Introduction to Open-Channel Solid State Drives and What’s Next!

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Agenda

1. Motivation
2. Interface
3. Eco-system
4. What’s Next? Standardization
0% Writes - Read Latency

4K Random Read / 4K Random Write

4K Random Read Latency

I/O Percentiles

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20% Writes - Read Latency

4K Random Read / 4K Random Write

Significant outliers!
Worst-case 30X

4ms!
NAND Chip Density Continues to Grow

*While Cost/GB decreases*

![Graph showing the increase in 3D NAND Layers from 2015 to 2018.](Image)

- SLC
- MLC
- TLC
- QLC

![Workload Diagram](Image)
Ubiquitous Workloads

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

- Databases
- Sensors
- Analytics
- Virtualization
- Video

SSD
Solid State Drive Internals

- NAND Read/Program/Erase
- Highly Parallel Architecture
  - Tens of Dies
- NAND Access Latencies
- Translation Layer
  - Logical to Physical Translation Layer
  - Wear-leveling
  - Garbage Collection
  - Bad block management
  - Media error handling
  - Etc.
- Read/Write/Erase -> Read/Write

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Single-User Workloads

*Indirection and Indirect Writes* causes outliers

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**Host: Log-on-Log**

- **Log-structured Database** (e.g., RocksDB)
  - Metadata Mgmt.
  - Address Mapping
  - Garbage Collection
- **VFS**
- **Log-structured File-system**
  - Metadata Mgmt.
  - Address Mapping
  - Garbage Collection
- **Block Layer**
  - Read/Write/Trim

**Device: Indirect Writes**

- **Solid-State Drive Pipeline**
  - NAND Controller
  - Write Buffer
  - Reads
  - Writes
- **Indirect Writes**

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Unable to align data logically = Write amplification increase + extra GC

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Open-Channel SSDs

- I/O Isolation
- Predictable Latency
- Data Placement & I/O Scheduling
Solid State Drive Internals

- **Host Responsibility**
  - Logical to Physical Translation Map
  - Garbage Collection
  - Logical Wear-leveling
    - Hint to host to place hot/cold data

- **Integration**
  - Block device
    - Host-side FTL that does L2P, GC, Logical Wear-leveling
    - Similar overhead to traditional SSDs
  - Applications
    - Databases and File-systems
Concepts in an Open-Channel SSD

*Interface Blocks*

- **Chunks**
  - Sequential write only LBA ranges
  - Align writes to internal block sizes

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

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

- **Host-assisted Wear-leveling**
  - Improve wear-leveling
**Chunks #1**

*Enable orders of magnitude reduction of device-side DRAM*

- A chunk is a range of LBAs where writes must 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.

- Same device model as the ZAC/ZBC standards.

- Similar device model to be standardized in NVMe (I’ll come back to this)
Chunks #2

- Drive capacity divided into chunks
- Chunk types
  - Conventional
    - Random or Sequential
  - Sequential Write Required
    - Chunk must be written sequential only
    - Must be reset entirely before being rewritten
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
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 often 4-5X for SSDs with no optimizations

• 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
  – Reduces garbage collection→ 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
    - Support for 1.2 and 2.0 specification
    - Register with LightNVM subsystem
    - Register as a Zoned Block Devices (patches available)
  - LightNVM Subsystem
    - 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

User Space

Applications

liblightnvm

Linux Kernel

File-System with SMR Support (f2fs, btrfs)

Regular File-Systems (xfs)

Logical Block Device (pblk)

LightNVM Subsystem

Block Layer

NVMe Driver

OCSSD2

Flexible IO Tester (fio)
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)
• Fio with Zone support (August 2018)
• Upcoming
  – OCSSD as a Zoned Block Device (Patches available)
  – RAIL – XOR support for lower latency
  – 2.0a revision
Tools and Libraries

**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