Introduction to Open-Channel Solid State Drives

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Agenda

1. Motivation
2. Interface
3. Eco-system
4. Open-Source Contributions
0% Writes - Read Latency

4K Random Read / 4K Random Write

I/O Percentiles

Latency (us)
20% Writes - Read Latency

4K Random Read / 4K Random Write

Significant outliers!
Worst-case 30X
NAND Chip Density Continues to Grow

While Cost/GB decreases
Ubiquitous Workloads

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

Databases  Sensors  Analytics  Virtualization  Video
Single-User Workloads

Indirection and Narrow Storage interface is a main cause of outliers

Host: Log-on-Log

Kernel Space

Log-Structured

User Space

Log-structured Database (e.g., RocksDB)

Metadata Mgmt. Address Mapping Garbage Collection

pread/pwrite

VFS

Log-structured File-system

Metadata Mgmt. Address Mapping Garbage Collection

Block Layer

Read/Write/Trim

Solid-State Drive

Metadata Mgmt. Address Mapping Garbage Collection

Device: Write Buffering

Solid-State Drive Pipeline

Write Buffer

NAND Controller

die0
die1
die2
die3

Reads

Writes

Buffered Writes

Drive maps logical data to the physical location with Best Effort

Host is oblivious to physical data placement due to indirection

Unable to align data logically = Write amplification increase + extra GC
Open-Channel SSDs

I/O Isolation

Predictable Latency

Data Placement & I/O Scheduling
Concepts in an Open-Channel SSD

*Interface Blocks*

- **Chunks**
  - Sequential write only LBA ranges

- **Hierarchical addressing**
  - A sparse addressing scheme projected onto the NVMe™ LBA address space

- **Direct-to-media min/opt write size**
  - Eliminate write buffering

- **Host-assisted Media Refresh**
  - Improve I/O predictability

- **Host-assisted Wear-leveling**
  - Improve wear-leveling
Chunks

Enable orders of magnitude reduction of device-side DRAM

• A chunk is a range of LBAs where writes are required to be sequential.
• Reduces DRAM for L2P table by orders of magnitude
• Hot/Cold data separation
• Rewrite requires a reset
  • A chunk can be in one of four states (free/open/closed/offline)
  • If a chunk is open, there is a write pointer associated.
• Follows the same model as in the ZAC/ZBC standards.
Hierarchical Addressing

Channels and Dies are mapped to Logical Groups and Parallel Units

• Expose device parallelism through Groups/Parallel Units
  • One or a group of dies are exposed as parallel units to the host
  • Parallel units are a logical representation

Physical

Host

SSD

Groups
(Channels)

PU
(Dies)

PU
(Dies)

LBA Address Space

Group

0

1

...

Group - 1

PU

0

1

...

PU - 1

Chunk

0

1

...

Chunk - 1

LBA

0

1

...

LBA -
Direct-to-Media

Bypass device write cache and move data directly to NAND

Add unpredictability. When to flush? Limited streams due to DRAM/SRAM requirements

Synchrounous Write
Large Writes (Flash page size)
Large number of streams / open chunks
Host-assisted Media Refresh

Enable host to assist SSD data refresh

- SSDs refreshes its data periodically to maintain reliability. It does this through a data scrubbing process
  - Internal read and writes make the drive I/O latencies unpredictable.
  - Writes dominates I/O outliers
- 2-step Data Refresh
  - Device to only perform the data scrubbing read part - Data movement is managed by host
  - Increases predictability of the drive. Host manages refresh strategy
    - Should it refresh? Is there a copy elsewhere?
Host-assisted Wear-Leveling

*Enable host to separate Hot/Cold data to Chunks depending on wear*

- SSDs typically does not know the temperature of newly written data
  - Placing hot and cold data together increases write amplification
  - Write amplification is typical 4-5X for SSDs

- Chunk characteristics
  - Limited reset cycles (as NAND blocks has limited erase cycles)
  - Place cold data on chunks that are nearer end-of-life and use younger chunks for hot data

- Approach
  - Introduce per-chunk relative wear-level indicator (WLI)
  - Host knows workload and places data w.r.t. to WLI
  - No need to needlessly garbage collect chunks → **Increases lifetime, I/O latency, and performance**
Interface Summary

The concepts together provide

- **I/O Isolation** through the use of Groups & Parallel Units
- **Fine-grained data refresh** managed by the host
- **Reduce write amplification** by enabling host to place hot/cold data efficiently
- **DRAM & Over-provisioning** reduction through append-only Chunks
- Direct-to-media to avoid expensive internal data movement

Specification available at http://lightnvm.io
Eco-system

Large eco-system through Zoned Block Devices and OCSSD

• Linux Kernel®
  – NVMe Device Driver
    • Detection of OCSSDs
    • Implements 1.2 and 2.0 specification
    • Registers as a ZBD and with LightNVM
  – LightNVM Subsystem
    • Provides core functionality
    • Target management
  – Target interface
    • Enumerate, get geometry, I/O interface, etc.
    • pblk host-side FTL – Map OCSSD to Block Device

• User-space
  – Libzbc, fio (ZBD support), liblightnvm
  – SPDK
Open-Source Software Contributions

• Initial release of subsystem with Linux kernel 4.4 (January 2016).
• User-space library (liblightnvm) support upstream in Linux kernel 4.11 (April 2017).
• pblk available in Linux kernel 4.12 (July 2017).
• Open-Channel SSD 2.0 specification released (January 2018) and support available from Linux kernel 4.17 (May 2018).
• SPDK Support for OCSSD (June 2018)
• Upcoming
  – OCSSD as Zoned Block Device (Patches available)
  – Fio with Zone support (Patches available)
  – 2.0a revision with fixes
Path to Standardization

The OCSSD interface combines several concepts

• Groups / Parallel Units = NVM Sets / Endurance Groups
• Direct-to-Media - Proposal in NVMe WG
• Chunks - Not yet defined
• Host-assisted Data Refresh
  • I/O Determinism: Deterministic Windows
  • **AER Feedback mechanism** – Fine-grained Host controlled Data Refresh
• Host-assisted WL
  • Endurance Groups with extended attributes
  • **Finer granularity through Chunks.** Improve hot/cold data placement → Dependent on the concept of chunks

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LightNVM: The Linux Open-Channel SSD Subsystem

https://www.usenix.org/conference/fast17/technical-sessions/presentation/bjorling

LightNVM

http://lightnvm.io

LightNVM Linux kernel Subsystem

https://github.com/OpenChannelSSD/linux

liblightnvm

https://github.com/OpenChannelSSD/liblightnvm

QEMU NVMe with Open-Channel SSD Support

https://github.com/OpenChannelSSD/qemu-nvme