ACCELERATING I/OS IN VIRTUALIZATION VIA SPDK VHOST SOLUTION

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INTRODUCTION
SPDK VHOST ARCHITECTURE

QEMU
Guest VM
virtio-scsi/blk
vhost

SPDK vhost
virtio-scsi/blk
DPDK vhost

eventfd
UNIX domain socket

virtqueue
Shared Guest VM Memory
Host Memory
1. Add IO to virtqueue
2. Poll virtqueue
3. Device executes IO
4. Guest completion interrupt
COMPARISON WITH EXISTING SOLUTIONS

QEMU VIRTIO SCSI Target

- QEMU
  - Guest VM
    - Guest Kernel
      - VIRTIO_SCSI
  - VIRTIO_SCSI_PCI

- Host Kernel
  - NVME_MOD

VHOST Kernel Target

- QEMU
  - Guest VM
    - Guest Kernel
      - VIRTIO_SCSI
  - VHOST_SCSI_PCI
    - IOCTL

- Host Kernel
  - VHOST
    - LIO
  - NVME_MOD

VHOST Userspace Target

- QEMU
  - Guest VM
    - Guest Kernel
      - VIRTIO_SCSI
  - VHOST_USER_SCSI_PCI

- SPDK VHOST
  - VHOST_USER
    - SCSI
  - PMD_NVME
## SPDK VHOST Target Summary

<table>
<thead>
<tr>
<th>Vhost Target</th>
<th>QEMU Support</th>
<th>Guest Support</th>
<th>Container similar Solution Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vhost SCSI Target</td>
<td>Yes</td>
<td>Yes, Kernel+PMD</td>
<td>Yes</td>
</tr>
<tr>
<td>Vhost Blk Target</td>
<td>Yes</td>
<td>Yes, Kernel+PMD</td>
<td>Yes</td>
</tr>
<tr>
<td>Vhost NVMe Target</td>
<td>No, SPDK QEMU branch</td>
<td>Yes, Kernel+PMD</td>
<td>No</td>
</tr>
</tbody>
</table>

- Vhost-SCSI: QEMU 2.9 added vhost-user-scsi-pci host driver support
- Vhost-Blk: QEMU 2.11 added vhost-user-blk-pci host driver support
- Vhost NVMe: a new device type which can demonstrate NVMe controller to VM, native kernel NVMe driver can be used
USE CASES
Virtual Machine Acceleration

- Provides dynamic block device provisioning
- Increase VM Density
- Decrease Guest Latency
- Works with KVM/QEMU

**Diagram:**
- VM
- Vhost Target
- SPDK
- SCSI
- BDEV Logical volume
- Blobstore
- BDEV NVMe BD
- NVMe Driver
- BDEV NVMeoF BD
- NVMe-oF Initiator
- SSD for Datacenter
- NVMe-oF Target
Virtio SCSI/blk Driver

Virtio SCSI/Blk is an initiator for SPDK Vhost target

Virtio SCSI/Blk driver supports 2 usage models:

• PCI Mode: Polling mode driver inside Guest VM
• User vhost: Can be used to connect to vhost target directly via socket, e.g.: containers or multi-process application
BENCHMARKS
48 VMs: vhost-scsi performance (SPDK vs. Kernel)

Intel Xeon Platinum 8180 Processor, 24x Intel P4800x 375GB
2 partitions per VM, 10 vhost I/O processing cores

- Aggregate IOPS across all 48x VMs reported. All VMs on separate cores than vhost-scsi cores.
- 10 vhost-scsi cores for I/O processing
- SPDK vhost-scsi up to 3.2x better with 4K 100% Random read I/Os
- Used cgroups to restrict kernel vhost-scsi processes to 10 cores

System Configuration:
Intel Xeon Platinum 8180 @ 2.5GHz. 56 physical cores 6x 16GB, 2667 DDR4, 6 memory Channels, SSD: Intel P4800x 375GB x24 drives, Bios: HT disabled, p-states enabled, turbo enabled, Ubuntu 16.04.1 LTS, 4.11.0 x86_64 kernel, 48 VMs, number of partition: 2, VM config: 1core 1GB memory, VM OS: fedora 25, blk-mq enabled, software packages: Qemu-2.9, libvirt-3.0.0, spdk (3bfec994), IO distribution: 10 vhost-cores for SPDK / Kernel. Rest 46 cores for QEMU using cgroups. FIO-2.1.10 with SPDK plugin, io depth=1, 8, 32 numjobs=1, direct=1, block size 4k
NUMA vs. Non-NUMA: SPDK vhost-scsi
Intel Xeon Platinum 8180 Processor, 24x Intel P4800x 375GB 48VMs, 10 vhost-scsi cores

- 10% performance improvement with NUMA optimized.
- NUMA optimization done to ensure vhost-scsi core match to NVMe drive socket location

System Configuration: Intel Xeon Platinum 8180 @ 2.5GHz. 56 physical cores 6x 16GB, 2667 DDR4, 6 memory Channels, SSD: Intel P4800x 375GB x24 drives, Bios: HT disabled, p-states enabled, turbo enabled, Ubuntu 16.04.1 LTS, 4.11.0 x86_64 kernel, 48 VMs, number of partition: 2, VM config: 1core 1GB memory, VM OS: fedora 25, blk-mq enabled, software packages: Qemu-2.9, libvirt-3.0.0, spdk (3bece994), IO distribution: 10 vhost-cores for SPDK / Kernel. Rest 46 cores for QEMU using cgroups, FIO-2.1.10 with SPDK plugin, io depth=1,8,32 numjobs=1, direct=1, block size 4k
Virtio-blk protocol extension

• Faster than virtio-scsi protocol due to eliminate SCSI middle layer inside Guest kernel
• Linux Block layer supports multi-queues for virtio-blk
• Lack of support for DISCARD/WRITE ZEROES commands.
• Virtio-Blk protocol specification has added this feature.

See https://github.com/oasis-tcs/virtio-spec for reference. Linux kernel driver and QEMU driver will be kicked soon.
Vhost-NVMe

• **What's vhost-nvme?**

  NVMe specification as the communication protocol between Guest and slave I/O target

  Make use of UNIX domain socket as the message channel to setup I/O queues and interrupt notifier for Guest

  NVMe 1.3 specification virtualization enhancement

• **What's the benefit?**

  Native kernel NVMe driver can be used inside VM without any extra modifications

  Eliminate the SCSI middle layer driver compared with exist vhost scsi solution, which can improve the performance
NVMe 1.3 Specification Enhancement

**Host Memory**

<table>
<thead>
<tr>
<th>Submission Queue</th>
<th>Completion Queue</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

**Submission Queue Tail**

<table>
<thead>
<tr>
<th>3</th>
</tr>
</thead>
</table>

**Completion Queue Head**

<table>
<thead>
<tr>
<th>3</th>
</tr>
</thead>
</table>

**NVMe 1.3 Virtualization Enhancement:**
1. Optional Admin Command Support
2. Doorbell Buffer Config
Vhost-NVMe Implementation

<table>
<thead>
<tr>
<th>Vhost Message Protocol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Get Controller Capabilities</td>
<td>Controller capabilities register of NVMe specification</td>
</tr>
<tr>
<td>Get Device ID</td>
<td>Vendor ID of the emulated NVMe controller of QEMU</td>
</tr>
<tr>
<td>Get/Set Controller Configuration</td>
<td>Enable/Disable emulated NVMe controller</td>
</tr>
<tr>
<td>Admin Command Pass-through</td>
<td>Admin commands routed to slave target</td>
</tr>
<tr>
<td>Set Memory Table</td>
<td>Sets the memory map regions on the slave target so it can translate the I/O queues' addresses.</td>
</tr>
<tr>
<td>Set Guest Notifier</td>
<td>Set the event file descriptor for the purpose to interrupt the Guest when I/O is completed.</td>
</tr>
<tr>
<td>Set Event Notifier</td>
<td>Set the event file descriptor for AER.</td>
</tr>
</tbody>
</table>

Table 1: Vhost socket messages

<table>
<thead>
<tr>
<th>Admin Commands</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify/Identify NS</td>
<td>QEMU gets the identify data from slave target, QEMU can cache it with a local copy to avoid repeated vhost messages.</td>
</tr>
<tr>
<td>Create/Delete Submission Queue</td>
<td>QEMU allocates/deletes the queues and send the Admin command to slave target.</td>
</tr>
<tr>
<td>Create/Delete Completion Queue</td>
<td>Each Create Completion Queue command should follow with a Set Guest Notifier for IRQ notification.</td>
</tr>
<tr>
<td>Abort</td>
<td>Slave target will process Abort command.</td>
</tr>
<tr>
<td>Asynchronous Event Request</td>
<td>QEMU sends the command to slave target and follows with a Set Event Notifier for real AER.</td>
</tr>
<tr>
<td>Doorbell Buffer Config</td>
<td>Set the shadow doorbell buffer in slave target</td>
</tr>
</tbody>
</table>

Table 2: Mandatory Admin commands in slave target
Use Cases

- Integrating SPDK Blobstore with RocksDB to MySQL inside VM

- Optane™ can be parted into several logical volumes to each VM for critical log usage.

- Enable WAL with SPDK to provide short I/O path without any data copies.
Benchmarks

1 VM with 1 NVMe SSD, 4 VCPU

Randread, IOPS(K), Higher is better

CPU Usage (usr+sys), lower is better

System Configuration: 2 * Intel Xeon E5 2699v4 @ 2.2GHz, 128GB, 2667 DDR4, 6 memory Channels, SSD: Intel P3700 800GB, FW: 8DV101H0, Bios: HT disabled, CentOS 7.4(kernel 4.12.5), 1 VMs, VM config: 4core 4GB memory, VM OS: Fedora 25(kernel 4.14.0), blk-mq enabled, Software packages: Qemu-2.11, IO distribution: 1 vhost-cores for SPDK, FIO, io depth=128 numjobs=1,2,4 direct=1, block size 4k.
Benchmarks and KVM Events

8 VMs shared 4 NVMe SSD, 4 VCPU

Randread, IOPS(K), Higher is better

1 VMs with 1 NVMe SSD, 4 VCPU

KVM Events, Lower is better

System Configuration: 2 * Intel Xeon E5 2699v4 @ 2.2GHz, 128GB, 2667 DDR4, 6 memory Channels, SSD: Intel P4510 2TB, FW: QDV1013A, Bios: HT disabled, CentOS 7.4(kernel 4.12.5), 1 VMs, VM config: 4core 4GB memory, VM OS: Fedora 25(kernel 4.14.0), blk-mq enabled. Software packages: Qemu-2.11, IO distribution: 1 vhost-cores for SPDK, FIO, io depth=128, numjobs=2; FIO, io depth=64 numjobs=4, size=100GB; direct=1 block size 4k, block size 4k.