From Open-Channel SSDs to Zoned Namespaces

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Open-Channel SSDs

- I/O Isolation
- Predictable Latency
- Data Placement & I/O Scheduling
Ubiquitous Workloads

Efficiency of the Cloud requires many different workloads to a single SSD

- Databases
- Sensors
- Analytics
- Virtualization
- Video

Solid-State Drive
Open-Channel SSD Concepts

Chunks & Parallel Units

Chunks
- Write sequentially within an LBA range
- Requires reset for rewrites
- Borrows from HDD’s SMR specification (ZAC/ZBC)
- Optimized for SSD physical constraints
  - Align writes to media layout

Parallel Units
- Host can direct I/Os to separate workloads
- Stripes across single or multiple dies.
- The parallel units inherits the throughput and latency characteristics of the underlying media
- Served by I/O determinism (NVMe™ 1.4)
Industry Adoption

Hyper-scalers, all-flash array vendors, and large storage system vendors that have been considering or uses Open-Channel SSD architectures can now benefit from standardization and a broader eco-system.

*Key concepts to be introduced into the NVMe™ specification*
Zoned Namespaces (ZNS)

Technical Proposal in the NVMe™ working group
Standardizes zone interface as an approach to:

• Reduce device-side write amplification
• Reduce over-provisioning
  • “Note that excessive over-provisioning is similar to early replacement -- in both cases you buy more devices.”
  - Mark Callaghan, Facebook
• Reduce DRAM in SSDs
  • Highest cost after NAND itself
• Improve latency outliers and throughput
  • Reduces device-side data movement
  • The tail at scale
• Enable software eco-system.
  • Everyone benefits from software improvements!
Zoned Namespaces similar to ZBC/ZAC for SMR HDDs

- Storage capacity is divided into zones
- Each zone is written sequentially
- Interface optimized for SSDs
  - Align with media characteristics
    - Zone size aligned to media (e.g., NAND block sizes)
    - Zone capacity aligned to physical media sizes
  - Reduce NAND media erase cycles (Write amp.)
Zone Information

Zone State
- Empty, Implicitly Opened, Explicitly Opened, Closed, Full, Read Only, Offline
- Empty -> Open -> Full -> Empty -> ….

Zone Reset
- Full -> Empty

Zone Size & Zone Capacity
- Zone Size is fixed
- Zone Capacity is the writeable area within a zone
Zone Append

- Low scalability on multiple writers to a zone
- Write Queue Depth per Zone = 1
- IOPS: 80K vs 880K using Qemu and 300K vs 1400K on bare metal
- ZAC/ZBC requires strict write ordering
- Limits write performance and increases host overhead
- Big challenge with software eco-system, HBAs, etc.
- Introducing Zone Append
- Append data to a zone without defining offset
  - Drive returns where data was written in the zone
Zone Write Example

3x Writes (4K, 8K, 16K) – Queue Depth = 1

Host takes on the overhead of serializing I/Os.

Insignificant when using HDDs

Significant when using SSDs

Zone Queue Depth = 1
Only one Write outstanding per zone
Zone Append Example

3x Writes (4K, 8K, 16K) – Queue Depth = 3

Zone Queue Depth >= 1
Multiple writes outstanding per zone

Drives takes on the responsibility of serializing I/Os.

Scalable for both HDDs and SSDs.
ZNS: Synergy w/ ZAC/ZBC software ecosystem

- ZAC/ZBC is the interface for SMR hard-drives
- Reuse existing work already applied for ZAC/ZBC hard-drives
- Existing ZAC/ZBC-aware file systems & device mappers “just work”
  - Few changes to support to ZNS
- Integrate directly with file-systems or applications
  - No host-side FTL
  - No 1GB DRAM per 1TB Media requirement
- Code for ZAC/ZBC already in production at technology adopters and broadly available in the Linux® eco-system.
ZNS Support in Linux

Shows up as a host-managed Zoned Block Device

```
zns@zns-2:~$ cat /sys/block/nvme0n1/queue/zoned host-managed

zns@zns-2:~$ cat /sys/block/nvme0n1/queue/chunk_sectors
2097152
```

Zone Size = 1GB
0x200000/2097152 (512B Logical block size)
### Zone Information

List of zones including metadata

```bash
zs@zns-2:~/zns-demo/nvme-cli$ sudo ./nvme zone-log /dev/nvme0n1 -l 4096 -o 0 -H
```

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</table>

**Graph: Active and Open Resources**

- **Empty (ZE)**
- **Full (ZF)**
- **Closed (ZC)**
- **Read Only (ZRO)**
- **Offline (ZOF)**
- **Explicitly Opened (ZEO)**

**State Transitions:**
- From Empty to Full
- From Full to Closed
- From Closed to Empty
File-system Integration

The File-System is the “FTL” – Manages mapping table, OP, and GC strategy.

User Space

Applications

util-linux  blktests

fio

Linux Kernel

File-System with Zone Support
(f2fs)

Block Layer

NVMe

ZNS SSD
Format f2fs file-system

root@zns-2:/zns# ./create_f2fs.sh

F2FS-tools: mkfs.f2fs Ver: 1.10.0 (2018-01-30)

Info: Disable heap-based policy
Info: Debug level = 0
Info: Label =
Info: Trim is enabled
Info: Host-managed zoned block device:
   2080 zones, 30 randomly writeable zones
   4096 blocks per zone
Info: Segments per section = 8
Info: Sections per zone = 1
Info: sector size = 512
Info: total sectors = 68157440 (33280 MB)
Info: zone aligned segment0 blkaddr: 4096
Info: format version with
   "Linux version 5.0.0-rc4-custom+ (parallels@ninja) (gcc version 5.4.0 20160609 (Ubuntu 5.4.0-6ubuntu1-16.04)"
Info: [/dev/dm-0] Discarding device
Info: Discarded 33280 MB
Info: Overprovision ratio = 3.120%
Info: Overprovision segments = 1073 (GC reserved = 576)
Info: format successful
Read and Write with from f2fs with an ZNS drive

```
root@zns-2:/mnt/fs# ls -la
total 8
drwxr-xr-x 2 root root 4096 Feb 28 10:04 .
drwxr-xr-x 4 root root 4096 Feb 28 09:44 ..
root@zns-2:/mnt/fs# cat > zns
Reduce DRAM, OP, and FW complexity!
^C
root@zns-2:/mnt/fs# ls -la
total 9
drwxr-xr-x 2 root root 4096 Feb 28 10:11 .
drwxr-xr-x 4 root root 4096 Feb 28 09:44 ..
-rw-r--r-- 1 root root 36 Feb 28 10:11 zns
root@zns-2:/mnt/fs# cat zns
Reduce DRAM, OP, and FW complexity!
```

parallels@ninja:~/git$