not shareable
14e4  164e  default  false
14e4  164f  default  false
14e4  1650  default  false
14e4  1662  link     false
# Qlogic 8Gb FC card can not be shared
1077  2532  default  false
# LSILogic 1068 based SAS controllers
1000  0056  d3d0     default
1000  0058  d3d0     default
# NVIDIA
10de  ffff  bridge   false
# AMD FCH SATA Controller [AHCI mode]
1022  7901  d3d0     default

# Intel VMD Device with a quirk reset type workaround
8086  28c0  d3d0     default
[root@localhost:~]
```

Figure 10 Edit config file /etc/vmware/passthru.map

2. Login to vSphere client and from the left-hand navigation menu, select **Manage** → **Hardware** → **PCI Devices** → **VMD device (PCI address: C2:00.5)** → **Toggle passthrough**. The status of Passthrough for VMD device is changed to **Active** as shown in Figure 11.

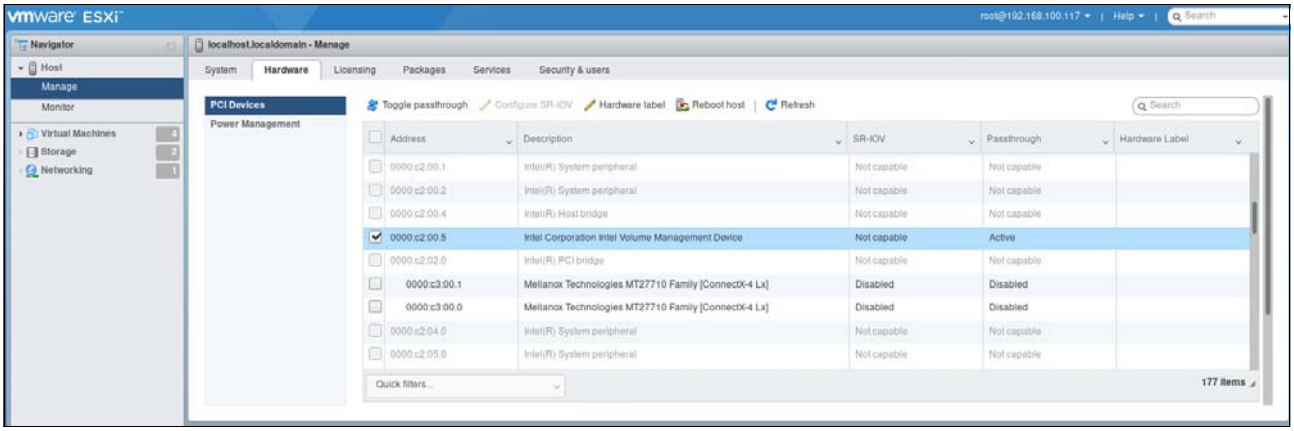

Figure 11 Toggle passthrough in VI client

3. Reboot the OS.

Step 4: Create RHEL 8.2 VM and add new PCI device

1. Create a new VM and install RHEL8.2 guest OS on the VM.
2. Before powering on the VM, select the VM and click the Edit button to edit settings of the VM, select Memory RAM 8 GB and check the box **Reserve all guest memory (all locked)**.
3. Click **Add other device** → **PCI device**, and add **Intel Volume Management Device - 0000:c2:00.5** as new PCI device. See Figure 12 on page 11.
4. Click **Save** to finish the settings.

Note that if there are multiple NVMe drives behind the VMD controller, they will be all assigned to the VM.

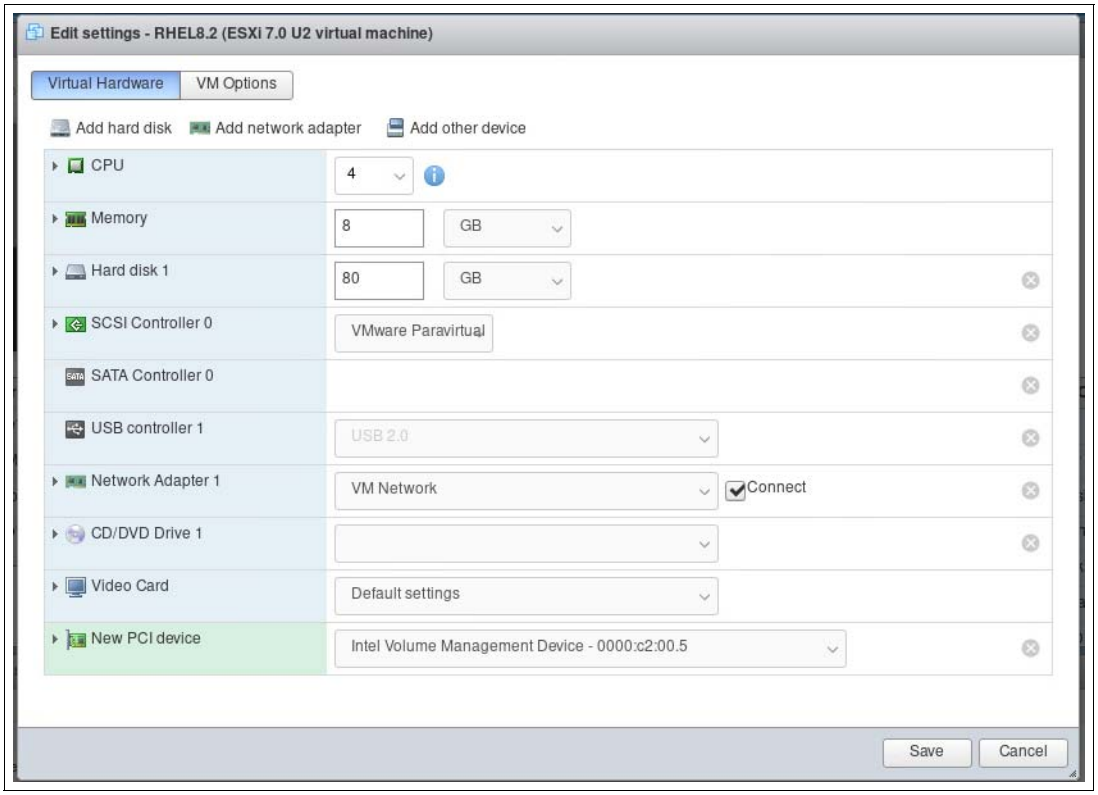

Figure 12 VM configuration

Step 5. Install Intel add-on VMD driver and add bootloader parameter

After the guest OS installation is completed, install the add-on VMD driver in the guest OS. This driver provides enhanced security features and optimized performance benefits.

1. Go to Intel website and download Intel the add-on VMD driver of VMD Direct Assign setup for RHEL 8.2 VM. Currently Intel provides an add-on VMD driver for RHEL 8.0 and newer, and SLES15 SP2 and newer.

   https://www.intel.com/content/www/us/en/search.html?ws=text#q=vmd&t=All

2. Use the following command from OS command line to install the VMD replacement driver

   ```
   ~# rpm -ivh kmod-iavmd-9.13.1.821-rhel_82.x86_64.rpm
   ```

   The output of the command is shown in Figure 13.

```
[root@localhost RHEL8_2_Signed_VMD_DA]# rpm -ivh kmod-iavmd-0.13.1.821-rhel_82.x86_64.rpm
warning: kmod-iavmd-0.13.1.821-rhel_82.x86_64.rpm: Header V4 RSA/SHA256 Signature, key ID c343c1b0: NOKEY
Verifying...                          ################################# [100%]
Preparing...                          ################################# [100%]
grub2-editenv: error: environment block too small.
grub2-editenv: error: environment block too small.
Updating / installing...
   1:kmod-iavmd-0.13.1.821-rhel_82    ################################# [100%]
[root@localhost RHEL8_2_Signed_VMD_DA]#
```

Figure 13 Install Intel add-on VMD driver

3. Modify OS bootloader GRUB configuration and add two boot parameters:

   ```
   initcall_blacklist=vmd_drv_init
   iavmd.direct_assign=1
   ```

   The first parameter is to tell OS to disable native VMD driver and use the add-on VMD driver.

   The second parameter is to pass driver parameter of allowing direct assignment of VMD controller from hypervisor to guest.

   After modification, the configuration file will be as shown in Figure 14.

```
[root@localhost ~]# cat /boot/grub2/grubenv
# GRUB Environment Block
saved_entry=72e3be8ec5014c5dae1fdedec28e7411-4.18.0-193.19.1el8.x86_64
boot_success=0
###############
kernelopts=root=/dev/mapper/rhel-root ro resume=/dev/mapper/rhel-swap rd.lvm.lv=
rhel/root rd.lvm.lv=rhel/swap biosdevname=0 net.ifnames=0 iavmd.direct_assign=1
initcall_blacklist=vmd_drv_init
################
[root@localhost ~]#
```

Figure 14 Modified OS bootloader configuration

4. Reboot the VM to take effect.

Test VMD Device in Guest OS

Now we can login as a root user, open a terminal and check if the VMD devices works properly in guest OS by using the following methods.

1. Check the OS log with the following command to make sure there are no error in the log.

   ```
   ~# dmesg | grep -i vmd
   ```

   The output is shown in Figure 15.

```
[root@localhost /]# dmesg|grep -i vmd
[    0.000000] Command line: BOOT_IMAGE=(hd0,gpt2)/vmlinuz-4.18.0-193.19.1.el8_2.x86_64 root=
/dev/mapper/rhel-root ro resume=/dev/mapper/rhel-swap rd.lvm.lv=rhel/root rd.lvm.lv=rhel/swap
 biosdevname=0 net.ifnames=0 iavmd.direct_assign=1 initcall_blacklist=vmd_drv_init
[    0.000000] Kernel command line: BOOT_IMAGE=(hd0,gpt2)/vmlinuz-4.18.0-193.19.1.el8_2.x86_6
4 root=/dev/mapper/rhel-root ro resume=/dev/mapper/rhel-swap rd.lvm.lv=rhel/root rd.lvm.lv=rh
el/swap biosdevname=0 net.ifnames=0 iavmd.direct_assign=1 initcall_blacklist=vmd_drv_init
[    0.000000] blacklisting initcall vmd_drv_init
[    1.242067] initcall vmd_drv_init blacklisted
[    1.701697] iavmd: loading out-of-tree module taints kernel.
[    1.702355] iavmd: module verification failed: signature and/or required key missing - tai
nting kernel
[    2.053083] vmd 0000:13:00.0: enabling device (0000 -> 0002)
[    2.080378] vmd 0000:13:00.0: PCI host bridge to bus 10000:00
[    2.182191] vmd 0000:13:00.0: Bound to PCI domain 10000
[root@localhost /]#
```

Figure 15 Check log in guest OS

2. Check NVMe drive existence with the following command

   ```
   ~# nvme list
   ```

The output is shown in Figure 16.

```
[root@localhost /]# nvme list
Node             SN                   Model                                    Namespace Usage                      F
ormat           FW Rev
---------------- -------------------- ---------------------------------------- --------- -------------------------- -
-------------- --------
/dev/nvme0n1     BTLJ9045076D1P0FGN   SSDPE2KX010T8L                           1          1.00  TB /   1.00  TB    5
12   B +  0 B   VDV1LY35
[root@localhost /]#
```

Figure 16 Check nvme drive

3. Check lspci command output with the following command to make sure VMD device and NVMe drive behind the VMD domain are listed.

   ~# lspci

   Output of the command is shown in Figure 17.

```
0000:00:17.3 PCI bridge: VMware PCI Express Root Port (rev 01)
0000:00:17.4 PCI bridge: VMware PCI Express Root Port (rev 01)
0000:00:17.5 PCI bridge: VMware PCI Express Root Port (rev 01)
0000:00:17.6 PCI bridge: VMware PCI Express Root Port (rev 01)
0000:00:17.7 PCI bridge: VMware PCI Express Root Port (rev 01)
0000:00:18.0 PCI bridge: VMware PCI Express Root Port (rev 01)
0000:00:18.1 PCI bridge: VMware PCI Express Root Port (rev 01)
0000:00:18.2 PCI bridge: VMware PCI Express Root Port (rev 01)
0000:00:18.3 PCI bridge: VMware PCI Express Root Port (rev 01)
0000:00:18.4 PCI bridge: VMware PCI Express Root Port (rev 01)
0000:00:18.5 PCI bridge: VMware PCI Express Root Port (rev 01)
0000:00:18.6 PCI bridge: VMware PCI Express Root Port (rev 01)
0000:00:18.7 PCI bridge: VMware PCI Express Root Port (rev 01)
0000:02:00.0 USB controller: VMware USB1.1 UHCI Controller
0000:02:01.0 USB controller: VMware USB2 EHCI Controller
0000:02:03.0 SATA controller: VMware SATA AHCI controller
0000:03:00.0 Serial Attached SCSI controller: VMware PVSCSI SCSI Controller (rev 02)
0000:0b:00.0 Ethernet controller: VMware VMXNET3 Ethernet Controller (rev 01)
0000:13:00.0 RAID bus controller: Intel Corporation Volume Management Device NVMe RA
ID Controller (rev 04)
10000:00:04.0 PCI bridge: Intel Corporation Device 347c (rev 04)
10000:00:05.0 PCI bridge: Intel Corporation Device 347d (rev 04)
10000:01:00.0 Non-Volatile memory controller: Intel Corporation NVMe Datacenter SSD
[3DNAND, Beta Rock Controller]
[root@localhost /]#
```

Figure 17 lspci command output

Resources

For additional information, see these resources:

- Intel Volume Management Device (Intel VMD)

  https://www.intel.com/content/www/us/en/architecture-and-technology/intel-volume-management-device-overview.html

- vSphere VMDirectPath I/O and Dynamic DirectPath I/O: Requirements for Platforms and Devices

  https://kb.vmware.com/s/article/2142307

- Lenovo ThinkSystem SD630 V2 Server Product Guide

  https://lenovopress.com/lp1394-thinksystem-sd630-v2-server

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- Chengcheng Peng, Lenovo VMware Engineer
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- Gary Cudak, Lenovo OS Architect
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