To study Linux and Hardware with QEMU

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When to study and debug SCSI ...

When to study the concept of SCSI <adapter, channel, id, lun> ...

- There is no SCSI hardware available
- To reboot the test server is time-consuming
- It is hard to customize SCSI topology (e.g., #lun or #target)
- It is hard to customize SCSI config (e.g., #queue for mq)

SCSI is not the end ...

We may want to study more **Linux and Hardware features**...

- SCSI
- NVMe
- NVDIMM
- Virtio
- Ethernet
- PCI and PCIe
- BIOS
- IOMMU
- NUMA
- CPU Hotplug
- Memroy Hotplug
- PM Suspend

Why QEMU

QEMU is a generic and open source machine emulator and virtualizer

- QEMU can emulate lots of hardware
- QEMU can boot from Linux kernel on host
  - It is time-consuming to build and install kernel in VM

This tutorial is **NOT** to...

- teach how to use QEMU cmdline
- how to build and debug kernel inside guest
- how to debug generic features like buddy allocator or CFS scheduler
- how to debug advanced features (e.g., qlogic) with QEMU
- what is SCSI, NVMe, NVDIMM ...

Build QEMU and Guest Linux

- QEMU version in the tutorial: commit **076243ffe6c1**
- Linux version in the tutorial: tag **v5.2-rc4**

To build Linux on host (All CONFIG is 'Y'):
make defconfig
make menuconfig
make -j8 > /dev/null

The output is something like:
/.../linux/arch/x86_64/boot/bzImage

To build QEMU:
./configure –target-list=x86_64-softmmu
make -j8 > /dev/null

We directly use output w/o 'make install':
./x86_64-softmmu/qemu-system-x86_64

Boot QEMU and Guest Linux

- No need to work with guest IP, but only <**host_ip**>**:5022**
- Connect to guest via **VNC**
- Serial console output is redirected to **stdio**

To boot guest with Linux kernel locating on host:

```
# qemu-system-x86_64 -machine accel=kvm -vnc :0 -serial stdio -smp 4 -m 4096M \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text console=ttyS0" \
-hda /home/user/img/boot.qcow2
```

To login to guest in another shell:

```
# ssh user@<host_ip> -p 5022
```

or

```
# vncviewer <host_ip>
```

SeaBIOS 1/2

- SeaBIOS is the default BIOS for QEMU and KVM
- https://git.seabios.org/seabios.git
- SeaBIOS version for the tutorial: commit **6e56ed129c97**

The below options are enabled to dump debug message to serial port:

```
CONFIG_DEBUG_LEVEL=8
CONFIG_DEBUG_SERIAL=y
CONFIG_DEBUG_SERIAL_PORT=0x3f8
CONFIG_DEBUG_IO=y
```

To build SeaBIOS:

```
# make menuconfig
# make
```

The output is at:
/.../seabios/out/bios.bin

-serial stdio is used to dump debug message to stdio

To boot guest with Linux kernel and BIOS:

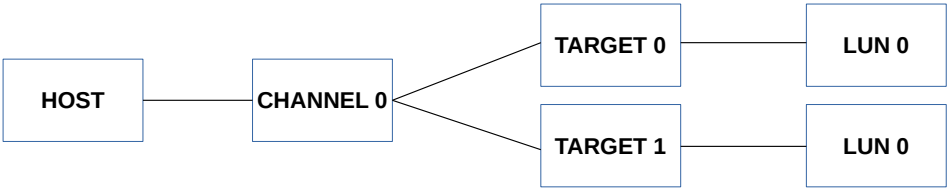
```
# qemu-system-x86_64 -machine accel=kvm -vnc :0 -smp 4 -m 4096M \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-hda /home/user/img/boot.qcow2 \
-bios /home/user/seabios/out/bios.bin -serial stdio
```

SCSI: megasas 1/2

2 targets (each with a lun) on the same <adapter, channel>

```
# qemu-system-x86_64 -machine accel=kvm -vnc :0 -smp 4 -m 4096M \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-device megasas,id=scsi0 \
-device scsi-hd,drive=drive0,bus=scsi0.0,channel=0,scsi-id=0,lun=0,bootindex=1 \
-drive file=/home/user/img/boot.qcow2,if=none,id=drive0 \
-device scsi-hd,drive=drive1,bus=scsi0.0,channel=0,scsi-id=1,lun=0 \
-drive file=/home/user/img/disk.qcow2,if=none,id=drive1
```

SCSI: megasas 2/2



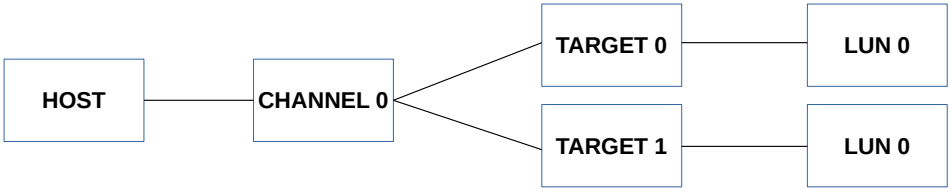
[0.626341] scsi host0: **Avago SAS based MegaRAID driver**
[0.644708] scsi 0:2:0:0: Direct-Access QEMU QEMU HARDDISK 2.5+ PQ: 0 ANSI: 5
[0.646012] scsi 0:2:1:0: Direct-Access QEMU QEMU HARDDISK 2.5+ PQ: 0 ANSI: 5
[0.671123] sd 0:2:0:0: Attached scsi generic sg0 type 0
[0.671710] sd 0:2:1:0: Attached scsi generic sg1 type 0
[0.673409] sd 0:2:1:0: [sdb] Attached SCSI disk
[0.680489] sd 0:2:0:0: [sda] Attached SCSI disk

SCSI: lsi53c895a 1/2

2 targets (each with a lun) on the same <adapter, channel>

```
# qemu-system-x86_64 -machine accel=kvm -vnc :0 -smp 4 -m 4096M \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-device lsi53c895a,id=scsi0 \
-device scsi-hd,drive=drive0,bus=scsi0.0,channel=0,scsi-id=0,lun=0,bootindex=1 \
-drive file=/home/user/img/boot.qcow2,if=none,id=drive0 \
-device scsi-hd,drive=drive1,bus=scsi0.0,channel=0,scsi-id=1,lun=0 \
-drive file=/home/user/img/disk.qcow2,if=none,id=drive1
```

SCSI: lsi53c895a 2/2



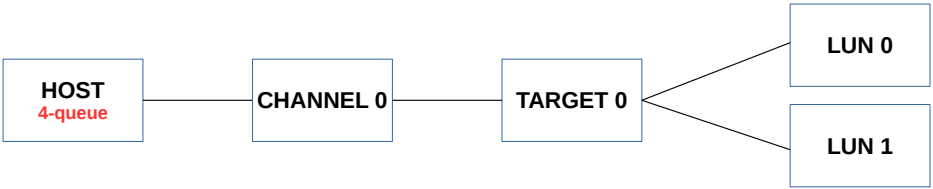

```
[ 0.610488] scsi host0: sym-2.2.3
[ 3.603414] scsi 0:0:0:0: Direct-Access QEMU QEMU HARDDISK 2.5+ PQ: 0 ANSI: 5
[ 3.613141] scsi 0:0:1:0: Direct-Access QEMU QEMU HARDDISK 2.5+ PQ: 0 ANSI: 5
[ 3.623833] sd 0:0:0:0: Attached scsi generic sg0 type 0
[ 3.624993] sd 0:0:1:0: Attached scsi generic sg1 type 0
[ 3.632309] sd 0:0:0:0: [sda] Attached SCSI disk
[ 3.641668] sd 0:0:1:0: [sdb] Attached SCSI disk
```

SCSI: virtio_scsi 1/3

2 lun on the same <adapter, channel, id>

```
# qemu-system-x86_64 -machine accel=kvm -vnc :0 -smp 4 -m 4096M \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-device virtio-scsi-pci,id=scsi0,num_queues=4 \
-device scsi-hd,drive=drive0,bus=scsi0.0,channel=0,scsi-id=0,lun=0,bootindex=1 \
-drive file=/home/user/img/boot.qcow2,if=none,id=drive0 \
-device scsi-hd,drive=drive1,bus=scsi0.0,channel=0,scsi-id=0,lun=1 \
-drive file=/home/user/img/disk.qcow2,if=none,id=drive1
```

SCSI: virtio_scsi 2/3



[0.604610] scsi host0: **Virtio SCSI HBA**
[0.606220] scsi 0:0:0:0: Direct-Access QEMU QEMU HARDDISK 2.5+ PQ: 0 ANSI: 5
[0.607168] scsi 0:0:0:1: Direct-Access QEMU QEMU HARDDISK 2.5+ PQ: 0 ANSI: 5
[0.617180] sd 0:0:0:0: Attached scsi generic sg0 type 0
[0.618537] sd 0:0:0:1: [sdb] Attached SCSI disk
[0.619014] sd 0:0:0:1: Attached scsi generic sg1 type 0
[0.625877] sd 0:0:0:0: [sda] Attached SCSI disk

SCSI: virtio_scsi 3/3

```
# ls /sys/block/sda/mq
0 1 2 3
# ls /sys/block/sdb/mq
0 1 2 3
```

```
# cat /proc/interrupts | grep virtio
24:          0          0          0          0 PCI-MSI 65536-edge      virtio0-config
25:          0          0          0          0 PCI-MSI 65537-edge      virtio0-control
26:          0          0          0          0 PCI-MSI 65538-edge      virtio0-event
27:       1171          0          0          0 PCI-MSI 65539-edge      virtio0-request
28:          0       1180          0          0 PCI-MSI 65540-edge      virtio0-request
29:          0          0        831          0 PCI-MSI 65541-edge      virtio0-request
30:          0          0          0       1636 PCI-MSI 65542-edge      virtio0-request
```

NVMe device with 8 hardware queues

- Customize **num_queues** to test how NVMe driver works with different #queues

```
# qemu-system-x86_64 -machine accel=kvm -vnc :0 -smp 4 -m 4096M \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-hda /home/user/img/boot.qcow2 \
-device nvme,drive=nvme0,serial=deadbeaf1,num_queues=8 \
-drive file=/home/user/img/disk.qcow2,if=none,id=nvme0
```

NVMe 2/2

```
[ 0.576209] nvme nvme0: pci function 0000:00:04.0
[ 0.620458] nvme nvme0: 4/0/0 default/read/poll queues
```

```
# ls /dev/nvme0
nvme0   nvme0n1
```

```
# cat /proc/interrupts | grep nvme
24:     11      0      0      0   PCI-MSI 65536-edge      nvme0q0
25:     40      0      0      0   PCI-MSI 65537-edge      nvme0q1
26:      0      0      0      0   PCI-MSI 65538-edge      nvme0q2
27:      0      0     41      0   PCI-MSI 65539-edge      nvme0q3
28:      0      0      0      0   PCI-MSI 65540-edge      nvme0q4
```

NVDIMM: Non-Volatile Dual In-line Memory Module

- **pmem** and **blk** types
- QEMU supports only **pmem** type

```
# qemu-system-x86_64 -vnc :0 -smp 4 \
-machine pc,nvdimm,accel=kvm \
-m 2G,maxmem=10G,slots=4 \
-object memory-backend-file,share,id=mem1,mem-path=nvdimm.img,size=16G \
-device nvdimm,memdev=mem1,id=nvdimm1 \
-net nic -net user,hostfwd=tcp::5022-:22 \
-hda /home/user/img/boot.qcow2 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text"
```

Install utility library for managing the libnvdimm

- sudo apt-get install **libndctl ndctl**
- https://github.com/pmem/ndctl

```
CONFIG_BLK_DEV_RAM_DAX=y
CONFIG_FS_DAX=y
CONFIG_X86_PMEM_LEGACY=y
CONFIG_LIBNVDIMM=y
CONFIG_BLK_DEV_PMEM=m
CONFIG_ARCH_HAS_PMEM_API=y
CONFIG_TRANSPARENT_HUGEPAGE=y
CONFIG_MEMORY_HOTPLUG=y
CONFIG_MEMORY_HOTREMOVE=y
CONFIG_ZONE_DEVICE=y
CONFIG_FS_DAX_PMD=y
CONFIG_ACPI_NFIT=y
```

```
# ndctl list
  "dev":"namespace0.0",
  "mode":"raw",
  "size":17179869184,
  "sector_size":512,
  "blockdev":"pmem0",
  "numa_noe":0
```

Virtio Block device with 4 hardware queues

```
# qemu-system-x86_64 -machine accel=kvm -vnc :0 -smp 4 -m 4096M \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-hda /home/user/img/boot.qcow2 \
-device virtio-blk-pci,drive=drive0,id=virtblk0,num-queues=4 \
-drive file=/home/user/img/disk.qcow2,if=none,id=drive0
```

Virtio Block 2/2

```
# ls /dev/vda
/dev/vda

#ls /sys/block/vda/mq/
0 1 2 3

#cat /proc/interrupts | grep virtio
 24:          0          0          0          0   PCI-MSI 65536-edge      virtio0-config
 25:          1          0          0          0   PCI-MSI 65537-edge      virtio0-req.0
 26:          0         30          0          0   PCI-MSI 65538-edge      virtio0-req.1
 27:          0          0         33          0   PCI-MSI 65539-edge      virtio0-req.2
 28:          0          0          0          0   PCI-MSI 65540-edge      virtio0-req.3
```

QEMU Tap Bridge Helper Script

- The script bridges **tap** created by QEMU to host bridge (e.g., br0)
- Used by QEMU **-netdev** during VM creation

```
# cat /home/user/qemu-ifup

#! /bin/sh
# Script to bring a network (tap) device for qemu up.

br="br0"

ifconfig $1 up
brctl addif $br "$1"

exit
```

Virtio Net 1/2

- To create Virtio Net device with **4** queues (consuming 9 vectors)
- **qemu-ifup** is from previous slide
- The **#vector** should be configured correctly (4(TX)+4(RX)+1(Conf)=9)

```
# qemu-system-x86_64 -machine accel=kvm -vnc :0 -smp 4 -m 4096M \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-hda /home/user/img/boot.qcow2 \
-device virtio-net-pci,netdev=tapnet,mq=true,vectors=9 \
-netdev tap,id=tapnet,ifname=tap0,\
    script=/home/user/qemu-ifup,downscript=no,queues=4,vhost=off
```

Virtio Net 2/2

host# ip addr | grep tap0

34: **tap0**: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc **mq** master **br0** state UNKNOWN group default qlen 1000

vm# cat /proc/interrupts | grep virtio

24:	0	0	0	0	PCI-MSI 49152-edge	virtio0-config
25:	57	1	0	0	PCI-MSI 49153-edge	**virtio0-input.0**
26:	0	0	1	0	PCI-MSI 49154-edge	**virtio0-output.0**
27:	0	110	0	1	PCI-MSI 49155-edge	**virtio0-input.1**
28:	1	0	0	0	PCI-MSI 49156-edge	**virtio0-output.1**
29:	0	1	135	0	PCI-MSI 49157-edge	**virtio0-input.2**
30:	0	0	1	0	PCI-MSI 49158-edge	**virtio0-output.2**
31:	0	0	0	49	PCI-MSI 49159-edge	**virtio0-input.3**
32:	0	0	0	0	PCI-MSI 49160-edge	**virtio0-output.3**

E1000e

The e1000e can be substituted by:

- rtl8139(8139cp), vmxnet3(vmxnet3), i82550(e100), e1000(e1000)

```
# qemu-system-x86_64 -machine accel=kvm -vnc :0 -smp 4 -m 4096M \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-hda /home/user/img/boot.qcow2 \
-device e1000e,netdev=tapnet \
-netdev tap,id=tapnet,ifname=tap0,script=/home/user/qemu-ifup,downscript=no
```

```
vm# ethtool -i enp0s3 | grep driver
driver: e1000e
```

Create 2 PCI-2-PCI bridge's secondary bus

- The 1st secondary bus is with 1 E1000 NIC
- The 2nd secondary bus is with 2 E1000 NIC

```
# qemu-system-x86_64 -machine pc,accel=kvm -vnc :0 -smp 4 -m 4096M \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-hda /home/user/img/boot.qcow2 \
-device pci-bridge,id=bridge0,chassis_nr=1 \
    -device e1000,bus=bridge0,addr=0x3 \
-device pci-bridge,id=bridge1,chassis_nr=2 \
    -device e1000,bus=bridge1,addr=0x3 \
    -device e1000,bus=bridge1,addr=0x4
```

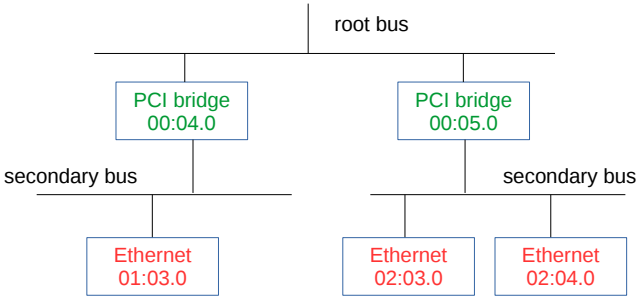
PCI Bridge 2/3

00:00.0 Host bridge: Intel Corporation 440FX - 82441FX PMC [Natoma] (rev 02)
00:01.0 ISA bridge: Intel Corporation 82371SB PIIX3 ISA [Natoma/Triton II]
00:01.1 IDE interface: Intel Corporation 82371SB PIIX3 IDE [Natoma/Triton II]
00:01.3 Bridge: Intel Corporation 82371AB/EB/MB PIIX4 ACPI (rev 03)
00:02.0 VGA compatible controller: Device 1234:1111 (rev 02)
00:03.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)
00:04.0 PCI bridge: Red Hat, Inc. **QEMU PCI-PCI bridge**
00:05.0 PCI bridge: Red Hat, Inc. **QEMU PCI-PCI bridge**
01:03.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)
02:03.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)
02:04.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)

PCI Bridge 3/3

00:04.0 PCI bridge: Red Hat, Inc. QEMU PCI-PCI bridge
00:05.0 PCI bridge: Red Hat, Inc. QEMU PCI-PCI bridge
01:03.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)
02:03.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)
02:04.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)

```
# lspci -t
-[0000:00]-+-00.0
           +-01.0
           +-01.1
           +-01.3
           +-02.0
           +-03.0
           +-04.0-[01]----03.0
           \-05.0-[02]--+-03.0
                        \-04.0
```



PCI Root Bus 1/3

Create 2 PCI Expander Bridge (PXB)'s root bus (exposed through ACPI)

- The 1st PCI root bus is with 1 E1000 NIC
- The 2nd PCI root bus is with 2 E1000 NIC

```
# qemu-system-x86_64 -machine pc,accel=kvm -vnc :0 -smp 4 -m 4096M \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-hda /home/user/img/boot.qcow2 \
-device pxb,id=bridge1,bus=pci.0,bus_nr=3 \
    -device e1000,bus=bridge1,addr=0x3 \
-device pxb,id=bridge2,bus=pci.0,bus_nr=8 \
    -device e1000,bus=bridge2,addr=0x3 \
    -device e1000,bus=bridge2,addr=0x4
```

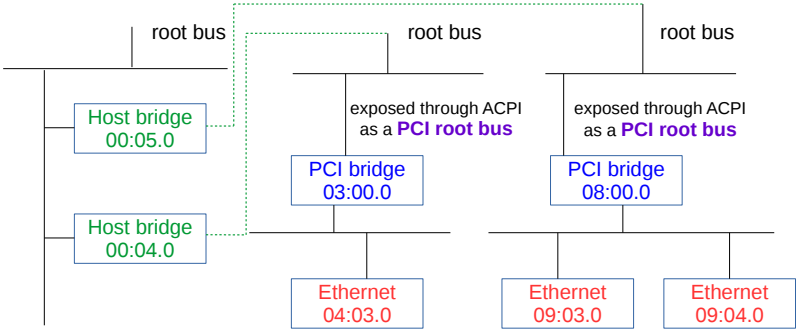
PCI Root Bus 2/3

00:00.0 Host bridge: Intel Corporation 440FX - 82441FX PMC [Natoma] (rev 02)
00:01.0 ISA bridge: Intel Corporation 82371SB PIIX3 ISA [Natoma/Triton II]
00:01.1 IDE interface: Intel Corporation 82371SB PIIX3 IDE [Natoma/Triton II]
00:01.3 Bridge: Intel Corporation 82371AB/EB/MB PIIX4 ACPI (rev 03)
00:02.0 VGA compatible controller: Device 1234:1111 (rev 02)
00:03.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)
00:04.0 Host bridge: Red Hat, Inc. QEMU **PCI Expander bridge**
00:05.0 Host bridge: Red Hat, Inc. QEMU **PCI Expander bridge**
03:00.0 PCI bridge: Red Hat, Inc. QEMU **PCI-PCI bridge**
04:03.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)
08:00.0 PCI bridge: Red Hat, Inc. QEMU **PCI-PCI bridge**
09:03.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)
09:04.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)

PCI Root Bus 3/3

00:04.0 Host bridge: Red Hat, Inc. QEMU PCI Expander bridge
00:05.0 Host bridge: Red Hat, Inc. QEMU PCI Expander bridge
03:00.0 PCI bridge: Red Hat, Inc. QEMU PCI-PCI bridge
04:03.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)
08:00.0 PCI bridge: Red Hat, Inc. QEMU PCI-PCI bridge
09:03.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)
09:04.0 Ethernet controller: Intel Corporation 82540EM Gigabit Ethernet Controller (rev 03)

```
# lspci -t
-+-[0000:08]---00.0-[09]--+-03.0
 |                        \-04.0
 +-[0000:03]---00.0-[04]----03.0
 \-[0000:00]-+-00.0
             +-01.0
             +-01.1
             +-01.3
             +-02.0
             +-03.0
             +-04.0
             \-05.0
```



PCI Express Root Complex 1/3

Create 2 extra PCI Express Root Complex (exposed through ACPI)

- The 1st PCI Express Root Complex is with 2 E1000 NIC
- The 2nd PCI Express Root Complex is with 1 E1000 NIC

```
# qemu-system-x86_64 -machine q35,accel=kvm -vnc :0 -smp 4 -m 4096M \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-hda /home/user/img/boot.qcow2 \
-device pxb-pcie,id=pcie.1,bus_nr=2,bus=pcie.0 \
   -device ioh3420,id=pcie_pci_bridge1,bus=pcie.1,chassis=1 \
      -device e1000e,bus=pcie_pci_bridge1 \
   -device ioh3420,id=pcie_pci_bridge2,bus=pcie.1,chassis=2 \
      -device e1000e,bus=pcie_pci_bridge2 \
-device pxb-pcie,id=pcie.2,bus_nr=8,bus=pcie.0 \
   -device ioh3420,id=pcie_pci_bridge3,bus=pcie.2,chassis=3 \
      -device e1000e,bus=pcie_pci_bridge3
```

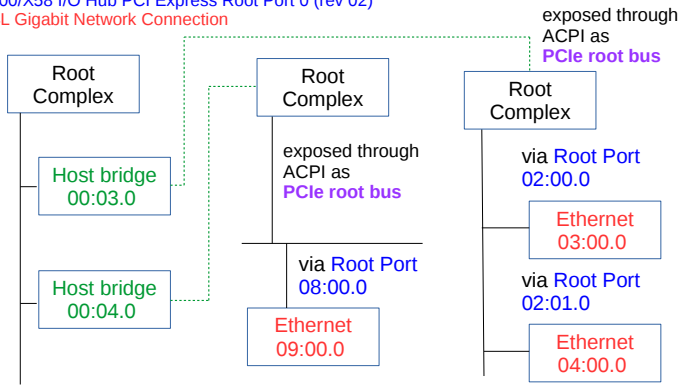
PCI Express Root Complex 2/3

00:00.0 Host bridge: Intel Corporation 82G33/G31/P35/P31 Express DRAM Controller
00:01.0 VGA compatible controller: Device 1234:1111 (rev 02)
00:02.0 Ethernet controller: Intel Corporation 82574L Gigabit Network Connection
00:03.0 Host bridge: Red Hat, Inc. QEMU **PCIe Expander bridge**
00:04.0 Host bridge: Red Hat, Inc. QEMU **PCIe Expander bridge**
00:1f.0 ISA bridge: Intel Corporation 82801IB (ICH9) LPC Interface Controller (rev 02)
00:1f.2 SATA controller: Intel Corporation 82801IR/IO/IH (ICH9R/DO/DH) 6 port SATA Controller [AHCI mode] (rev 02)
00:1f.3 SMBus: Intel Corporation 82801I (ICH9 Family) SMBus Controller (rev 02)
02:00.0 PCI bridge: Intel Corporation 7500/5520/5500/X58 **I/O Hub PCI Express Root Port** 0
02:01.0 PCI bridge: Intel Corporation 7500/5520/5500/X58 **I/O Hub PCI Express Root Port** 0
03:00.0 Ethernet controller: Intel Corporation 82574L Gigabit Network Connection
04:00.0 Ethernet controller: Intel Corporation 82574L Gigabit Network Connection
08:00.0 PCI bridge: Intel Corporation 7500/5520/5500/X58 **I/O Hub PCI Express Root Port** 0
09:00.0 Ethernet controller: Intel Corporation 82574L Gigabit Network Connection

PCI Express Root Complex 3/3

```
00:03.0 Host bridge: Red Hat, Inc. QEMU PCIe Expander bridge
00:04.0 Host bridge: Red Hat, Inc. QEMU PCIe Expander bridge
02:00.0 PCI bridge: Intel Corporation 7500/5520/5500/X58 I/O Hub PCI Express Root Port 0 (rev 02)
02:01.0 PCI bridge: Intel Corporation 7500/5520/5500/X58 I/O Hub PCI Express Root Port 0 (rev 02)
03:00.0 Ethernet controller: Intel Corporation 82574L Gigabit Network Connection
04:00.0 Ethernet controller: Intel Corporation 82574L Gigabit Network Connection
08:00.0 PCI bridge: Intel Corporation 7500/5520/5500/X58 I/O Hub PCI Express Root Port 0 (rev 02)
09:00.0 Ethernet controller: Intel Corporation 82574L Gigabit Network Connection
```

```
# lspci -t
-+-[0000:08]---00.0-[09]----00.0
 +-[0000:02]-+-00.0-[03]----00.0
 |           \-01.0-[04]----00.0
 \-[0000:00]-+-00.0
             +-01.0
             +-02.0
             +-03.0
             +-04.0
             +-1f.0
             +-1f.2
             \-1f.3
```



Create 1 PCI Express Switch

- There is 1 Upstream Port connecting to 2 Downstream Ports
- Each Downstream Port is connected to 1 E1000e NIC

```
# qemu-system-x86_64 -machine q35,accel=kvm -vnc :0 -smp 4 -m 4096M \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-hda /home/user/img/boot.qcow2 \
-device ioh3420,id=root_port1,bus=pcie.0 \
   -device x3130-upstream,id=upstream1,bus=root_port1 \
      -device xio3130-downstream,id=downstream1,bus=upstream1,chassis=9 \
         -device e1000e,bus=downstream1 \
      -device xio3130-downstream,id=downstream2,bus=upstream1,chassis=10 \
         -device e1000e,bus=downstream2
```

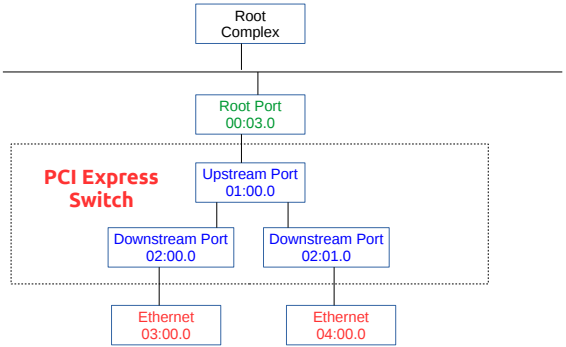
PCI Express Switches 2/3

00:00.0 Host bridge: Intel Corporation 82G33/G31/P35/P31 Express DRAM Controller
00:01.0 VGA compatible controller: Device 1234:1111 (rev 02)
00:02.0 Ethernet controller: Intel Corporation 82574L Gigabit Network Connection
00:03.0 PCI bridge: Intel Corporation 7500/5520/5500/X58 **I/O Hub PCI Express Root Port** 0
00:1f.0 ISA bridge: Intel Corporation 82801IB (ICH9) LPC Interface Controller (rev 02)
00:1f.2 SATA controller: Intel Corporation 82801IR/IO/IH (ICH9R/DO/DH) 6 port SATA Controller [AHCI mode] (rev 02)
00:1f.3 SMBus: Intel Corporation 82801I (ICH9 Family) SMBus Controller (rev 02)
01:00.0 PCI bridge: Texas Instruments XIO3130 **PCI Express Switch (Upstream)** (rev 02)
02:00.0 PCI bridge: Texas Instruments XIO3130 **PCI Express Switch (Downstream)** (rev 01)
02:01.0 PCI bridge: Texas Instruments XIO3130 **PCI Express Switch (Downstream)** (rev 01)
03:00.0 Ethernet controller: Intel Corporation 82574L Gigabit Network Connection
04:00.0 Ethernet controller: Intel Corporation 82574L Gigabit Network Connection

PCI Express Switches 3/3

00:03.0 PCI bridge: Intel Corporation 7500/5520/5500/X58 I/O Hub PCI Express Root Port 0 (rev 02)
01:00.0 PCI bridge: Texas Instruments XIO3130 PCI Express Switch (Upstream) (rev 02)
02:00.0 PCI bridge: Texas Instruments XIO3130 PCI Express Switch (Downstream) (rev 01)
02:01.0 PCI bridge: Texas Instruments XIO3130 PCI Express Switch (Downstream) (rev 01)
03:00.0 Ethernet controller: Intel Corporation 82574L Gigabit Network Connection
04:00.0 Ethernet controller: Intel Corporation 82574L Gigabit Network Connection

```
# lspci -t
-[0000:00]-+-00.0
           +-01.0
           +-02.0
           +-03.0-[01-04]----00.0-[02-04]--+-00.0-[03]----00.0
           |                               \-01.0-[04]----00.0
           +-1f.0
           +-1f.2
           \-1f.3
```



Intel VT-d with Interrupt Remapping (IR) enabled

- Only **q35** machine supports virtual IOMMU
- **intel_iommu=on** should be added to kernel cmdline

```
# qemu-system-x86_64 -vnc :0 -smp 4 -m 4096M \
-machine q35,accel=kvm,kernel-irqchip=split \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text intel_iommu=on" \
-hda /home/user/img/boot.qcow2 \
-device nvme,drive=nvme0,serial=deadbeaf1,num_queues=8 \
-drive file=/home/user/img/disk.qcow2,if=none,id=nvme0 \
-device intel-iommu,intremap=on
```

IOMMU 2/2

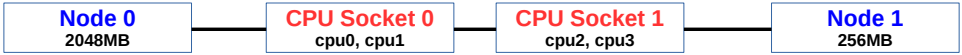
```
# dmesg | egrep "IOMMU|iommu"

[ 0.000000] DMAR: IOMMU enabled
[ 0.003000] DMAR-IR: IOAPIC id 0 under DRHD base 0xfed90000 IOMMU 0
[ 0.477614] pci 0000:00:00.0: Adding to iommu group 0
[ 0.478078] pci 0000:00:01.0: Adding to iommu group 1
[ 0.478517] pci 0000:00:02.0: Adding to iommu group 2
[ 0.478963] pci 0000:00:03.0: Adding to iommu group 3
[ 0.479421] pci 0000:00:1f.0: Adding to iommu group 4
[ 0.479857] pci 0000:00:1f.2: Adding to iommu group 4
[ 0.480316] pci 0000:00:1f.3: Adding to iommu group 4
```

Machine of 2 NUMA node

- 2 memory NUMA node (1st=2048MB, 2nd=256MB)
- 2 CPU socket and each has 2 cores (of 1 thread)

```
# qemu-system-x86_64 -machine accel=kvm -vnc :0 \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-hda /home/user/img/boot.qcow2 \
-smp 4,sockets=2,cores=2,threads=1 -m 2304M \
-numa node,mem=2048,cpus=0-1 \
-numa node,mem=256,cpus=2-3
```

NUMA 2/2




```
# ls /sys/devices/system/node/node0 | grep cpu[0-9]
cpu0 cpu1
# ls /sys/devices/system/node/node1 | grep cpu[0-9]
cpu2 cpu3
```

```
[ 0.007388] Initmem setup node 0 [mem 0x0000000000001000-0x00000007fffffff]
[ 0.007390] On node 0 totalpages: 524190
[ 0.015744] Initmem setup node 1 [mem 0x0000000080000000-0x00000008ffdfffff]
[ 0.015746] On node 1 totalpages: 65504
```

CPU Hotplug 1/3

- Can be used to debug how block/net drivers work with hotplug
- Init #cpu is 2 while the max #cpu is 4

```
# qemu-system-x86_64 -machine accel=kvm -vnc :0 -m 4096M \
-smp 2,maxcpus=4 \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-hda /home/user/img/boot.qcow2 \
-device nvme,drive=nvme0,serial=deadbeaf1,num_queues=8 \
-drive file=/home/user/img/disk.qcow2,if=none,id=nvme0 \
-monitor stdio
QEMU 4.0.50 monitor - type 'help' for more information
(qemu)
```

CPU Hotplug 2/3

To add new vcpu from QEMU:
(qemu) device_add **qemu64-x86_64-cpu**,id=core1,socket-id=**2**,core-id=**0**,thread-id=**0**

To add online new vcpu by VM:
vm# echo 1 > **/sys/devices/system/cpu/cpu2/online**

vm# dmesg
[1021.173154] CPU2 has been hot-added
[1029.524516] smpboot: Booting Node 0 Processor 2 APIC 0x2
[1029.604423] Will online and init hotplugged CPU: 2

To offline new vcpu by VM:
vm# echo 0 > **/sys/devices/system/cpu/cpu2/online**

vm# dmesg
[1354.176282] smpboot: CPU 2 is now offline

CPU Hotplug 3/3

- A block-mq cpu hotplug bug reproduced by QEMU: https://patchwork.kernel.org/patch/10889307
- Inflight requests on software queue is spliced to the incorrect hardware queue during cpu offline

```
When a cpu is offline, blk_mq_hctx_notify_dead() is called once for each
hctx for the offline cpu.

While blk_mq_hctx_notify_dead() is used to splice all ctx->rq_lists[type]
to hctx->dispatch, it never checks whether the ctx is already mapped to the
hctx.

For example, on a VM (with nvme) of 4 cpu, to offline cpu 2 out of the
4 cpu (0-3), blk_mq_hctx_notify_dead() is called once for each io queue
hctx:

1st: blk_mq_ctx->cpu = 2 for blk_mq_hw_ctx->queue_num = 3
2nd: blk_mq_ctx->cpu = 2 for blk_mq_hw_ctx->queue_num = 2
3rd: blk_mq_ctx->cpu = 2 for blk_mq_hw_ctx->queue_num = 1
4th: blk_mq_ctx->cpu = 2 for blk_mq_hw_ctx->queue_num = 0

Although blk_mq_ctx->cpu = 2 is only mapped to blk_mq_hw_ctx->queue_num = 2
in this case, its ctx->rq_lists[type] will however be moved to
blk_mq_hw_ctx->queue_num = 3 during the 1st call of
blk_mq_hctx_notify_dead().

This patch would return and go ahead to next call of
blk_mq_hctx_notify_dead() if ctx is not mapped to hctx.
```

Memory Hotplug 1/2

Boot with:

- initial 2048MB memory
- extra 4 slots to hotplug memory up to extra 4096MB-2048MB=2048MB

```
# qemu-system-x86_64 -machine accel=kvm -vnc :0 -smp 4 \
-m 2048M,slots=4,maxmem=4096M \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-hda /home/user/img/boot.qcow2 \
-monitor stdio
QEMU 4.0.50 monitor - type 'help' for more information
(qemu)
```

Memory Hotplug 2/2

Before memory hotplug:
cat /proc/meminfo | grep MemTotal
MemTotal: 1972380 kB

To add 1024MB memory:
(qemu) object_add memory-backend-ram,id=mem1,size=1024M
(qemu) device_add pc-dimm,id=dimm1,memdev=mem1

dmesg
[99.324281] Built 1 zonelists, mobility grouping on. Total pages: 523480
[99.324282] Policy zone: Normal

After memory hotplug (more 'memory<section>' available under **/sys/devices/system/memory/**):
cat /proc/meminfo | grep MemTotal
MemTotal: 3020956 kB

PM Suspend 1/3

- To debug how each kernel component works during PM freezing, e.g., unlike **jbd2**, **o2hb_thread** does NOT freeze itself proactively
- To debug how each driver (e.g, nvme or virtio) works with PM suspend

```
# qemu-system-x86_64 -machine accel=kvm -vnc :0 -smp 4 -m 4096M \
-net nic -net user,hostfwd=tcp::5022-:22 \
-kernel /home/user/linux/arch/x86_64/boot/bzImage \
-append "root=/dev/sda1 init=/sbin/init text" \
-hda /home/user/img/boot.qcow2 \
-device nvme,drive=nvme0,serial=deadbeaf1,num_queues=8 \
-drive file=/home/user/img/disk.qcow2,if=none,id=nvme0 \
-monitor stdio \
QEMU 4.0.50 monitor - type 'help' for more information \
(qemu)
```

PM Suspend 2/3

 # echo freeze > /sys/power/state —> to suspend from VM
(qemu) system_powerdown —> to resume from QEMU

```
# dmesg
[  84.198422] PM: suspend entry (s2idle)
[  85.249993] Filesystems sync: 1.051 seconds
[  85.252942] Freezing user space processes ... (elapsed 0.001 seconds) done.
[  85.254433] OOM killer disabled.
[  85.254434] Freezing remaining freezable tasks ... (elapsed 0.000 seconds) done.
[  85.255212] printk: Suspending console(s) (use no_console_suspend to debug)
[  85.261298] sd 0:0:0:0: [sda] Synchronizing SCSI cache
[  85.283587] sd 0:0:0:0: [sda] Stopping disk
[ 105.107310] sd 0:0:0:0: [sda] Starting disk
[ 105.115072] nvme nvme0: 4/0/0 default/read/poll queues
[ 105.261509] ata2.01: NODEV after polling detection
[ 105.261896] ata1.01: NODEV after polling detection
[ 105.265826] OOM killer enabled.
[ 105.265827] Restarting tasks ... done.
[ 105.273076] PM: suspend exit
[ 107.172694] e1000: enp0s3 NIC Link is Up 1000 Mbps Full Duplex, Flow Control: RX
```

PM Suspend 3/3

- Sample kernel warning at kernel/irq/chip.c:210 irq_startup+0xd6/0xe0
- Bug reported: http://lists.infradead.org/pipermail/linux-nvme/2019-April/023234.html
- How I reproduce with QEMU: http://lists.infradead.org/pipermail/linux-nvme/2019-April/023237.html

On 04/04/2019 04:55 PM, Ming Lei wrote:

> On Thu, Apr 04, 2019 at 08:23:59AM +0000, fin4478 fin4478 wrote:
>
> > Hi,
> >
> > I do not use suspend/resume but noticed this kernel warning when testing it. This warning is present in earlier kernels too. My system works fine after resume.
> > If there is a patch to fix this, I can test it.
> >
> > [53.403033] PM: suspend entry (deep)
> > [53.403034] PM: Syncing filesystems ... done.
> > [53.404775] Freezing user space processes ... (elapsed 0.001 seconds) done.
> > [53.405972] OOM killer disabled.
> > [53.405973] Freezing remaining freezable tasks ... (elapsed 0.001 seconds) done.
> > [53.407036] printk: Suspending console(s) (use no_console_suspend to debug)
> > [53.407491] ACPI Debug: "RRIO"
> > [53.407505] serial 00:03: disabled
> > [53.407560] r8169 0000:07:00.0 enp7s0: Link is Down
> > [53.415042] sd 5:0:0:0: [sda] Synchronizing SCSI cache
> > [53.415065] sd 5:0:0:0: [sda] Stopping disk
> > [53.428943] WARNING: CPU: 10 PID: 3127 at kernel/irq/chip.c:210 irq_startup+0xd6/0xe0
>
> Looks the 'WARN_ON_ONCE(force)' in irq_startup() is a bit too strict.
>
> irq_build_affinity_masks() doesn't guarantee that each IRQ's affinity
> can include at least one online CPU.

Do not always trust QEMU

- QEMU can have bug: https://www.spinics.net/lists/linux-block/msg37936.html
- Fixed in QEMU commit **9d6459d21a6e ("nvme: fix write zeroes offset and count")**

```
Hi,

It is observed that ext4 is corrupted easily by running some workloads
on QEMU NVMe, such as:

1) mkfs.ext4 /dev/nvme0n1

2) mount /dev/nvme0n1 /mnt

3) cd /mnt; git clone git://git.kernel.org/pub/scm/linux/kernel/git/torvalds/linux.git

4) then the following error message may show up:

[ 1642.271816] EXT4-fs error (device nvme0n1): ext4_mb_generate_buddy:747: group 0, block bitmap and bg descriptor inconsistent: 32768 vs 23513
free clusters

Or fsck.ext4 will complain after running 'umount /mnt'

The issue disappears by reverting 6e02318eaea53eaafe6 ("nvme: add support for the
Write Zeroes command").

QEMU version:

QEMU emulator version 2.10.2(qemu-2.10.2-1.fc27)
Copyright (c) 2003-2017 Fabrice Bellard and the QEMU Project developers

Thanks,
Ming
```

Take-Home Message

How to **effectively** setup **debug/study** environment with QEMU:

- Build and run Linux kernel from host
- Use QEMU but not libvirt

Components and Features to debug:

- SCSI (megasas, lsi53c895a, virtio_scsi), NVMe, NVDIMM
- Virtio Block and Virtio Net
- Ethernet Card (e1000e, e1000, e100, 8139cp, vmxnet3)
- PCI Bus, PCIe Root Complex and PCIe Switch
- BIOS (seabios), IOMMU (intel), PM Suspend
- NUMA, Memory Hotplug, CPU Hotplug