SPDK

(Storage Performance Development Kit)

Contents

**** 版本修订记录 ****

版本号	*修订时间*	*修订内容*
v1.0	*2018-11-02*	*初版修订*

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1.Introduction:

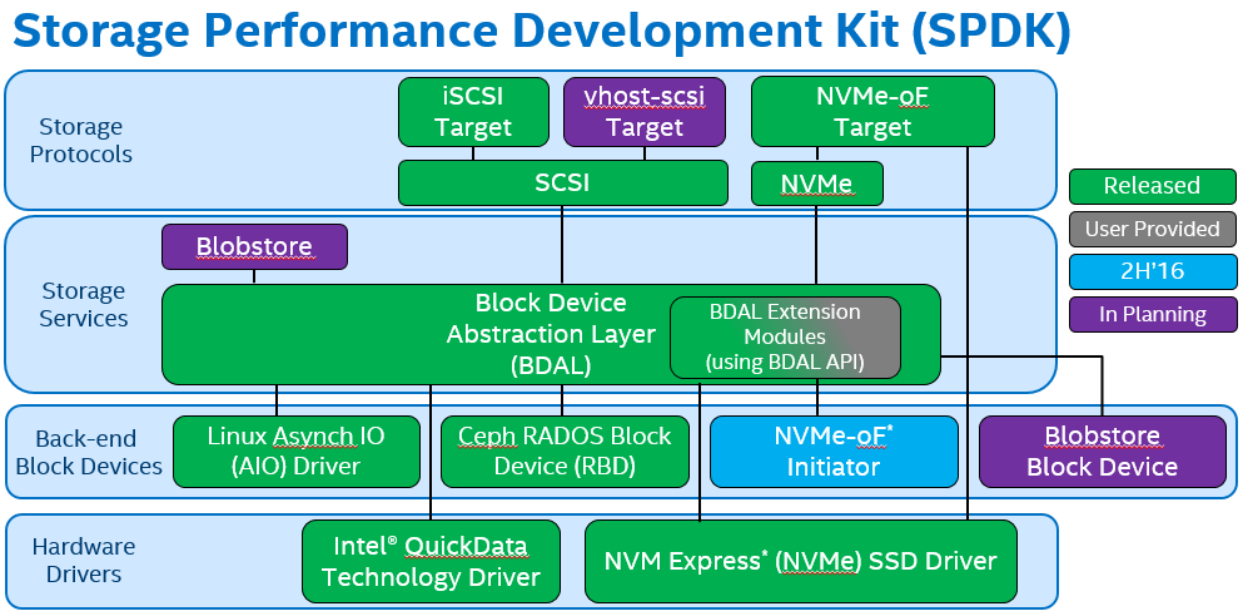
*Storage Performance Development Kit (**SPDK**)*

- Moving all of the necessary drivers into userspace, which avoids syscalls and enables zero-copy access from the application.
- Polling hardware for completions instead of relying on interrupts, which lowers both total latency and latency variance.
- Avoiding all locks in the I/O path, instead relying on message passing.

The bedrock of SPDK is a **user space**, **polled-mode**, **asynchronous**, **lockless NVMe driver**. This provides **zero-copy**, **highly parallel access directly to an SSD** from a user space application. The driver is written as a C library with a single public header.

SPDK further provides a full **block stack** as a user space library that performs many of the same operations as a block stack in an operating system. This includes unifying the interface between disparate storage devices, queueing to handle conditions such as out of memory or I/O hangs, and logical volume management.

Finally, SPDK provides **NVMe-oF**, **iSCSI**, and **vhost servers** built on top of these components that are capable of serving disks over the network or to other processes. The standard Linux kernel initiators for NVMe-oF and iSCSI interoperate with these targets, as well as QEMU with vhost. These servers can be up to an order of magnitude more CPU efficient than other implementations. These targets can be used as examples of how to implement a high performance storage target, or used as the basis for production deployments.



2.Getting Started:

a. get source code

```
[cpu@mon SPDK]$ git clone https://github.com/spdk/spdk
[cpu@mon SPDK]$ cd spdk/
[cpu@mon spdk]$ git submodule update --init
```

b. install prerequisites

```
[cpu@mon spdk]$ sudo scripts/pkgdep.sh
```

c.build

```
[cpu@mon spdk]$ ./configure
[cpu@mon spdk]$ make

# support RDMA
[cpu@mon spdk]$ ./configure --with-rdma
[cpu@mon spdk]$ make
```

d.run unit tests

```
[yang@admin spdk]$ ./test/unit/unittest.sh
```

3.Concepts:

a.User Space Driver

- a driver is software that directly controls a particular device attached to a computer
- operating systems segregate the system's virtual memory into two categories of addresses based on privilege level - kernel space and user space
- Once the device is unbound from the operating system kernel, the devices corresponding to it such as /dev/nvme0n1 will disappear.
- User space drivers utilize features in uio or vfio to map the PCI BAR for the device into the current process, which allows the driver to perform MMIO directly.

b.Interrupts

- SPDK polls devices for completions instead of waiting for interrupts.

- Operations in SPDK are almost universally asynchronous and allow the user to provide a callback on completion.
- Polling an NVMe device is fast(Intel's DDIO technologies)

c.Threading

- software can send requests to the device from multiple threads of execution in parallel without locks.

d.Memory Management:

- NVMe devices transfer data to and from system memory using Direct Memory Access (DMA);
- The NVMe 1.0 specification requires all physical memory to be describable by what is called a PRP list; memory must have the following properties:
    1. The memory is broken into physical 4KiB pages, which we'll call device pages.
    2. The first device page can be a partial page starting at any 4-byte aligned address. It may extend up to the end of the current physical page, but not beyond.
    3. If there is more than one device page, the first device page must end on a physical 4KiB page boundary.
    4. The last device page begins on a physical 4KiB page boundary, but is not required to end on a physical 4KiB page boundary.
- The NVMe 1.1 specification added support for fully flexible scatter gather lists, but the feature is optional and most devices available today do not support it.
- SPDK relies on DPDK to allocate pinned memory.

e.IOMMU Support

- All DMA operations between the PCI device and system memory are then translated through the IOMMU(input/output memory management unit) by converting the bus address to a virtual address and then the virtual address to the physical address.

f.Message Passing and Concurrency

- SPDK will often assign that data to a single thread.

4.Driver Modules

- NVMe Driver
    1. The NVMe driver is a C library that may be linked directly into an application that provides direct, zero-copy data transfer to and from NVMe SSDs.

2. it spawns no threads and only performs actions in response to function calls from the application itself.
3. The library controls NVMe devices by directly mapping the PCI BAR into the local process and performing MMIO(Memory-mapped IO).
4. I/O is submitted asynchronously via queue pairs.
5. the library has been improved to also connect to remote NVMe devices via NVMe over Fabrics.(spdk_nvme_probe())

```
# bind nvme driver  and allocate hugepages
[root@nvme spdk]# ./scripts/setup.sh status
Hugepages
node     hugesize     free /  total
node0     2048kB       0 /     0
NVMe devices
BDF          Numa Node      Driver name          Device name
0000:00:0e.0    0            nvme                nvme0
I/OAT DMA
BDF          Numa Node      Driver Name
virtio
BDF          Numa Node      Driver Name          Device Name
[root@nvme spdk]# ./scripts/setup.sh config
0000:00:0e.0 (80ee 4e56): nvme -> uio_pci_generic
[root@nvme spdk]# ./scripts/setup.sh status
Hugepages
node     hugesize     free /  total
node0     2048kB     1024 /   1024
NVMe devices
BDF          Numa Node      Driver name          Device name
0000:00:0e.0    0            uio_pci_generic       -
I/OAT DMA
BDF          Numa Node      Driver Name
virtio
BDF          Numa Node      Driver Name          Device Name

# run hello-world
[root@nvme spdk]# cd examples/nvme/hello_world/
[root@nvme hello_world]# ./hello_world
Starting SPDK v18.10-pre / DPDK 18.05.0 initialization...
[ DPDK EAL parameters: hello_world -c 0x1 --legacy-mem --file-prefix=spdk0 --base-
virtaddr=0x200000000000 --proc-type=auto ]
EAL: Detected 1 lcore(s)
EAL: Detected 1 NUMA nodes
EAL: Auto-detected process type: PRIMARY
EAL: Multi-process socket /var/run/dpdk/spdk0/mp_socket
EAL: Probing VFIO support...
EAL: WARNING! Base virtual address hint (0x20040008f000 != 0x7ff46def9000) not respected!
EAL:    This may cause issues with mapping memory into secondary processes
EAL: WARNING! Base virtual address hint (0x2008000f0000 != 0x7ff46de98000) not respected!
```

```
EAL:    This may cause issues with mapping memory into secondary processes
EAL: WARNING! Base virtual address hint (0x200c00151000 != 0x7ff46de37000) not respected!
EAL:    This may cause issues with mapping memory into secondary processes
Initializing NVMe Controllers
EAL: PCI device 0000:00:0e.0 on NUMA socket 0
EAL:   probe driver: 80ee:4e56 spdk_nvme
Attaching to 0000:00:0e.0

Message from syslogd@localhost at Oct  9 23:20:29 ...
 kernel:Disabling IRQ #22
Attached to 0000:00:0e.0
Using controller ORCL-VBOX-NVME-VER12 (VB1234-56789        ) with 1 namespaces.
  Namespace ID: 1 size: 8GB
Initialization complete.
INFO: using host memory buffer for IO
Hello world!
```

- I/OAT Driver

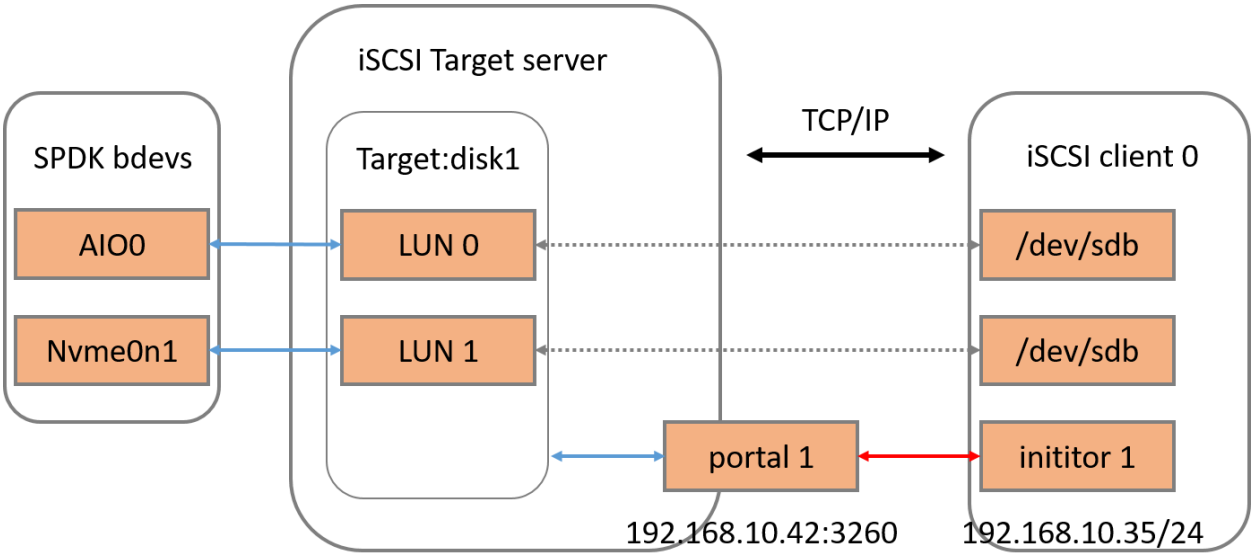
- Virtio Driver

The driver supports two different usage models:

- PCI : This is the standard mode of operation when used in a guest virtual machine, where QEMU has presented the virtio controller as a virtual PCI device.
- vhost-user : Can be used to connect to a vhost socket directly on the same host.

5.Application and tests:

- iSCSI




```
# configure target
[root@nvme spdk]# sudo scripts/setup.sh # if you have NVMe devices, you can execute this script to change the driver.
[root@nvme spdk]# cd app/iscsi_tgt/
[root@nvme iscsi_tgt]# cp ../../etc/spdk/iscsi.conf.in iscsi.conf # copy the configure file
[root@nvme iscsi_tgt]# vim iscsi.conf # edit iscsi configure file and you can reference the Appendix part of this document
[root@nvme iscsi_tgt]# ./iscsi_tgt -c iscsi.conf # start iscsi target
[root@nvme spdk]# ../spdk/scripts/rpc.py get_bdevs # get the device
[  {
    "name": "Nvme0n1",
    "aliases": [],
    "product_name": "NVMe disk",
    … …
    },
  {
    "name": "AIO0",
    "aliases": [],
    "product_name": "AIO disk",
    … …
    },
    "driver_specific": {
      "aio": {
        "filename": "/dev/sdb"
      }
    }
  }
]

# configure initiator
[root@mon1 ~]# yum -y install iscsi-initiator-utils
```

```
[root@mon1 ~]# rpm -qa | grep iscsi
iscsi-initiator-utils-iscsiuio-6.2.0.874-7.el7.x86_64
iscsi-initiator-utils-6.2.0.874-7.el7.x86_64
[root@mon1 ~]# vim /etc/iscsi/initiatorname.iscsi # edit initiator name
[root@mon1 ~]# cat /etc/iscsi/initiatorname.iscsi
InitiatorName=iqn.1994-05.com.redhat:8518f439a5c3
[root@mon1 ~]# systemctl start iscsid # start the daemon
[root@mon1 ~]# systemctl status iscsid
● iscsid.service - Open-iSCSI
   Loaded: loaded (/usr/lib/systemd/system/iscsid.service; disabled; vendor preset: disabled)
   Active: active (running) since Wed 2018-09-26 22:57:25 EDT; 26min ago

# Discovery and Login
# Run command on initiator
[root@admin ~]# iscsiadm -m discovery -t st -p 192.168.10.42
192.168.10.42:3260,1 iqn.2018-09.io.spdk:disk1
[root@admin ~]# iscsiadm -m node -T iqn.2018-09.io.spdk:disk1 -p 192.168.10.42 -l
Logging in to [iface: default, target: iqn.2018-09.io.spdk:disk1, portal: 192.168.10.42,3260] (multiple)
Login to [iface: default, target: iqn.2018-09.io.spdk:disk1, portal: 192.168.10.42,3260] successful.
[root@admin ~]# fdisk -l
Disk /dev/sdc: 8589 MB, 8589934592 bytes, 16777216 sectors
Units = sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 4096 bytes / 4194304 bytes

Disk /dev/sde: 8589 MB, 8589934592 bytes, 16777216 sectors
Units = sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 4096 bytes / 4194304 bytes

# Logout from the target
[root@admin ~]# iscsiadm -m node -T iqn.2018-09.io.spdk:disk1 -p 192.168.10.42 -u
Logging out of session [sid: 5, target: iqn.2018-09.io.spdk:disk1, portal: 192.168.10.42,3260]
Logout of [sid: 5, target: iqn.2018-09.io.spdk:disk1, portal: 192.168.10.42,3260] successful.

# Tunning
[root@admin ~]# echo noop > /sys/block/sdc/queue/scheduler
[root@admin ~]# echo "2" > /sys/block/sdc/queue/nomerges
[root@admin ~]# echo "1024" > /sys/block/sdc/queue/nr_requests
```

- NVMe over Fabrics(SoftRoCE)

```
# Target and Initiator
[root@rocet nvmf_tgt]# pwd
/data/spdk/app/nvmf_tgt
[root@rocet nvmf_tgt]# lsmod | grep nvme
```

```
nvme_rdma           32768  0
rdma_cm             69632  7 rpcrdma,ib_srpt,ib_srp,nvme_rdma,ib_iser,ib_isert,rdma_ucm
ib_core            278528  14
rdma_cm,ib_ipoib,rdma_rxe,rpcrdma,ib_srpt,ib_srp,nvme_rdma,iw_cm,ib_iser,ib_umad,ib_isert,rdm
a_ucm,ib_uverbs,ib_cm
nvme_fabrics        24576  1 nvme_rdma
nvme                36864  0
nvme_core           81920  3 nvme,nvme_rdma,nvme_fabrics
[root@rocet nvmf_tgt]# lsmod | grep rdma_rxe
rdma_rxe           126976  0
ip6_udp_tunnel      16384  1 rdma_rxe
udp_tunnel          16384  1 rdma_rxe
ib_core            278528  14
rdma_cm,ib_ipoib,rdma_rxe,rpcrdma,ib_srpt,ib_srp,nvme_rdma,iw_cm,ib_iser,ib_umad,ib_isert,rdm
a_ucm,ib_uverbs,ib_cm
[root@rocet nvmf_tgt]#

# Target
[root@rocet nvmf_tgt]# cp ../../etc/spdk/nvmf.conf.in nvmf.conf
[root@rocet nvmf_tgt]# vim nvmf.conf # edit configuration file and reference nvmf.conf in Appendix
of this document.
[root@rocet nvmf_tgt]# ./nvmf_tgt -c nvmf.conf
Starting SPDK v18.07 / DPDK 18.05.0 initialization...
[ DPDK EAL parameters: nvmf -c 0x1 --legacy-mem --file-prefix=spdk_pid3775 ]
EAL: Detected 1 lcore(s)
EAL: Detected 1 NUMA nodes
EAL: Multi-process socket /var/run/dpdk/spdk_pid3775/mp_socket
EAL: Probing VFIO support...
app.c: 530:spdk_app_start: *NOTICE*: Total cores available: 1
reactor.c: 718:spdk_reactors_init: *NOTICE*: Occupied cpu socket mask is 0x1
reactor.c: 492:_spdk_reactor_run: *NOTICE*: Reactor started on core 0 on socket 0
EAL: PCI device 0000:00:0e.0 on NUMA socket 0
EAL:   probe driver: 80ee:4e56 spdk_nvme

# Initiator
[root@rocei ~]# yum -y install nvme-cli
[root@rocei ~]# nvme discover -t rdma -a 192.168.10.52
Discovery Log Number of Records 1, Generation counter 4
=====Discovery Log Entry 0======
trtype:  rdma
adrfam:  ipv4
subtype: nvme subsystem
treq:    not specified
portid:  0
trsvcid: 4420
subnqn:  nqn.2016-06.io.spdk:cnode1
traddr:  192.168.10.52
rdma_prtype: not specified
```

```
rdma_qptype: connected
rdma_cms:    rdma-cm
rdma_pkey: 0x0000

[root@rocei ~]# nvme connect -t rdma -n "nqn.2016-06.io.spdk:cnode1" -a 192.168.10.52 -s 4420
[root@rocei ~]# fdisk -l
Disk /dev/nvme0n1: 50 GiB, 53687091200 bytes, 104857600 sectors
Units: sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes

# Initiator fio and perf test
# fio file fio_softroce.job append in Appendix
[root@rocei ~]# fio fio_softroce.job
job0: (g=0): rw=randrw, bs=(R) 4096B-4096B, (W) 4096B-4096B, (T) 4096B-4096B, ioengine=libaio,
iodepth=128
fio-3.3
Starting 1 thread
Jobs: 1 (f=1): [m(1)][100.0%][r=61.1MiB/s,w=59.0MiB/s][r=15.6k,w=15.3k IOPS][eta 00m:00s]
job0: (groupid=0, jobs=1): err= 0: pid=3737: Fri Nov  2 14:49:52 2018
   read: IOPS=17.3k, BW=67.7MiB/s (70.0MB/s)(677MiB/10001msec)
    slat (usec): min=3, max=2512, avg= 8.71, stdev=23.13
    clat (usec): min=400, max=18418, avg=3711.75, stdev=796.46
     lat (usec): min=408, max=18425, avg=3720.61, stdev=794.04
    clat percentiles (usec):
     |  1.00th=[ 1205],  5.00th=[ 2966], 10.00th=[ 3163], 20.00th=[ 3294],
     | 30.00th=[ 3425], 40.00th=[ 3523], 50.00th=[ 3621], 60.00th=[ 3752],
     | 70.00th=[ 3916], 80.00th=[ 4146], 90.00th=[ 4555], 95.00th=[ 4948],
     | 99.00th=[ 5932], 99.50th=[ 6652], 99.90th=[10159], 99.95th=[11863],
     | 99.99th=[16057]
   bw (  KiB/s): min=62698, max=74360, per=100.00%, avg=69531.11, stdev=3181.02, samples=19
   iops        : min=15674, max=18590, avg=17382.74, stdev=795.34, samples=19
  write: IOPS=17.3k, BW=67.6MiB/s (70.9MB/s)(676MiB/10001msec)
    slat (usec): min=4, max=6789, avg= 9.24, stdev=31.20
    clat (usec): min=361, max=16183, avg=3656.96, stdev=804.29
     lat (usec): min=399, max=16190, avg=3666.34, stdev=802.19
    clat percentiles (usec):
     |  1.00th=[ 1156],  5.00th=[ 2638], 10.00th=[ 3130], 20.00th=[ 3261],
     | 30.00th=[ 3392], 40.00th=[ 3490], 50.00th=[ 3589], 60.00th=[ 3720],
     | 70.00th=[ 3884], 80.00th=[ 4080], 90.00th=[ 4490], 95.00th=[ 4883],
     | 99.00th=[ 5735], 99.50th=[ 6390], 99.90th=[ 9372], 99.95th=[11863],
     | 99.99th=[15926]
   bw (  KiB/s): min=61421, max=74168, per=100.00%, avg=69489.68, stdev=3392.20, samples=19
   iops        : min=15355, max=18542, avg=17372.37, stdev=848.17, samples=19
  lat (usec)   : 500=0.01%, 750=0.01%, 1000=0.22%
  lat (msec)   : 2=3.24%, 4=71.90%, 10=24.52%, 20=0.10%
  cpu          : usr=8.35%, sys=23.85%, ctx=7572, majf=0, minf=1
  IO depths    : 1=0.1%, 2=0.1%, 4=0.1%, 8=0.1%, 16=0.1%, 32=0.1%, >=64=100.0%
```

```
    submit    : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
    complete  : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.1%
    issued rwts: total=173357,173083,0,0 short=0,0,0,0 dropped=0,0,0,0
    latency   : target=0, window=0, percentile=100.00%, depth=128

Run status group 0 (all jobs):
   READ: bw=67.7MiB/s (70.0MB/s), 67.7MiB/s-67.7MiB/s (70.0MB/s-70.0MB/s), io=677MiB (710MB),
run=10001-10001msec
  WRITE: bw=67.6MiB/s (70.9MB/s), 67.6MiB/s-67.6MiB/s (70.9MB/s-70.9MB/s), io=676MiB (709MB),
run=10001-10001msec

Disk stats (read/write):
  nvme0n1: ios=171328/171110, merge=0/0, ticks=493028/486217, in_queue=1078298, util=97.97%

[root@rocei perf]# pwd
/data/spdk/examples/nvme/perf
[root@rocei perf]# ./perf -q 16 -s 4096 -w randwrite -t 10 /dev/nvme1n1
Starting SPDK v18.07 / DPDK 18.05.0 initialization...
[ DPDK EAL parameters: perf -c 0x1 --legacy-mem --file-prefix=spdk_pid4575 ]
EAL: Detected 1 lcore(s)
EAL: Detected 1 NUMA nodes
EAL: Multi-process socket /var/run/dpdk/spdk_pid4575/mp_socket
EAL: Probing VFIO support...
Initializing NVMe Controllers
EAL: PCI device 0000:00:0e.0 on NUMA socket 0
EAL:   probe driver: 80ee:4e56 spdk_nvme
Attaching to NVMe Controller at 0000:00:0e.0
Attached to NVMe Controller at 0000:00:0e.0 [80ee:4e56]
Associating ORCL-VBOX-NVME-VER12 (VB1234-56789       ) with lcore 0
Associating /dev/nvme1n1 with lcore 0
Initialization complete. Launching workers.
Starting thread on core 0
========================================================
                                                                    Latency(us)
Device Information                       :       IOPS      MB/s    Average       min       max
/dev/nvme1n1                     from core 0:     238.10       0.93   67594.83     682.64  963620.77
ORCL-VBOX-NVME-VER12 (VB1234-56789       ) from core 0:     394.60       1.54   41004.28      61.87
216086.25
========================================================
Total                                    :     632.70       2.47   51010.94      61.87  963620.77

# disconnect nvme device
[root@rocei perf]# nvme disconnect -d /dev/nvme1n1
```

6.Performance:

- fio-plugin

```
# compile fio-plugin
[yang@nvme fio]$ git clone https://github.com/axboe/fio
[yang@nvme SPDK]$ cd fio/
[yang@nvme fio]$ git checkout fio-3.3
[yang@nvme spdk]$ ./configure --with-fio=/home/yang/SPDK/fio/fio/
[yang@nvme spdk]$ make

# Usage
[root@nvme master-fio]# mkdir fio
[root@nvme fio]# cp ../spdk/etc/spdk/nvmf.conf.in nvmf.conf
[root@nvme fio]# vim nvmf.conf # just edit the [Nvme] part
[Nvme]
  TransportID "trtype:PCIe traddr:0000:00:0e.0" Nvme0

  RetryCount 4

  TimeoutUsec 0

  ActionOnTimeout None

  AdminPollRate 100000

  HotplugEnable No

# edit fio script
[root@nvme fio]# touch example.fio
[root@nvme fio]# vim example.fio
[global]
ioengine=spdk_bdev
spdk_conf=/home/yang/SPDK/master-fio/fio/nvmf.conf
thread=1
group_reporting=1
direct=1
verify=0
time_based=1
ramp_time=0
runtime=60
iodepth=128
rw=randread
bs=4k

[test]
numjobs=1
filename=Nvme0n1

# run fio
```

```
[root@nvme fio]# LD_PRELOAD=/home/yang/SPDK/master-
fio/spdk/examples/bdev/fio_plugin/fio_plugin /home/yang/SPDK/fio/fio/fio
/home/yang/SPDK/master-fio/fio/example.fio
test: (g=0): rw=randread, bs=(R) 4096B-4096B, (W) 4096B-4096B, (T) 4096B-4096B,
ioengine=spdk_bdev, iodepth=128
fio-3.3
Starting 1 thread
Starting SPDK v18.10-pre / DPDK 18.05.0 initialization...
[ DPDK EAL parameters: fio --no-shconf -c 0x1 --legacy-mem --file-prefix=spdk_pid4855 ]
EAL: Detected 1 lcore(s)
EAL: Detected 1 NUMA nodes
EAL: Multi-process socket /var/run/dpdk/spdk_pid4855/mp_socket
EAL: Probing VFIO support...
EAL: PCI device 0000:00:0e.0 on NUMA socket 0
EAL:   probe driver: 80ee:4e56 spdk_nvme
Jobs: 1 (f=1): [r(1)][100.0%][r=648MiB/s,w=0KiB/s][r=166k,w=0 IOPS][eta 00m:00s]
test: (groupid=0, jobs=1): err= 0: pid=4862: Wed Oct 10 02:59:15 2018
   read: IOPS=166k, BW=649MiB/s (680MB/s)(38.0GiB/60001msec)
    slat (usec): min=2, max=7657, avg= 4.67, stdev= 9.66
    clat (usec): min=2, max=14540, avg=633.75, stdev=757.57
     lat (usec): min=5, max=14551, avg=638.42, stdev=757.59
    clat percentiles (usec):
     |  1.00th=[    9],  5.00th=[   18], 10.00th=[   37], 20.00th=[   96],
     | 30.00th=[  184], 40.00th=[  285], 50.00th=[  383], 60.00th=[  482],
     | 70.00th=[  603], 80.00th=[  947], 90.00th=[ 1811], 95.00th=[ 2409],
     | 99.00th=[ 3130], 99.50th=[ 3556], 99.90th=[ 4686], 99.95th=[ 5473],
     | 99.99th=[ 7504]
   bw (  KiB/s): min=496275, max=690693, per=98.80%, avg=656126.07, stdev=25096.54, samples=119
   iops        : min=124068, max=172673, avg=164031.13, stdev=6274.11, samples=119
  lat (usec)   : 4=0.05%, 10=1.97%, 20=3.75%, 50=7.12%, 100=7.68%
  lat (usec)   : 250=16.09%, 500=25.06%, 750=14.12%, 1000=5.16%
  lat (msec)   : 2=10.61%, 4=8.14%, 10=0.26%, 20=0.01%
  cpu          : usr=99.41%, sys=0.07%, ctx=5178, majf=0, minf=9
  IO depths    : 1=0.1%, 2=0.1%, 4=0.1%, 8=0.1%, 16=0.1%, 32=0.1%, >=64=100.0%
     submit    : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
     complete  : 0=0.0%, 4=97.5%, 8=0.5%, 16=0.4%, 32=0.4%, 64=1.3%, >=64=0.1%
     issued rwt: total=9961517,0,0, short=0,0,0, dropped=0,0,0
     latency   : target=0, window=0, percentile=100.00%, depth=128

Run status group 0 (all jobs):
   READ: bw=649MiB/s (680MB/s), 649MiB/s-649MiB/s (680MB/s-680MB/s), io=38.0GiB (40.8GB),
run=60001-60001msec
```

- perf

```
[root@nvme spdk]# ./scripts/setup.sh status
```

```
Hugepages
node     hugesize     free /  total
node0      2048kB       0 /   1024
NVMe devices
BDF           Numa Node      Driver name           Device name
0000:00:0e.0    0            uio_pci_generic        -
I/OAT DMA
BDF           Numa Node      Driver Name
virtio
BDF           Numa Node      Driver Name           Device Name

# perf options
       [-q io depth]
       [-o io size in bytes]
       [-w io pattern type, must be one of
             (read, write, randread, randwrite, rw, randrw)]
       [-M rwmixread (100 for reads, 0 for writes)]
       [-L enable latency tracking via sw, default: disabled]
             -L for latency summary, -LL for detailed histogram
       [-l enable latency tracking via ssd (if supported), default: disabled]
       [-t time in seconds]
       [-c core mask for I/O submission/completion.]
             (default: 1)]
       [-D disable submission queue in controller memory buffer, default: enabled]
       [-r Transport ID for local PCIe NVMe or NVMeoF]
        Format: 'key:value [key:value] ...'
        Keys:
         trtype      Transport type (e.g. PCIe, RDMA)
         adrfam      Address family (e.g. IPv4, IPv6)
         traddr      Transport address (e.g. 0000:04:00.0 for PCIe or 192.168.100.8 for RDMA)
         trsvcid     Transport service identifier (e.g. 4420)
         subnqn      Subsystem NQN (default: nqn.2014-08.org.nvmexpress.discovery)
        Example: -r 'trtype:PCIe traddr:0000:04:00.0' for PCIe or
              -r 'trtype:RDMA adrfam:IPv4 traddr:192.168.100.8 trsvcid:4420' for NVMeoF
       [-e metadata configuration]
        Keys:
         PRACT       Protection Information Action bit (PRACT=1 or PRACT=0)
         PRCHK       Control of Protection Information Checking (PRCHK=GUARD|REFTAG|APPTAG)
        Example: -e 'PRACT=0,PRCHK=GUARD|REFTAG|APPTAG'
              -e 'PRACT=1,PRCHK=GUARD'
       [-s DPDK huge memory size in MB.]
       [-m max completions per poll]
             (default: 0 - unlimited)
       [-i shared memory group ID]

[root@nvme spdk]# cd examples/nvme/perf/
[root@nvme perf]# ./perf -q 128 -s 4096 -w randread -r 'trtype:PCIe traddr:0000:00:0e.0' -t 10
Starting SPDK v18.10-pre / DPDK 18.05.0 initialization...
```

```
[ DPDK EAL parameters: perf --no-shconf -c 0x1 --legacy-mem --file-prefix=spdk_pid3013 ]
EAL: Detected 1 lcore(s)
EAL: Detected 1 NUMA nodes
EAL: Multi-process socket /var/run/dpdk/spdk_pid3013/mp_socket
EAL: Probing VFIO support...
Initializing NVMe Controllers
EAL: PCI device 0000:00:0e.0 on NUMA socket 0
EAL:   probe driver: 80ee:4e56 spdk_nvme
Attaching to NVMe Controller at 0000:00:0e.0
Attached to NVMe Controller at 0000:00:0e.0 [80ee:4e56]
Associating ORCL-VBOX-NVME-VER12 (VB1234-56789       ) with lcore 0
Initialization complete. Launching workers.
Starting thread on core 0
========================================================
                                                                    Latency(us)
Device Information                       :       IOPS      MB/s    Average       min       max
ORCL-VBOX-NVME-VER12 (VB1234-56789       ) from core 0:  227018.20     886.79     563.78      5.46
9584.33
========================================================
Total                                    :  227018.20     886.79     563.78      5.46    9584.33

[root@nvme perf]#
```

7.Questions:

Q:
Crypto requires NASM version 2.12.02 or newer. Please install;
A: build newer nasm rpm package for arm.

```
[cpu@mon rpmsrc]$ wget https://www.nasm.us/pub/nasm/stable/linux/nasm-2.13.03-
0.fc24.src.rpm
[cpu@mon rpmsrc]$ rpm2cpio nasm-2.13.03-0.fc24.src.rpm | cpio -div
nasm-2.13.03.tar.xz
nasm.spec
1582 blocks
[cpu@mon rpmsrc]$ mkdir -p /home/cpu/NASM/aarch64
[cpu@mon rpmsrc]$ vim ~/.rpmmacros
%_topdir       /home/cpu/NASM/aarch64 # add this line

[cpu@mon rpmsrc]$ rpmdev-setuptree
[cpu@mon rpmsrc]$ mv nasm.spec ~/NASM/aarch64/SPECS/
[cpu@mon rpmsrc]$ mv nasm-2.13.03.tar.xz ~/NASM/aarch64/SOURCES/
[cpu@mon rpmsrc]$ cd ~/NASM/aarch64/SPECS/
[cpu@mon SPECS]$ ls
nasm.spec
```

[cpu@mon SPECS]$ sudo yum -y install asciidoc xmlto adobe-source-sans-pro-fonts adobe-source-code-pro-fonts perl-Font-TTF perl-Sort-Versions
[cpu@mon SPECS]$ rpmbuild -ba nasm.spec
[cpu@mon SPECS]$ cd ../RPMS/aarch64/
[cpu@mon aarch64]$ sudo yum -y install nasm-2.13.03-0.el7.aarch64.rpm

Q: log.c:40:23: fatal error: libunwind.h: No such file or directory
#include <libunwind.h>
A: [yang@nvme spdk]$ sudo yum -y install libunwind libunwind-devel

Q: EAL: Failed to create shared memory!
A: Privilege problem, Use super user to run spdk if possible.

Q: EAL: Multi-process socket /var/run/dpdk/spdk_pid1688/mp_socket
EAL: No free hugepages reported in hugepages-2048Kb
A:
[root@nvme hello_world]# cat /proc/meminfo | grep Huge
AnonHugePages: 14336 kB
HugePages_Total: 0
HugePages_Free: 0
HugePages_Rsvd: 0
HugePages_Surp: 0
Hugepagesize: 2048 kB
[root@nvme hello_world]# echo 1024 > /sys/kernel/mm/hugepages/hugepages-2048kB/nr_hugepages
[root@nvme hello_world]# cat /proc/meminfo | grep Huge
AnonHugePages: 14336 kB
HugePages_Total: 1024
HugePages_Free: 1024
HugePages_Rsvd: 0
HugePages_Surp: 0
Hugepagesize: 2048 kB
[root@nvme hello_world]#

Q:[root@nvme spdk]# ./scripts/spdkcli.py help
Traceback (most recent call last):
File "./scripts/spdkcli.py", line 5, in <module>
from configshell_fb import ConfigShell
ModuleNotFoundError: No module named 'configshell_fb'
A:
[root@nvme spdk]# pip install configshell_fb

Q:
CUnit/Basic.h: No such file or directory
A:
[root@roce spdk]# yum -y install CUnit CUnit-devel

Q:
fatal error: numa.h: No such file or directory
A:
[root@rocet spdk]# yum -y install numactl-devel

Q:
fatal error: libaio.h: No such file or directory
A:
[root@rocet spdk]# yum -y install libaio-devel

Q:
fatal error: uuid/uuid.h: No such file or directory
A:
[root@rocet spdk]# yum -y install libuuid-devel

8.Appendix

- iscsi.conf

```
# iSCSI target configuration file
#
# Please write all parameters using ASCII.
# The parameter must be quoted if it includes whitespace.
#
# Configuration syntax:
# Leading whitespace is ignored.
# Lines starting with '#' are comments.
# Lines ending with '\' are concatenated with the next line.
# Bracketed ([]) names define sections

[Global]
  # Shared Memory Group ID. SPDK applications with the same ID will share memory.
  # Default: <the process PID>
  #SharedMemoryID 0

  # Disable PCI access. PCI is enabled by default. Setting this
  # option will hide any PCI device from all SPDK modules, making
  # SPDK act as if they don't exist.
  #NoPci Yes

  # Tracepoint group mask for spdk trace buffers
  # Default: 0x0 (all tracepoint groups disabled)
  # Set to 0xFFFF to enable all tracepoint groups.
  #TpointGroupMask 0x0
```

```
# Users may activate entries in this section to override default values for
# global parameters in the block device (bdev) subsystem.
[Bdev]
  # Number of spdk_bdev_io structures allocated in the global bdev subsystem pool.
  #BdevIoPoolSize 65536

  # Maximum number of spdk_bdev_io structures to cache per thread.
  #BdevIoCacheSize 256

[iSCSI]
  # node name (not include optional part)
  # Users can optionally change this to fit their environment.
  NodeBase "iqn.2018-09.io.spdk"

  AuthFile /usr/local/etc/spdk/auth.conf

  MinConnectionsPerCore 4

  # Socket I/O timeout sec. (0 is infinite)
  Timeout 30

  # authentication information for discovery session
  # Options:
  # None, Auto, CHAP and Mutual.  Note that Mutual infers CHAP.
  DiscoveryAuthMethod Auto

  #MaxSessions 128
  #MaxConnectionsPerSession 2

  # iSCSI initial parameters negotiate with initiators
  # NOTE: incorrect values might crash
  DefaultTime2Wait 2
  DefaultTime2Retain 60

  # Maximum amount in bytes of unsolicited data the iSCSI
  # initiator may send to the target during the execution of
  # a single SCSI command.
  FirstBurstLength 8192

  ImmediateData Yes
  ErrorRecoveryLevel 0

# Users must change the PortalGroup section(s) to match the IP addresses
#  for their environment.
# PortalGroup sections define which network portals the iSCSI target
#  will use to listen for incoming connections.  These are also used to
#  determine which targets are accessible over each portal group.
```

```
# Up to 1024 portal directives are allowed.  These define the network
#  portals of the portal group. The user must specify a IP address
#  for each network portal, and may optionally specify a port and
#  a cpumask. If the port is omitted, 3260 will be used. Cpumask will
#  be used to set the processor affinity of the iSCSI connection
#  through the portal.  If the cpumask is omitted, cpumask will be
#  set to all available processors.
#  Syntax:
#    Portal <Name> <IP address>[:<port>[@<cpumask>]]
[PortalGroup1]
  Portal DA1 192.168.10.42:3260 # edit the IP address
# Portal DA2 192.168.10.42:3260@0xF

# Users must change the InitiatorGroup section(s) to match the IP
#  addresses and initiator configuration in their environment.
# Netmask can be used to specify a single IP address or a range of IP addresses
#  Netmask 192.168.1.20   <== single IP address
#  Netmask 192.168.1.0/24 <== IP range 192.168.1.*
[InitiatorGroup1]
  InitiatorName ANY
  Netmask 192.168.10.0/24 # filter for initiator which can connect to this target

# NVMe configuration options
[Nvme]
  # NVMe Device Whitelist
  # Users may specify which NVMe devices to claim by their transport id.
  # See spdk_nvme_transport_id_parse() in spdk/nvme.h for the correct format.
  # The second argument is the assigned name, which can be referenced from
  # other sections in the configuration file. For NVMe devices, a namespace
  # is automatically appended to each name in the format <YourName>nY, where
  # Y is the NSID (starts at 1).
  TransportID "trtype:PCIe traddr:0000:00:0e.0" Nvme0 # this is the address of your NVMe devices.
Use command ‘lspci’ to seek the number.
  # TransportID "trtype:PCIe traddr:0000:01:00.0" Nvme1

  # The number of attempts per I/O when an I/O fails. Do not include
  # this key to get the default behavior.
  RetryCount 4
  # Timeout for each command, in microseconds. If 0, don't track timeouts.
  TimeoutUsec 0
  # Action to take on command time out. Only valid when Timeout is greater
  # than 0. This may be 'Reset' to reset the controller, 'Abort' to abort
  # the command, or 'None' to just print a message but do nothing.
  # Admin command timeouts will always result in a reset.
  ActionOnTimeout None
  # Set how often the admin queue is polled for asynchronous events.
  # Units in microseconds.
  AdminPollRate 100000
```

```
  # Disable handling of hotplug (runtime insert and remove) events,
  # users can set to Yes if want to enable it.
  # Default: No
  HotplugEnable No

  # Set how often the hotplug is processed for insert and remove events.
  # Units in microseconds.
  HotplugPollRate 0

# Users may change this section to create a different number or size of
#  malloc LUNs.
# If the system has hardware DMA engine, it can use an IOAT
# (i.e. Crystal Beach DMA) channel to do the copy instead of memcpy
# by specifying "Enable Yes" in [Ioat] section.
# Offload is disabled by default even it is available.
[Malloc]
  # Number of Malloc targets
  NumberOfLuns 3
  # Malloc targets are 128M
  LunSizeInMB 128
  # Block size. Default is 512 bytes.
  BlockSize 4096

# Users can use offload by specifying "Enable Yes" in this section
# if it is available.
# Users may use the whitelist to initialize specified devices, IDS
#  uses BUS:DEVICE.FUNCTION to identify each Ioat channel.
[Ioat]
  Enable No
  Whitelist 00:04.0
  Whitelist 00:04.1

# Users must change this section to match the /dev/sdX devices to be
# exported as iSCSI LUNs. The devices are accessed using Linux AIO.
# The format is:
# AIO <file name> <bdev name> [<block size>]
# The file name is the backing device
# The bdev name can be referenced from elsewhere in the configuration file.
# Block size may be omitted to automatically detect the block size of a disk.
[AIO]
  # AIO /dev/sdb AIO0
  AIO /dev/sdb AIO0 # a block device must exist
  # AIO /tmp/myfile AIO2 4096

# PMDK libpmemblk-based block device
[Pmem]
  # Syntax:
```

```
  #   Blk <pmemblk pool file name> <bdev name>
  Blk /path/to/pmem-pool Pmem0

# The Split virtual block device slices block devices into multiple smaller bdevs.
# [Split]
  # Syntax:
  #   Split <bdev> <count> [<size_in_megabytes>]

  # Split Malloc1 into two equally-sized portions, Malloc1p0 and Malloc1p1
# Split Malloc1 2

  # Split Malloc2 into eight 1-megabyte portions, Malloc2p0 ... Malloc2p7,
  # leaving the rest of the device inaccessible
# Split Malloc2 8 1

# Users should change the TargetNode section(s) below to match the
#  desired iSCSI target node configuration.
# TargetName, Mapping, LUN0 are minimum required
[TargetNode1]
  TargetName disk1
  TargetAlias "Data Disk1"
  Mapping PortalGroup1 InitiatorGroup1
  AuthMethod Auto
  AuthGroup AuthGroup1
  # Enable header and data digest
  # UseDigest Header Data
  UseDigest Auto
  # Use the first malloc target
  # LUN0 Malloc0
  # Using the first AIO target
  LUN0 AIO0
  LUN1 Nvme0n1
  # Using the second storage target
  # LUN2 AIO1
  # Using the third storage target
  # LUN3 AIO2
  QueueDepth 128

#[TargetNode2]
  # TargetName disk2
  # TargetAlias "Data Disk2"
  #Mapping PortalGroup1 InitiatorGroup1
  # AuthMethod Auto
  # AuthGroup AuthGroup1
  # UseDigest Auto
  # LUN0 Nvme0n1
  # QueueDepth 32
```

- SPDK API

- fio_softroce.job

```
[global]
invalidate=1
norandommap=1
thread=1
rw=randrw
runtime=10
ioengine=libaio
direct=1
bs=4096
size=1G
iodepth=128
group_reporting
time_based=1
[job0]
filename=/dev/nvme0n1
```

9.Reference:

- URL

[1].SOURCE CODE: *https://github.com/spdk/spdk*

[2].ROADMAP: *http://spdk.io/roadmap/*

[3].SPDK fio:https://www.jianshu.com/p/3a38a4d10d94

[4]. Introduction to the Storage Performance Development Kit (SPDK):*https://software.intel.com/en-us/articles/introduction-to-the-storage-performance-development-kit-spdk?language=en-us&https=1*

- Explanation

MMIO:

Memory-mapped I/O(MMIO) uses the same address space to address both memory and I/O devices. The memory and registers of the I/O devices are mapped to (associated with) address values.

the CPU instructions used to access the memory can also be used for accessing devices(https://en.wikipedia.org/wiki/Memory-mapped_I/O).

PMIO:

Port-mapped I/O(PMIO) often uses a special class of CPU instructions designed specifically for performing I/O, such as the in and out instructions. I/O devices have a separate address space from general memory, either accomplished by an extra "I/O" pin on the CPU's physical interface, or an entire bus dedicated to I/O(https://en.wikipedia.org/wiki/Memory-mapped_I/O).

10.Compile SPDK for Arm:

- v18.04

```
[cpu@mon spdk-v18.04]$ git clone -b v18.04 https://github.com/spdk/spdk.git
[cpu@mon spdk-v18.04]$ cd spdk/
[cpu@mon spdk]$ git submodule update --init
[cpu@mon spdk]$ sudo scripts/pkgdep.sh
[cpu@mon spdk]$ ./configure
[cpu@mon spdk]$ make
```

- v18.07

```
 [cpu@mon spdk-v18.07]$ git clone -b v18.07 https://github.com/spdk/spdk.git
[cpu@mon spdk-v18.07]$ cd spdk/
[cpu@mon spdk]$ git submodule update --init
[cpu@mon spdk]$ sudo scripts/pkgdep.sh
[cpu@mon spdk]$ ./configure
[cpu@mon spdk]$ make

Q:
error: unknown field ‘ndo_change_mtu_rh74’ specified in initializer
A:
[cpu@mon spdk]$ vim dpdk/kernel/linux/kni/compat.h
107 #define ndo_change_mtu ndo_change_mtu_rh74 # comment this line

Q:
Error: constant expression required at operand 1 -- `dsb lt'
A:
[cpu@mon spdk]$ vim CONFIG
62 CONFIG_TESTS?=n # edit to n
```

- v18.10(master)

```
[cpu@mon spdk-v18.07]$ git clone https://github.com/spdk/spdk.git
[cpu@mon spdk-v18.04]$ cd spdk/
[cpu@mon spdk]$ vim scripts/pkgdep.sh
# comment these lines below
95                # make
96                # make install
[cpu@mon spdk]$ sudo scripts/pkgdep.sh
[cpu@mon spdk]$ cd ../../
[cpu@mon compile]$ mkdir dpdk/
[cpu@mon dpdk]$ git clone https://github.com/DPDK/dpdk.git
[cpu@mon dpdk]$ cd dpdk/
[cpu@mon dpdk]$ vim kernel/linux/kni/compat.h
# comment this line
107 //#define ndo_change_mtu ndo_change_mtu_rh74
[cpu@mon dpdk]$ make config T=arm64-armv8a-linuxapp-gcc
[cpu@mon dpdk]$ make install T=arm64-armv8a-linuxapp-gcc

Q:
home/cpu/SPDK/compile/dpdk/dpdk/drivers/event/octeontx/timvf_worker.c:88:1: error: could not split insn
A: recompile GCC for arm.
```

11.GCC:

- compile

```
[cpu@mon GCC]$ wget http://mirrors.concertpass.com/gcc/releases/gcc-7.2.0/gcc-7.2.0.tar.gz
[cpu@mon GCC]$ tar -zxvf gcc-7.2.0.tar.gz
[cpu@mon GCC]$ cd gcc-7.2.0
[cpu@mon gcc-7.2.0]$ sudo ./contrib/download_prerequisites
[cpu@mon gcc-7.2.0]$ ./configure --prefix=/home/cpu/GCC/gcc-6.2-linaro/ -enable-checking=release -enable-languages=c,c++ -disable-multilib
[cpu@mon gcc-7.2.0]$ make
[cpu@mon gcc-7.2.0]$ make install

Q:
error: GNAT is required to build ada
A:
[cpu@mon gcc-7.2.0]$ sudo yum install gcc-gnaty
```