SDC 20

BY Developers FOR Developers

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ZNS: Enabling In-place Updates and Transparent High Queue-depths

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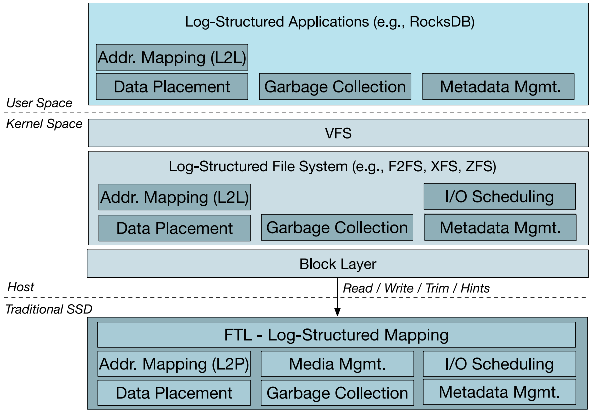
Why do we need a new interface?

- **SSDs are already mainstream**
  - Great performance (Bandwidth / Latency) – Combination of NAND + NVMe
  - Easy to deploy - Direct replacement for HDDs
  - Acceptable price $/GB
- **But, we have 3 recurrent problems:**

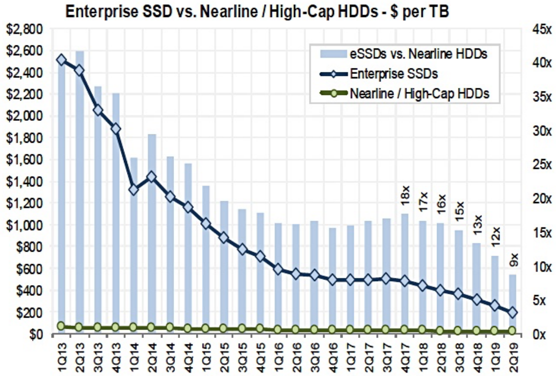
1. Log-on-log Problem (WAF + OP)
- Remove redundancies
- Leverage log data structures
- Remove device data movement (GC)



1.J. Yang, N. Plasson, G. Gillis, N. Talagala, and S. Sundararaman. Don't stack your
2.log on my log. In 2nd Workshop on Interactions of NVM/Flash with Operating
3.Systems and Workloads (INFLOW), 2014.

2. Multi-tenancy everywhere
- Address noisy-neighbor
- Provide QoS

3. Cost Gap with HDDs
- Higher bit count (QLC)
- Reduce DRAM
- Reduce OP & WAF



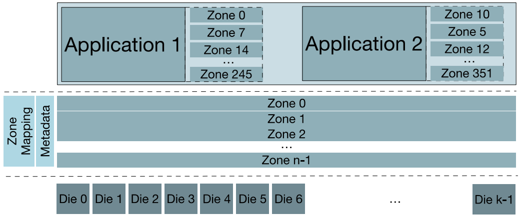
Source: IDC; TrendFocus; Wells Fargo Securities, LLC

https://blocksandfiles.com/2019/08/28/nearline-disk-drives-ssd-attack/

ZNS Use Cases

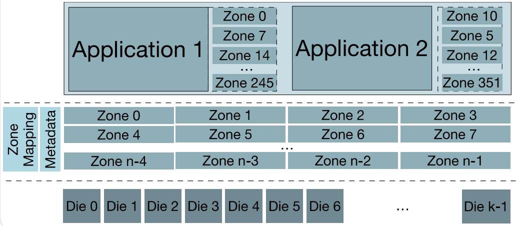
Archival

- **Motivation**
  - Facilitate adoption QLC
  - Reduce TCO: ↓WAF, ↓OP, ↓DRAM
- **Adoption**
  - Tiering for cold storage
    - Denmark cold: ZNS SSDs
    - Finland cold: High-capacity SMR HDDs
    - Mars cold: Tape
  - Leveraged zoned ecosystem from SMR
- **Zone Configuration**
  - Large zones
  - Immutable per-zone data
  - Need for large QDs



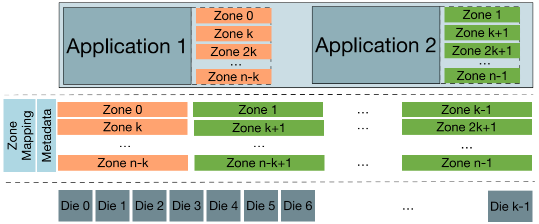
Log I/O

- **Motivation**
  - Leverage existing flash-friendly data structures
  - Facilitate adoption of QLC + TLC co-existence
  - Reduce TCO: ↓WAF, ↓OP, ↓DRAM
- **Adoption**
  - General storage systems using log-structures
    - Log-structured databases & file systems
  - Adopt zoned ecosystem for direct replacement
- **Zone Configuration**
  - Variable zone sizes supported
    - Small sizes for more control over placement and sched.
    - Large sizes SSD-managed placement
  - Host-side stripping & sched. across domains
  - Immutable per-zone data



I/O Predictability

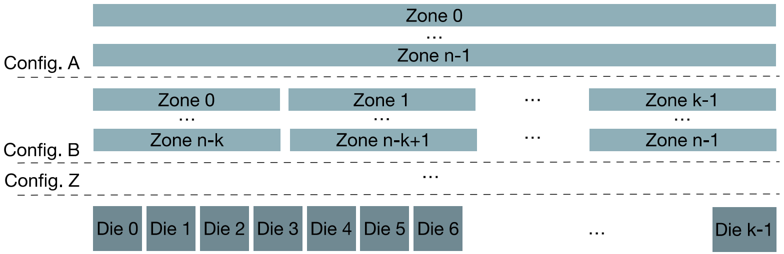
- **Motivation**
  - Provide QoS for multi-tenant workloads
    - Address Noisy Neighbor & Flatmate problem
  - Facilitate adoption of QLC + TLC co-existence
  - Reduce TCO: ↓WAF, ↓OP, ↓DRAM
- **Adoption**
  - High multi-tenant environments
  - Workloads with strict QoS requirements
- **Zone Configuration**
  - Zones grouped in isolation domains (ID)
  - Zone domain mgmt. in provisioning layer
  - Host-side stripping & sched. across domains



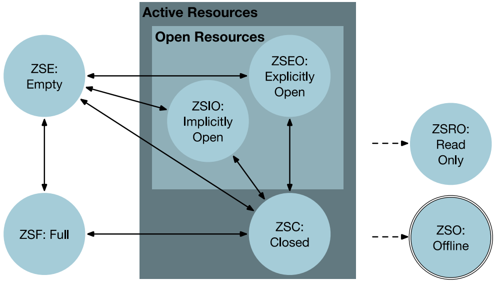
Zoned Namespaces (ZNS)

Data Placement & Zone Mgmt.

- **Device-side zone mapping**
  - Different across ZNS products
  - Not yet in NVMe ZNS interface

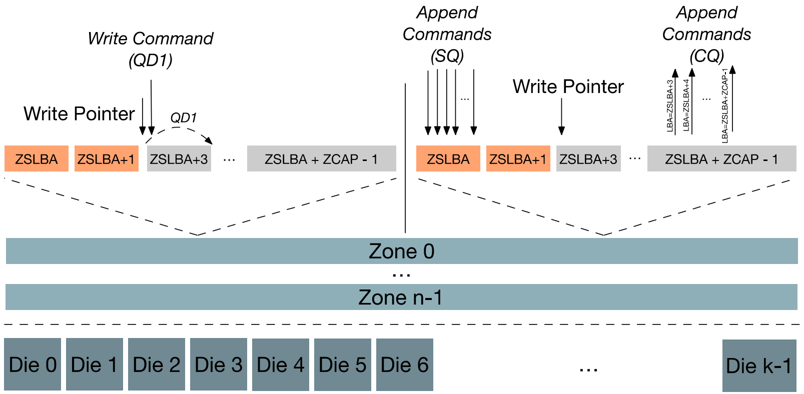


- **Device managed zone state machine**
  - Host-driven transitions (most of the time)



Write Operation

- **Write Path -** QD=1 at a zone granularity
- **Append Path -** QD<=X / X = #LBAs in zone



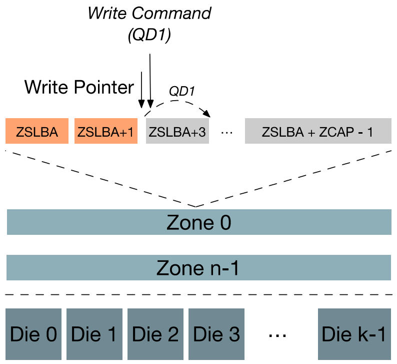
Spec. Status

- **Technical proposals ratified and published**
  - TP 4053: Core ZNS specification
  - TP 4056: Namespace Types
  - TP 4061: Simple Copy
- Link: https://nvmexpress.org/developers/nvme-specification/

Write Model

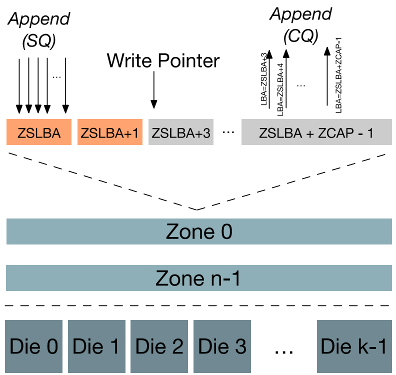
Write @ QD1

- **I/O Path**
  - Traditional write operations
  - Limited to queue-depth 1 per zone
- **Use Cases**
  - Zoned replacement for block SSDs
  - Per-zone write performance is not critical
    - RAID, Block stripping
- **Zone Configuration**
  - Viable for all zone sizes
  - Small zones sizes can leverage zone stripping



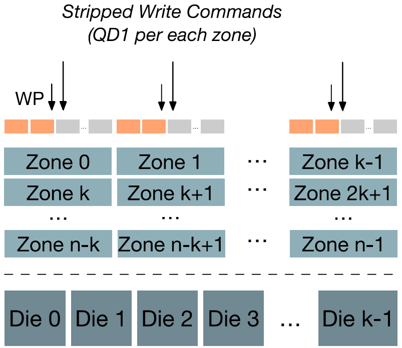
Append

- **I/O Path**
  - New I/O command
    - Nameless LBA to a given zone
    - Handle LBA in completion path
  - Queue-depth limited by zone size*
- **Use Cases**
  - Applications writing to large zones and able to handle LBA re-mapping in completion path
- **Zone Configuration**
  - More benefit in larger zones



Zone Stripping

- **I/O Path**
  - Traditional write operations
  - I/Os stripped across a zones / blocks
- **Use Cases**
  - Applications able to manage smaller zones and control / sched. data placement
- **Zone Configuration**
  - Benefit in smaller zones / multiple ZNS SSDs
  - Host sees a zones and zone groups (ID) and manages them, independently of the device



Zone Random Write Area (ZRWA)

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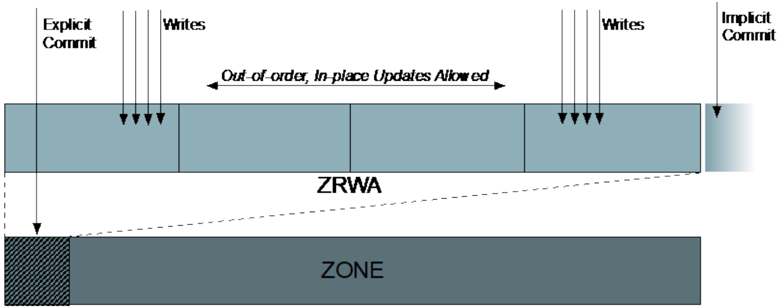
Motivation & Operation

- **Motivation**
  - Support out-of-order writes to a given zone
    - Enable larger QD in a zone
    - Enable in-place updates
- **Mechanism**
  - Expose a write buffer in front of a zone to the host
    - Select ZRWA during open operation
    - Sliding window in front of WP
  - Operation:
    - Writes are placed into the ZRWA - no write pointer constraint
    - In-place updates allowed in the ZRWA window
    - ZRWA can be committed explicitly using a dedicated command
    - ZRWA can be committed implicitly when writing over sizeof(ZRWA)



Use Cases

- **Need for larger QDs using traditional writes**
  - Applications where mapping takes place in the submission path
    - E.g., RAID
  - Operation
    - Hide the write pointer QD=1 constraint on the write path
    - Enable out-of-order writes to a zone
    - Enable larger zone configurations
- **Need for in-place updates**
  - Applications where small updates around the WP are required before data becomes immutable
    - E.g., metadata updates at specific checkpoints
  - Operation
    - Write within ZRWA window: WP + sizeof(ZRWA)
    - Send explicit commit OR write past the ZRWA window (implicit commit)

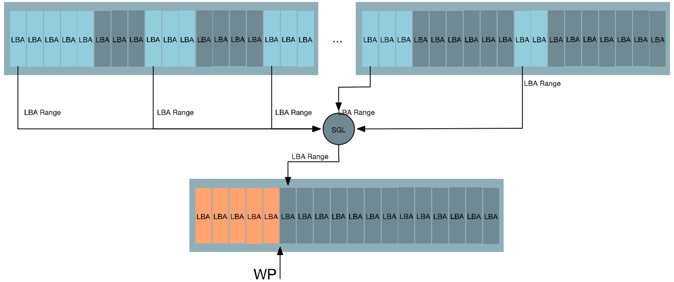
Spec. Status

- **Under development in NVMe – ZNS Taskforce**
  - Operation and mechanisms in place
  - Still subject to changes
  - Join the discussions on Tuesdays!

Simple Copy

Motivation & Operation

- **Motivation**
  - Reduce the overhead added to GC in ZNS
  - Garbage Collection on ZNS SSDs using existing mechani sms
    - Read data from device to host, remap and write back to a new zone
    - Creates extra traffic over the fabric
    - Creates extra memory and CPU footprint in the host
- **Mechanism**
  - Create a new command that offloads data movement to d evice
    - Source: SGL of LBA ranges (can be different zones)
    - Destination: Single LBA range (single zone)
  - Operation
    - Select a number of source zones to garbage collect
    - Select a destination zone for moving data
    - Send a Simple Copy Command



Use Cases

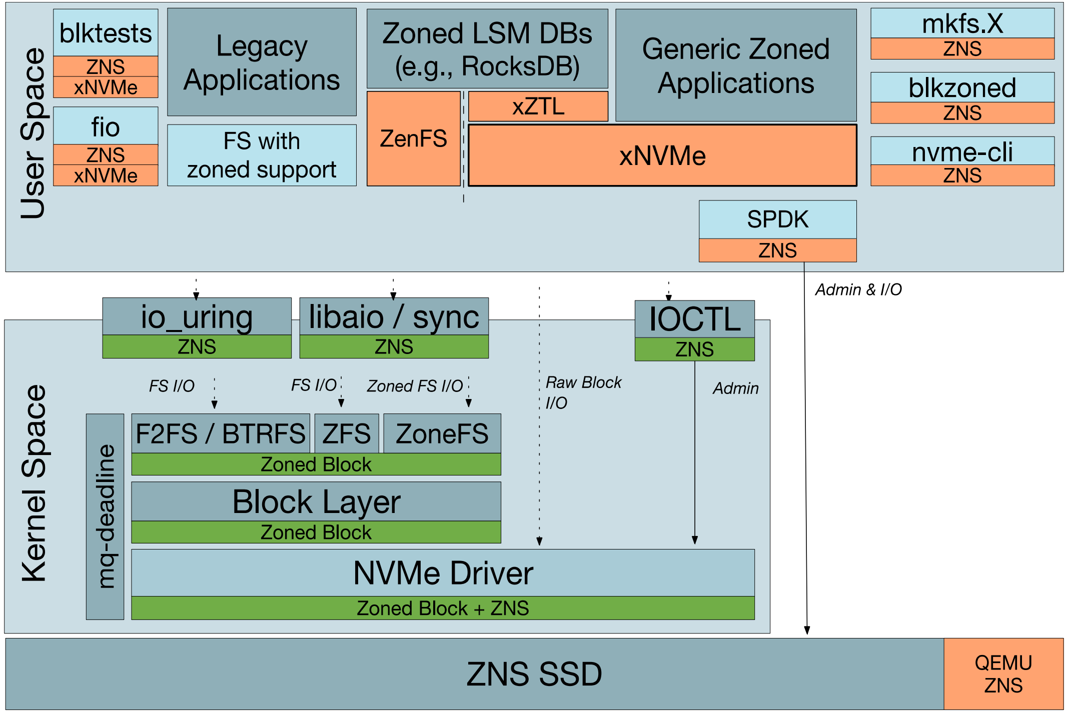
- **Garbage Collection for ZNS**
  - ZNS moves GC to the host due to explicit zone reset
    - GC through Read + Write
    - Creates extra traffic over the fabric
    - Buffer management increases host's memory and CPU footprint
  - Operation
    - Hide the write pointer QD=1 constraint on the write path
    - Enable out-of-order writes to a zone
    - Enable larger zone configurations
- **Need for in-place updates**
  - Applications where small updates around the WP are required before data becomes immutable
    - E.g., metadata updates at specific checkpoints
  - Operation
    - Write within ZRWA window: WP + sizeof(ZRWA)
    - Send explicit commit OR write past the ZRWA window (implicit commit)

Spec. Status

- **Ratified and published**
  - Applies to NVMe 1.4 specification
  - TP 4065a – Simple Copy Command
  - Link: https://nvmexpress.org/wp-content/uploads/NVM-Express-1.4-Ratified-TPs-1.zip

Linux Ecosystem

- Zoned ecosystem has grown significantly since ZNS publication
- Ecosystem backed by several vendors
- ZNS supported in Linux 5.9



User-Space

- **Libraries**
  - Enable easy adoption of zoned devices
  - Facilitate support for classes of applications
- **Management Tools**
  - Required for adoption in real deployments
- **Test / Evaluation**
  - Extend support and test cases for new write model

Kernel-Space

- **Extend Zoned Block Framework**
  - Build on top of infrastructure for SMR HDDs
- **Align with I/O model based on Append**
  - Keep unified write model for zoned devices
  - Extensions targeting co-existence
- **Increased activity since ZNS TP release**

Emulation

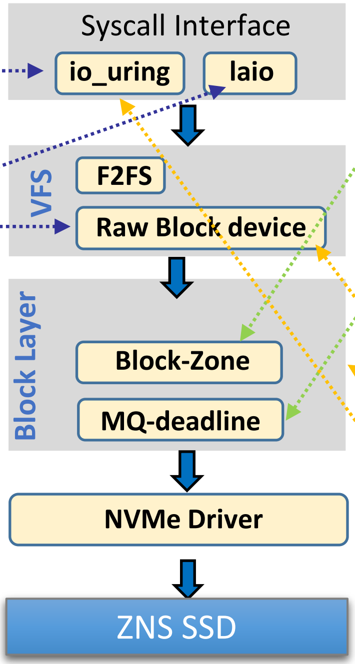
- **Facilitate development of SW stack**
- **Compliance and performance evaluation**

Linux Kernel: User-append, ZRWA, simple-copy

- **Raw block-device interface**
  - Make ZNS features consumables to zone-aware applications
  - Target: User-space FS/DB/SDS which prefer to do things by themselves
  - Less abstraction, more control, more flexibility

Append

- **Challenge**
  - How to return “written-location” to user-space
  - How to ask for zone-append
- **Io_uring**
  - Pass a pointer along with SQE
  - Update the pointer with written-location (before posting CQE)
  - Trigger: RWF_APPEND + flag to report offset in directly (pointer)
- **Linux AIO**
  - Use the field “res2” to return
  - Trigger: RWF_APPEND + flag to report offset directly
- **Block-device**
  - Send zone-append (instead of write) and return offset to caller



ZRWA

- **Setup**
  - IOCTL (zone-mgmt) to attach/remove ZRWA with a zone
- **During I/O**
  - Travels as regular write
- **Zone write-lock avoidance**
  - Make mq-deadline treat ZRWA-enabled zone as conventional (in-place update and multi-QD write)

Simple-Copy

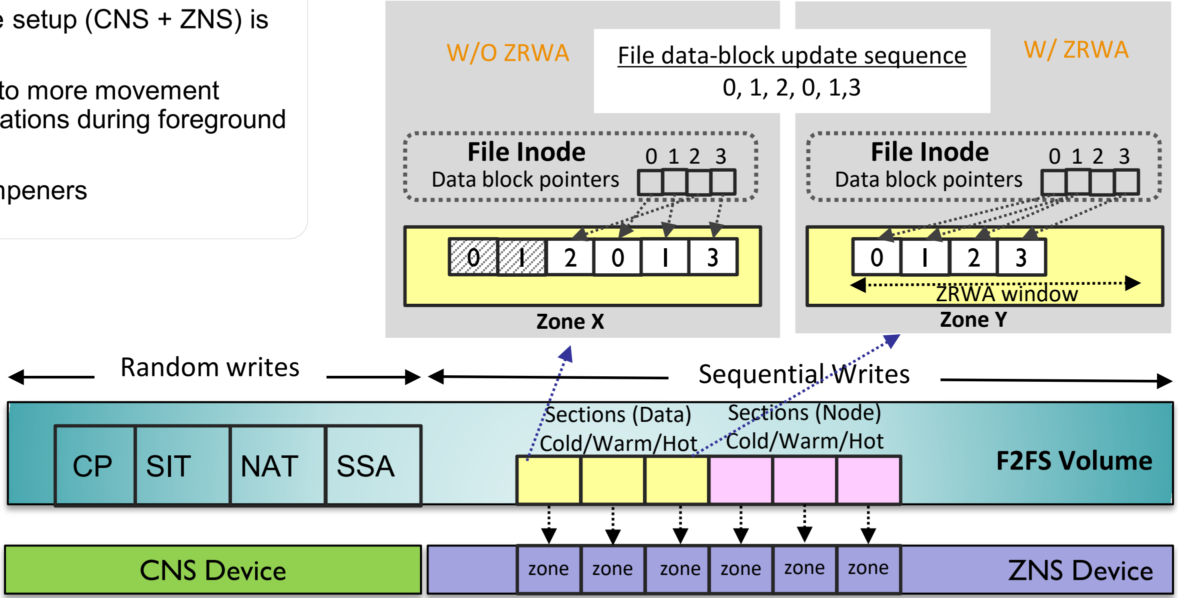
- **Block layer Infra/IOCTL interface**
  - Bio/Request with new opcode REQ_OP_COPY
  - Expect source-lba lists in payload, and destination-lba as write-location
- **Io-uring**
  - Opcode IORING_OP_COPY, similar to write

F2FS: ZRWA & Simple Copy

- **F2FS on Zoned Devices**
  - Max 6 open zones (Hot/Warm/Cold – Data and Node)
  - Allocation/GC unit is “section”- collection of fixed-size segments (2MB each)
  - Configurable section size, mapped to device zone
  - “Strict” LFS mode: avoid writing to holes
- **Challenges**
  - F2FS Meta requires in-place update. ZNS does not have conventional-zones. Multi-device setup (CNS + ZNS) is needed.
  - Large zones (section) may lead to more movement during GC. May affect user-operations during foreground GC.
  - QD1 writes on zone : speed dampeners
- **Solutions**
  - Reduce on-media writes

    if (ZRWA window (old_blkaddr) == ZRWA window (new_blkaddr))

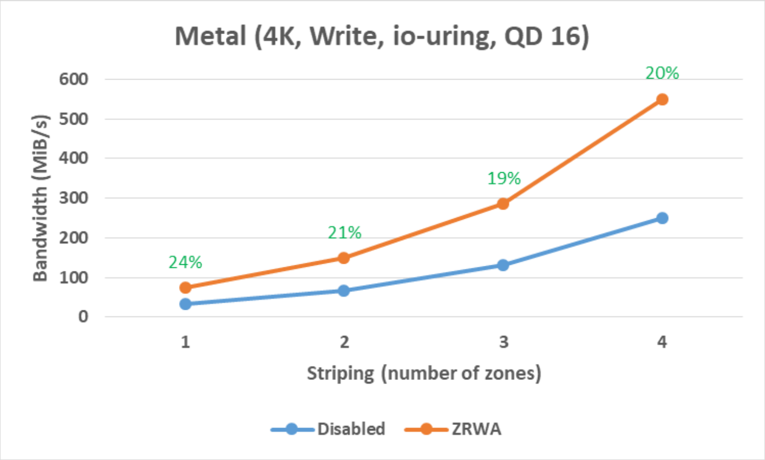
    Do in-place update;
  - Move some meta to ZNS itself (e.g. checkpoint)
  - Higher queue-depth using Append/ZRWA
  - Simple-copy: offload GC data-movement to device



Linux Kernel: Performance characterization

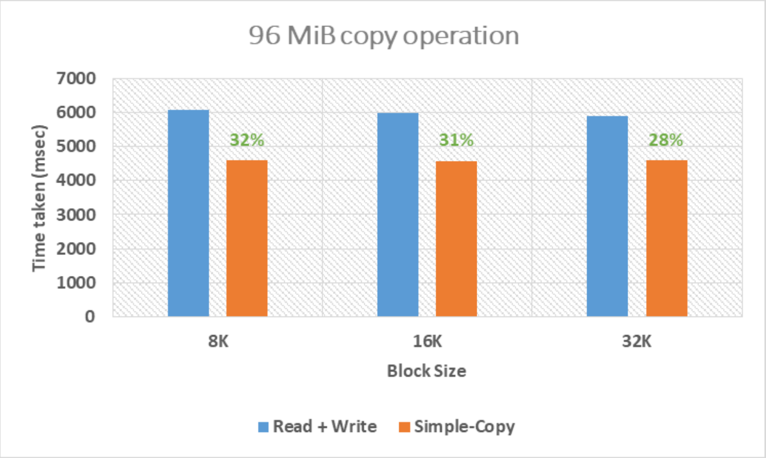
ZRWA

- **Linear scalability within ZRWA window**
  - Also across several zones
- **Makes sense for metadata writes**
  - Leverage in-place update at no BW cost
  - 4KB at moderate / high QD

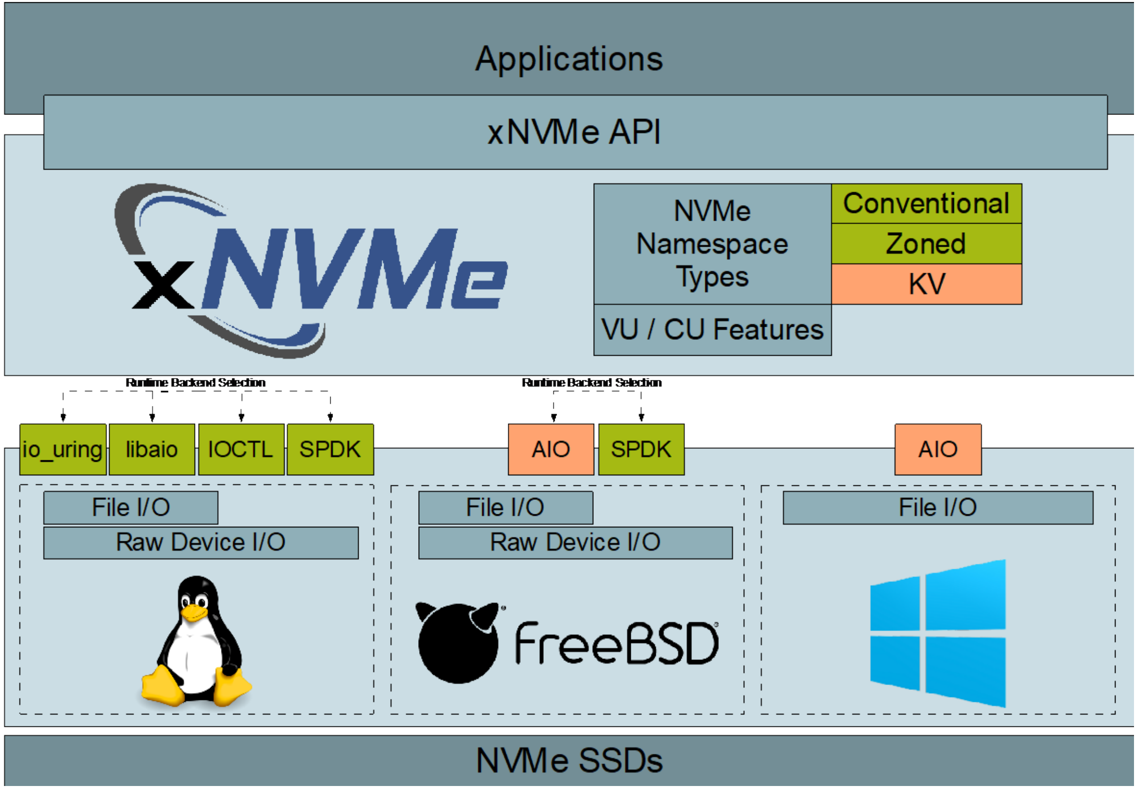


Simple-Copy

- **Better use of fabric bandwidth**
  - Lower latency, higher bandwidth
  - Scales with block size (SGL for source LBA ranges)
- **Lower host CPU utilization**
  - Offload data movement
  - Limited to I/O submission



xNVMe



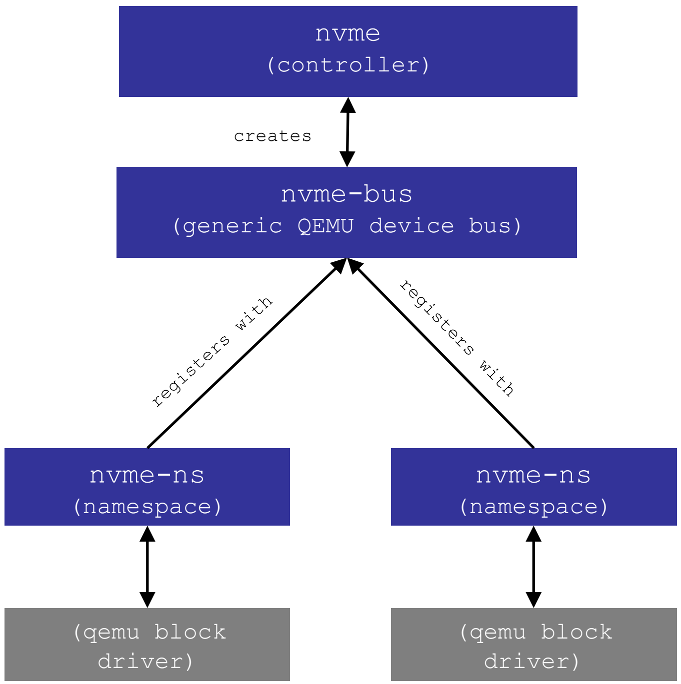
Status

- **Support for NVMe 1.4**
- **Support for ZNS**
  - Namespaces Types
  - ZNS Mandatory & Optional
  - Simple Copy
  - ZRWA (Release after publication)
- **Focus on Linux support**
  - Working on io_uring passthru
- **Backend selection @ runtime**
- **Ongoing support in FreeBSD and Windows**
- **Open-Source**
  - https://github.com/OpenMPDK/xNVMe
  - https://xnvme.io/

Implemented | Ongoing

Simon Lund: xNVMe: Programming Emerging Storage Interfaces for Productivity and Performance

QEMU Emulated NVMe Device



Status

- **Improved NVMe Device in QEMU**
  - v1.3 support, cleanups & refactoring merged in Q2 2020
- **Submitted & Reviewed (pending upstream merge)**
  - SGLs, multiple namespaces
- **Submitted (under review):**
  - v1.4 support
  - metadata (separate and extended LBAs)
  - DULBE
  - I/O Command Sets & Zoned Namespaces
- **Submitted (pending reviews)**
  - Simple Copy Command
- **Upcoming**
  - Compare, DIF/DIX & Verify, Write Uncorrectable
  - ZRWA
  - NVMe Low-latency Mode (i.e., QEMU null_blk device)

[Klaus Jensen: Reviving The QEMU NVMe Device (from Zero to ZNS)]

LSM-based Databases – ZNS through xZTL

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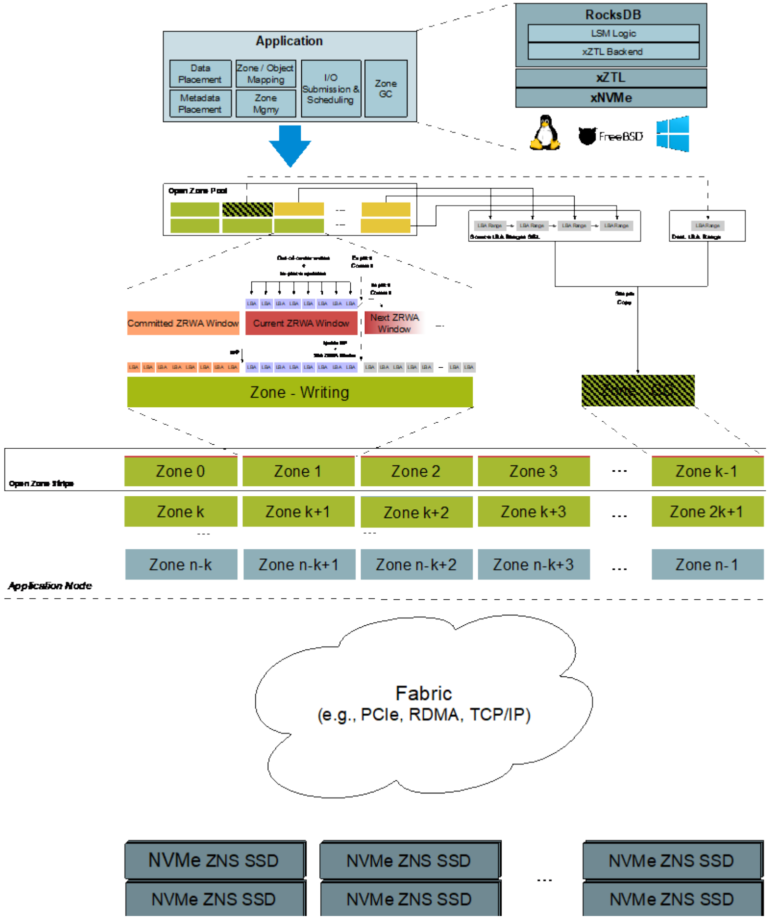


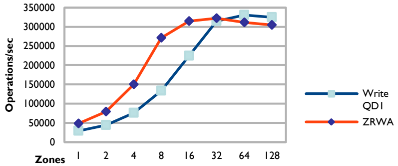
RocksDB - ZNS through xZTL

- **Enable RocksDB with thin backend: ~1000 LOC**
- **Add zoned logic for LSM DBs in xZTL**
  - Easy to port other DBs (e.g., Cassandra)
  - Transparent support for several ZNS architectures and I/O models
    - Append: Large zones
    - Stripping: Small zones
  - Support for all ZNS functionality
    - E.g., ZRWA, Simple Copy
  - Easy to enable Vendor / Customer Unique features
  - xZTL: https://github.com/OpenMPDK/xZTL
  - RocksDB w/ xZTL: https://github.com/ivpi/rocksdb
- **Tight integration with xNVMe**
  - Leverage changes in application to run on multiple OSs and I/O backends
    - Linux: io_uring, libaio, SPDK, IOCTL
    - FreeBSD: SPDK
    - Windows (ongoing)

RocksDB - Evaluation

- **2X WAF improvement in SW**
- **5-15X WAF improvement in total**

- **ZRWA: In-place updates**
- **No write BW degradation (within ZRWA window)**



Conclusion

- **ZNS is the NVMe way of performing host data placement**
  - Reduces TCO: ↑ Capacity (QLC), ↓WAF, ↓OP, ↓DRAM
  - Improves I/O determinism: Host orchestrates zone GC
- **Use cases are increasing as ZNS SSDs are available**
  - From Archival to I/O determinism
    - Different I/O models supported
  - Extensions to ZNS facilitating transition from Open-Channel SSD architectures
    - ZRWA and Simple Copy are just the beginning
- **Solid ecosystem in Linux**
  - Several vendors contributing and adding new features
  - Core support in Linux kernel: NVMe driver, block layer & file systems
- **Cross I/O path support in xNVMe**
  - Single API for all I/O backends
  - Support for Linux, FreeBSD and Windows
  - Support for io_uring, libaio, SPDK and IOCTL
- **First applications with upstream zoned support ongoing**
  - Working on libraries to facilitate support in classes of applications (xZTL → LSM-based DBs)

Talk to us about ZNS! - javier.gonz@samsung.com & joshi.k@samsung.com