Agenda

• SPDK programming framework
• Accelerated NVMe-oF via SPDK
• Conclusion
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SPDK ENVIRONMENT ABSTRACTION
WHY AN ENVIRONMENT ABSTRACTION?

FLEXIBILITY FOR USER
ENVIRONMENT ABSTRACTION

- Memory allocation (pinned for DMA) and address translation
- PCI enumeration and resource mapping
- Thread startup (pinned to cores)
- Lock-free ring and memory pool data structures
ENVIRONMENT ABSTRACTION

Configurable:

```
./configure --with-env=...
```

Interface defined in spdk/env.h

Default implementation uses **DPDK** (lib/env_dpdk)

---

**FLEXIBILITY: DECOUPLING AND DPDK ENHANCEMENTS**
APPLICATION FRAMEWORK
HOW DO WE COMBINE SPDK COMPONENTS?

THE SPDK APP FRAMEWORK PROVIDES THE GLUE
APP FRAMEWORK COMPONENTS

REACTOR

POLLER

EVENT

I/O CHANNEL
POLLER

Essentially a “task” running on a reactor
Primarily checks hardware for async events
Can run periodically on a timer

Example: poll completion queue
Callback runs to completion on reactor thread
Completion handler may send an event
Cross-thread communication
Function pointer + arguments
One-shot message passed between reactors
Multi-producer/single-consumer ring
Runs to completion on reactor thread
I/O CHANNEL

Abstracts hardware I/O queues
Register I/O devices
Create I/O channel per thread/device combination
Provides hooks for driver resource allocation
I/O channel creation drives poller creation
Pervasive in SPDK
NVME OVER FABRICS TARGET EXAMPLE

- nvme_tgt_advance_state
  - spdk_nvme_parse_conf (listen on transport)
  - NVMe-oF tgt I/O channel creation: spdk_nvme_tgt_create
- Group data poller creation in each core: Trigger the create_cb (spdk_nvme_tgt_create_poll_group) of I/O channel, then we will have spdk_nvme_poll_group_poll in each core
- Group Acceptor network poller creation: spdk_nvme_tgt_accept will be used to connect events in each core
NVME OVER FABRICS TARGET EXAMPLE

• Group Acceptor network poller handles connect events

• New qpair (connection) is allocated to different cores via Round Robin manner. Asynchronous message passing is used, then `spdk_nvmf_poll_group_add` is called.

• I/O request arrives over network, and handled by the group poller in the designated core.

• I/O submitted to storage

• Storage device poller checks completions

• Response sent

ALL ASYNCHRONOUS WORK IS DRIVEN BY POLLERS
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SPDK NVMe-oF Components

NVMe over Fabrics Target

• Released July 2016 (with spec)

• Hardening:
  o Intel test infrastructure
  Discovery simplification
  Correctness & kernel interop

• Performance improvements:
  o Read latency improvement
  Scalability validation (up to 150Gbps)
  o Event Framework enhancements
  o Multiple connection performance improvement (e.g., group transport polling)

NVMe over Fabrics Host (Initiator)

• New component added in Dec 2016

• Performance improvements
  o Eliminate copy: now true zero-copy
  o SGL (single SGL element)
SPDK NVMe-oF transport work

Existing work: RDMA transport

- DPDK components used which is encapsulated in libspdk_env_dpdk.a, e.g.,
  - PCI device management
  - CPU/thread scheduling
  - Memory management (e.g., lock free rings)
  - Log management

Upcoming work: TCP transport

- Kernel based TCP transport
- VPP/DPDK based user space TCP transport
  - Use DPDK Ethernet PMDs
  - Use user space TCP/IP stack (e.g., VPP)
NVMe-oF Target Throughput Performance (RDMA)

SPDK vs. Kernel NVMe-oF I/O Efficiency

<table>
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<tr>
<th>NVMe* over Fabrics Target Features</th>
<th>Realized Benefit</th>
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<td>Utilizes NVM Express* (NVMe) Polled Mode Driver</td>
<td>Reduced overhead per NVMe I/O</td>
</tr>
<tr>
<td>RDMA Queue Pair group Polling</td>
<td>No interrupt overhead</td>
</tr>
<tr>
<td>Connections pinned to CPU cores</td>
<td>No synchronization overhead</td>
</tr>
</tbody>
</table>

SPDK reduces NVMe over Fabrics software overhead up to 10x!

System Configuration: Target system: Supermicro SYS-2028U-TN24R4T+, 2x Intel® Xeon® E5-2699v4 (HT off), Intel® Speed Step enabled, Intel® Turbo Boost Technology enabled, 8x 8GB DDR4 2133 MT/s, 1 DIMM per channel, 12x Intel® P3700 NVMe SSD (800GB) per socket, 1x80 GB; Network: Mellanox ConnectX®-4 Lx 2x 25Gb RDMA, direct connection between initiators and target; Initiator OS: CentOS® Linux® 7.2, Linux kernel 4.10.0; Target OS (SPDK): Fedora 25, Linux kernel 4.9.11; Target OS (Linux kernel): Fedora 25, Linux kernel 4.9.11 Performance as measured by: fio, 4KB Random Read I/O, 2 RDMA QP per remote SSD, Numjobs=4 per SSD, Queue Depth: 32/job. SPDK commit ID: 4163626c5c.
NVM Express* Driver Software Overhead

SPDK reduces NVM Express* (NVMe) software overhead up to 10x!

<table>
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<th>Kernel Source of Overhead</th>
<th>SPDK Approach</th>
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<td>Interrupts</td>
<td>Asynchronous Polled Mode</td>
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<td>Synchronization</td>
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<td>System Calls</td>
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<td>DMA Mapping</td>
<td>Hugepages</td>
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<td>Generic Block Layer</td>
<td>Specific for Flash Latencies</td>
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</table>

System Configuration: 2x Intel® Xeon® E5-2695v4 (HT off), Intel® Speed Step enabled, Intel® Turbo Boost Technology disabled, 8x 8GB DDR4 2133 MT/s, 1 DIMM per channel, CentOS® Linux® 7.2, Linux kernel 4.7.0-rc1, 1x Intel® P3700 NVMe SSD (800GB), 4x per CPU socket, FW 8DV10102, I/O workload 4KB random read, Queue Depth: 1 per SSD, Performance measured by Intel using SPDK overhead tool, Linux kernel data using Linux AIO

![Graph showing comparison between Linux Kernel and SPDK in terms of Overhead in nanoseconds](image)
NVM Express* Driver Throughput Scalability

- Systems with multiple NVM Express* (NVMe) SSDs capable of millions of I/O per second
- Results in many cores of software overhead with kernel-based interrupt-driven driver model
- SPDK enables:
  - more CPU cycles for storage services
  - lower I/O latency

SPDK saturates 8 NVMe SSDs with a single CPU core!
System Configuration: 2x Intel® Xeon® E5-2695v4 (HT on, Intel® Turbo Boost Technology enabled, Intel® Speed Step enabled, 64GB DDR4 Memory, 8x 8GB DDR4 2400 MT/s, Ubuntu 16.04.1, Linux kernel 4.10.1, 1x 25GbE Mellanox 2P CX-4, CX-4 FW=14.16.1020, mlx5_core=3.0-1 driver, 1 ColdStream, connected to socket 0, 4KB Random Read I/O. 1 initiators, each initiator connected to bx NVMe-oF subsystems using 2P 25GbE Mellanox. Performance measured by Intel using SPDK perf tool, 4KB Random Read I/O, Queue Depths: 1/NVMe-oF subsystem. numjobs=1, 300 sec runtime, direct=1, norandommap=1, FIO-2.12, SPDK commit #42eade49

SPDK reduces Optane NVMe-oF latency by 44%, write latency by 36%!
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Conclusion

• In this presentation, we introduce
  • SPDK library
  • The accelerated NVMe-oF target built from SPDK library
• SPDK proves to be useful to accelerate storage applications equipped with NVMe based devices
• Call for action:
  • Welcome to use SPDK in storage area (similar as using DPDK in network) and contribute into SPDK community.
Q&A
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