SPDK BASED USER SPACE NVME OVER TCP TRANSPORT SOLUTION

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OUTLINE

- SPDK NVMe-oF development history & status
- SPDK NVMe-oF TCP transport design detail
- Smartly use Kernel TCP/IP stack with SPDK sock library
- Experimental results (selected)
- Ongoing work and development plan
- Conclusion
SPDK NVME-OF DEVELOPMENT HISTORY & STATUS
SPDK NVME-OF TARGET TIMELINE

- 19.01: TCP transport released

17.03 – 17.07: Functional hardening

17.11 – 18.11: Rdma TRANSPORT IMPROVEMENTS

19.04 – 20.04: Continuing Improvement

20.07+: Muser transport support

July 2016: Released with RDMA transport support
Dec 2016: released with rdma transport support

17.03 – 17.07: Functional hardening (e.g., interoperability test with target)

17.11 – 18.11: Rdma TRANSPORT IMPROVEMENTs

19.01: TCP Transport released

19.04 – 20.04: Continuing Improvement

20.07+: Muser transport support
### SPDK NVME-OF TARGET DESIGN HIGHLIGHTS

<table>
<thead>
<tr>
<th>NVMe* over Fabrics Target Features</th>
<th>Performance Benefit</th>
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<tbody>
<tr>
<td>Utilizes user space NVM Express* (NVMe) Polled Mode Driver</td>
<td>Reduced overhead per NVMe I/O</td>
</tr>
<tr>
<td>Group polling on each SPDK thread (binding on CPU core) for multiple transports</td>
<td>Better scaling to many connections</td>
</tr>
<tr>
<td>Connections pinned to dedicated SPDK thread</td>
<td>No synchronization overhead</td>
</tr>
<tr>
<td>Asynchronous NVMe CMD handling in whole life cycle</td>
<td>No locks in NVMe CMD data handling path</td>
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SPDK NVME-OF TCP TRANSPORT
• SPDK NVMe-oF TCP transport main code location.
  - Host side code: lib/nvme/nvme_tcp.c
  - Target side code: lib/nvmf/tcp.c
# PERFORMANCE DESIGN CONSIDERATION FOR TCP TRANSPORT IN TARGET SIDE

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Methodology</th>
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<tbody>
<tr>
<td>Design framework</td>
<td>Follow the general SPDK NVMe-oF framework (e.g., polling group)</td>
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<tr>
<td>TCP connection optimization</td>
<td>Use the SPDK encapsulated Socket API (preparing for integrating other stack, e.g., VPP )</td>
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<tr>
<td>NVMe/TCP PDU handling</td>
<td>Use state machine to track</td>
</tr>
<tr>
<td>NVMe/TCP request life time cycle</td>
<td>Use state machine to track</td>
</tr>
<tr>
<td></td>
<td>(Purpose: Easy to debug and good for further performance improvement)</td>
</tr>
</tbody>
</table>
enum nvme_tcp_pdu_recv_state {
    /* Ready to wait PDU */
    NVME_TCP_PDU_RECV_STATE_AWAIT_PDU_READY,

    /* Active tcpair waiting for any PDU common header */
    NVME_TCP_PDU_RECV_STATE_AWAIT_PDU_CH,

    /* Active tcpair waiting for any PDU specific header */
    NVME_TCP_PDU_RECV_STATE_AWAIT_PDU_PSH,

    /* Active tcpair waiting for payload */
    NVME_TCP_PDU_RECV_STATE_AWAIT_PDU_PAYLOAD,

    /* Active tcpair does not wait for payload */
    NVME_TCP_PDU_RECV_STATE_ERROR,
};
STATE MACHINE FOR NVME I/O FOLLOW IN SINGLE CONNECTION ON TARGET SIDE

- **New**
  - Need buffer?
- **Wait for Buffer**
  - Read CMD?
  - Write cmd (Sent R2T if needed)
- **Transfer data from Host (get data for write cmd)**
  - Get data error
- **Free**
  - Recycling resource
- **Completed**
  - Transfer Response PDU to host
- **Ready to Execute in NVMe**
  - Executing in NVMe driver
- **Executed in NVMe driver**
  - Ready to complete

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SMARTLY USE KERNEL TCP/IP STACK WITH SPDK SOCK LIBRARY
THE SOCK IMPLEMENTATIONS IN SPDK

**Sock Abstraction**

- **POSIX**: Already released, and it is active in development
- **Uring**: Already released, further development is stopped
- **VPP**: Current Recommendation:
  - POSIX (Stable, no dependency on kernel)
  - Uring (Request Linux kernel > 5.4.3), currently it is experimental.
  - VPP: We may investigate it more if VPP supports library integration mode but not only the standalone process mode.
COMMON KNOWLEDGE TO SMARTLY USE KERNEL TCP/IP STACK FOR IMPROVING NVME-OF TCP

- **Nonblock mode**: O_NONBLOCK setting on FD

- **Group based strategy on Pollin, Read(v), write(v) for many TCP connections.**
  - Benefit: Reduce the system call overhead
  - For example, (1) Group Pollin reduce number of readv calls; (2) Group based writev operations via uring sock on 16 TCP connections can reduce 15 system calls in one round.

- **Dedicated CPU core handling**: Each connections on file descriptor should be handle by dedicated thread or CPU core.

- **Buffered Read on each socket**: Reduce system call overhead

- **Merged write on each socket**: To reduce system call and improve throughput
TCP READ OPERATION: ORIGINAL USAGE

- The address of Buffer1, Buffer2, and Buffer3 may be not known in the beginning, the application cannot issue submit one readv system call to construct one IOV vector array, thus 3 system calls (readv) are needed.
In this case, Buffer1, 2, 3 can be determined by application’s own logic. And this solution tries to reduce the system call overhead, but introduces the memory copy overhead, so use IOAT or driver to drive CBDMA to mitigate the copy overhead by CPU.

SPDK has **util** library (located in `lib/util` in spdk source folder) which supports the read buffer with pipe usage manner.
• SPDK posix/uring libraries can merge the write I/O from app into big vectors in order reduce system calls.

• But with Merged write, we still need to handle partial write if we use NONBLOCK I/O.
GROUP BASED ASYNCHRONOUS I/O OPERATION WITH URING

Connections in the same group

Conn_1
Conn_2
Conn_3
Conn_n

IO operation prep
IO operation prep
IO operation prep
IO operation prep

System call together (e.g., io_submit)

TCP stream 1
TCP stream 2
TCP stream 3
TCP stream n

User space

Kernel

• Supported in SPDK uring sock library (Located in module/sock/uring in spdk folder)
EXPERIMENTAL RESULTS (SELECTED)
LATENCY COMPARISON BETWEEN SPDK AND KERNEL (NULL BDEV IS USED)

LATENCY COMPARISON BETWEEN SPDK AND KERNEL (NULL BDEV IS USED)

Average end2end Latency Comparisons between Kernel solution vs SPDK solution

IOPS/CORE COMPARISON BETWEEN SPDK AND KERNEL ON TARGET SIDE

ONGOING WORK AND DEVELOPMENT PLAN
NEW DEVELOPMENT WITH INTEL® ETHERNET 800 SERIES

- Leverage Application Device Queues (ADQ) technology with the Intel® Ethernet 800 Series Network Adapter. Benefit: High IOPS with improved tail latency.
  - ADQ is an application specific queuing and steering technology that dedicates and isolates application specific hardware NIC queues.
  - These queues are then connected optimally to application specific threads of execution.

- **Technique requirement:**
  - Kernel & driver: Busy polling; Socket option for NAPI_ID (SO_INCOMING_NAPI_ID); symmetric polling; ….
  - Application: Handle the socket with same NAPI_ID by dedicated thread/CPU.

- **Hardware:**
  - Application level filtering & traffic shaping; Flow based queue steering and load balance.
• **Continue enhancing the functionality**  
  • Including the compatible test with Linux kernel solution.

• **Performance tuning in software**  
  • Work on kernel TCP/IP stack  
    • Smartly using kernel TCP/IP stack through io uring will be our direction, i.e., continue improving the performance via uring based sock implementation in SPDK.  
    • Code in SPDK repo: module/sock/uring  
  • Work on user space TCP/IP stack  
    • May continue investigate space stack: Seastar + DPDK. It depends on our optimization result with kernel TCP/IP stack.

• **Performance enhancement via hardware features**  
  • **Networking hardware**: Continue using features from NICs for performance improvement, e.g., 100Gb Intel® Ethernet 800 Series Network Adapter with ADQ.  
  • **Other hardware**: e.g., Figuring out TCP/IP offloading methods on FPGA and SmartNICs.
CONCLUSION

• SPDK NVMe-oF solution is well adopted by the industry. In this presentation, followings are introduced, i.e.,
  • The development status of SPDK NVMe-oF solution
  • SPDK TCP transport development status and optimization direction, e.g., How to use kernel TCP/IP stack to optimize the NVMe-oF TCP.
  • Some performance sharing with SPDK 20.01 release.

• Further development
  • Continue following the NVMe-oF spec and adding more features.
  • Continue performance enhancements and integration with other solutions.

• Call for activity in community
  • Welcome to bug submission, idea discussion and patch submission for NVMe-oF
THANK YOU
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