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CINABRO:
a Software Driven, Open Flash Array Architecture for Scalable Cloud Storage Services

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Motivation

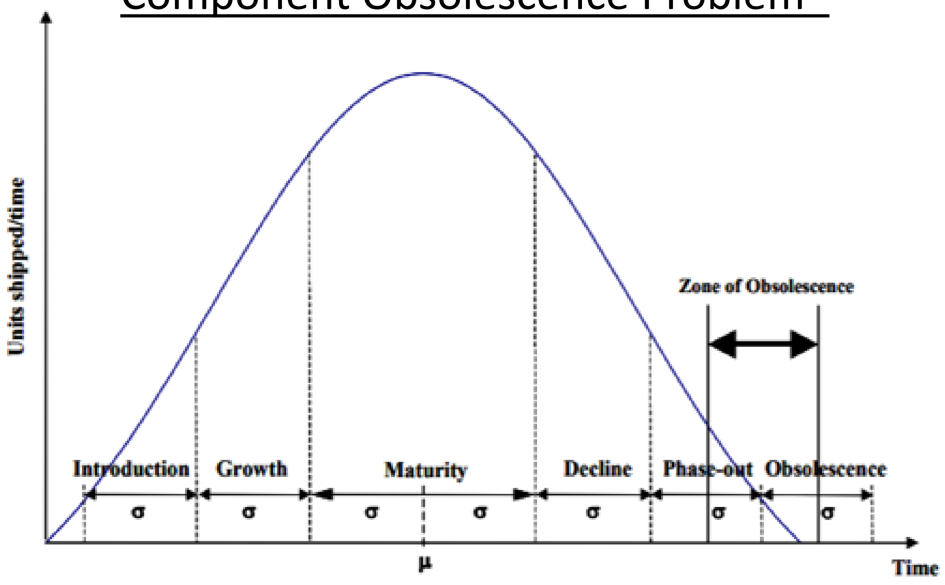
1. Serves diverse cloud storage requirements

- Data center workloads are dynamic, diverse and constantly evolving
- Data center SSDs typically run 3 to 5 years after rigorous qualification process
- SSD FW update is expensive and usually limited to critical bug fixing

2. Streamlines flash memory deployments

- SSD designs optimized for single self contained units
- Data center SSDs often have old generation NANDs
- Need for deploying latest NANDs in scale

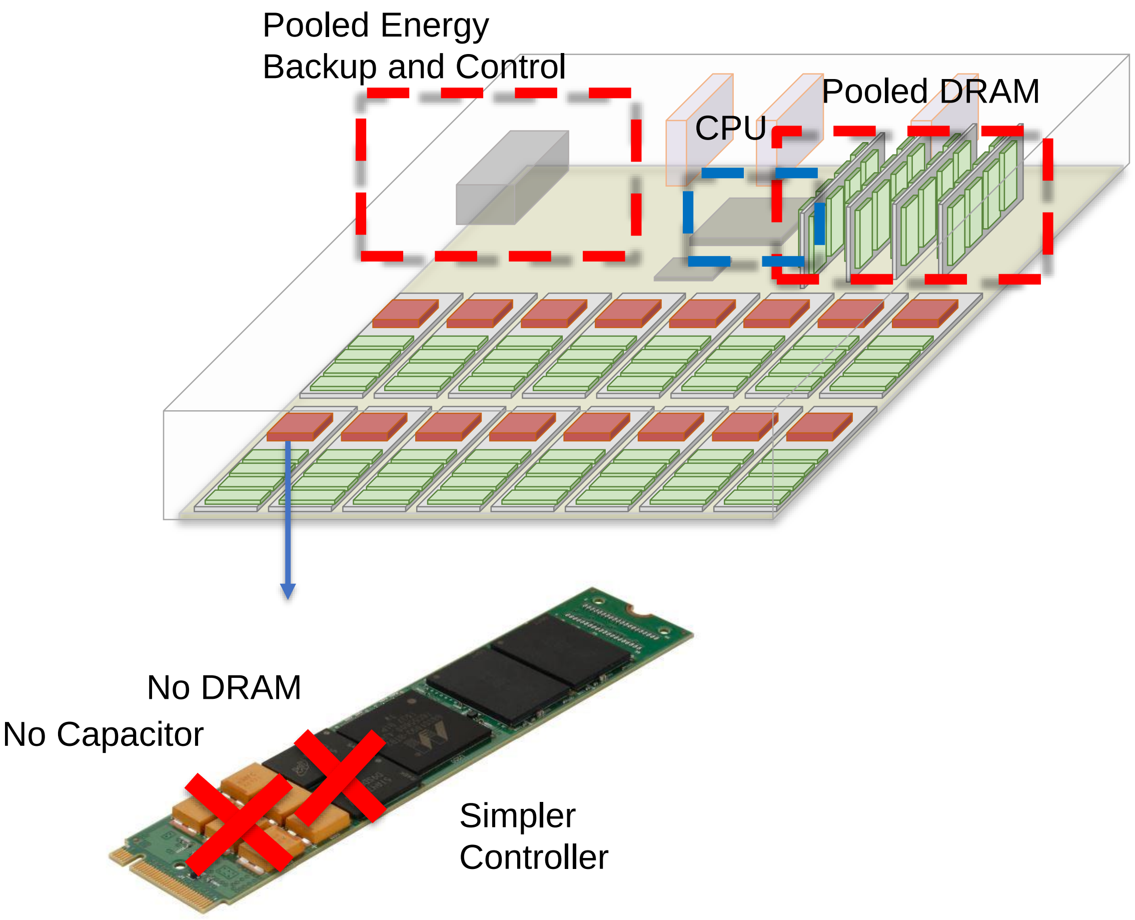
Component Obsolescence Problem*



* Source: Electronic Part Life Cycle Concepts and Obsolescence Forecasting, Solomon, Sandborn, and Pecht

Solution

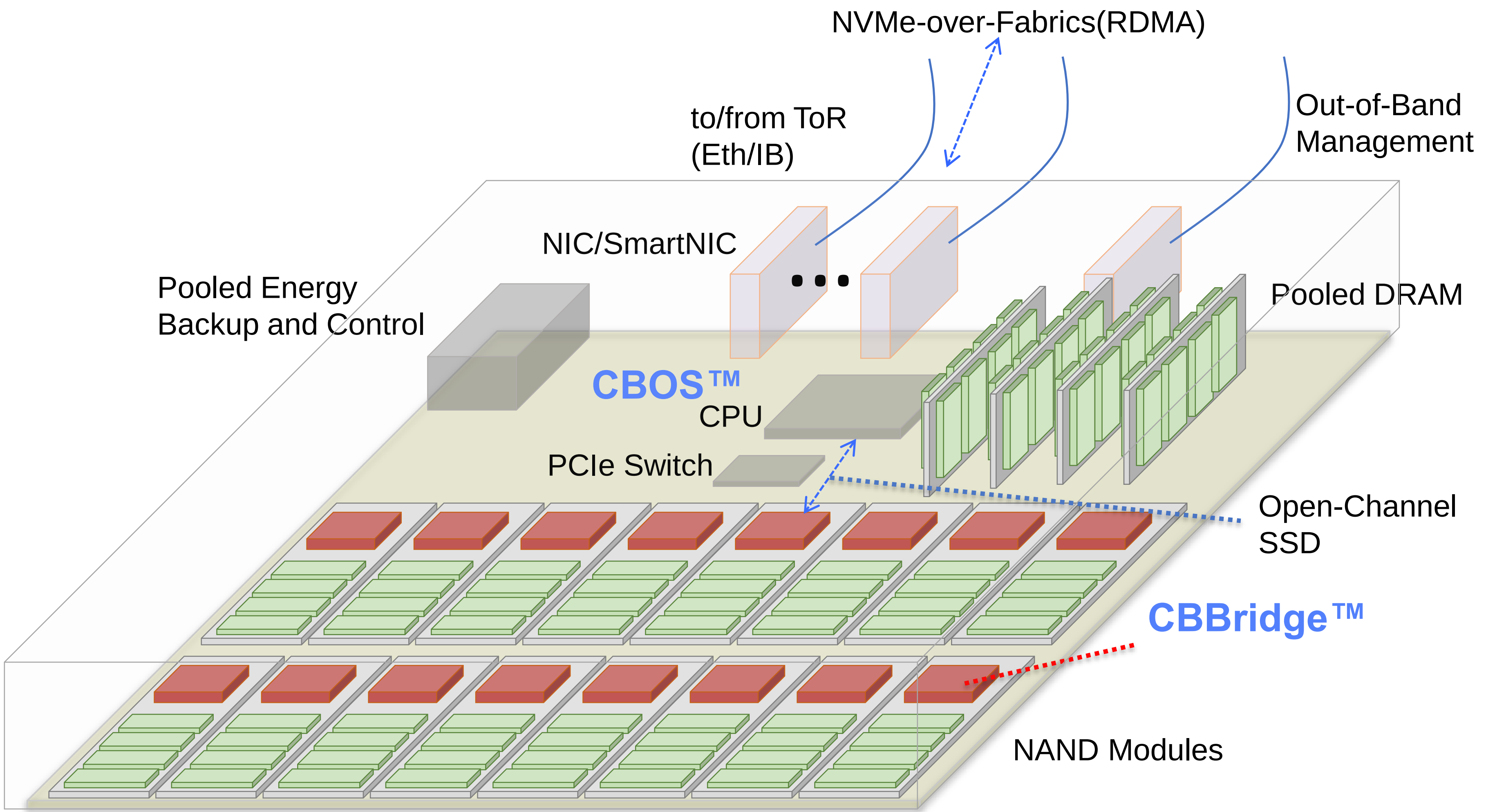
- Lower Total BOM and Simpler SSD Device Architecture
- Large portions of SSD intelligence run on host server CPU



Category	Conventional SSD	Cinabro SSD
1GB DRAM	$$	X
1TB NAND	$$$	**$$$**
SoC Controller	$$	**$**
Capacitors (x20) – Power Loss Protection	$	X
Power Consumption	High	**Low**
Development Complexity	High	**Low**

Cinabro™ System Architecture

Disaggregated and composable All Flash Array based on COTS server



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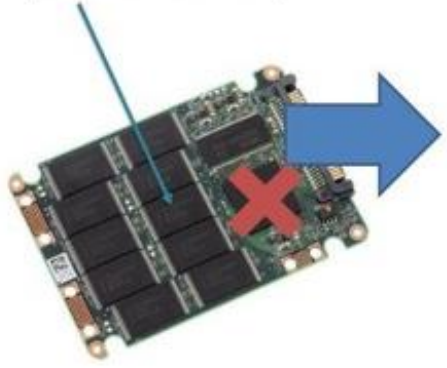
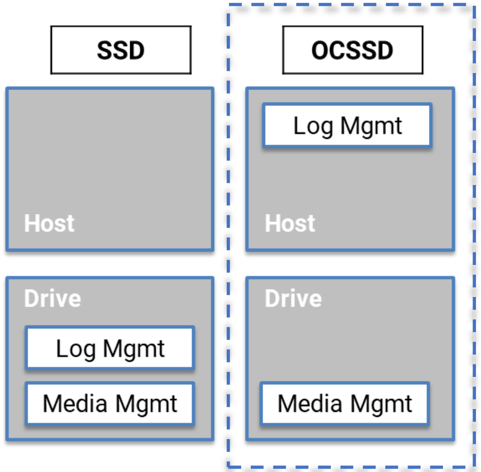
NAND Flash Interface

Leverage OCSSD Standard to Provide Optimized Solution with Simpler ASIC

Physical flash exposed to the host (Read, write, erase)



Host
- Data placement
- IO Scheduling
- Over-provisioning
- Garbage collection
- Wear levelling



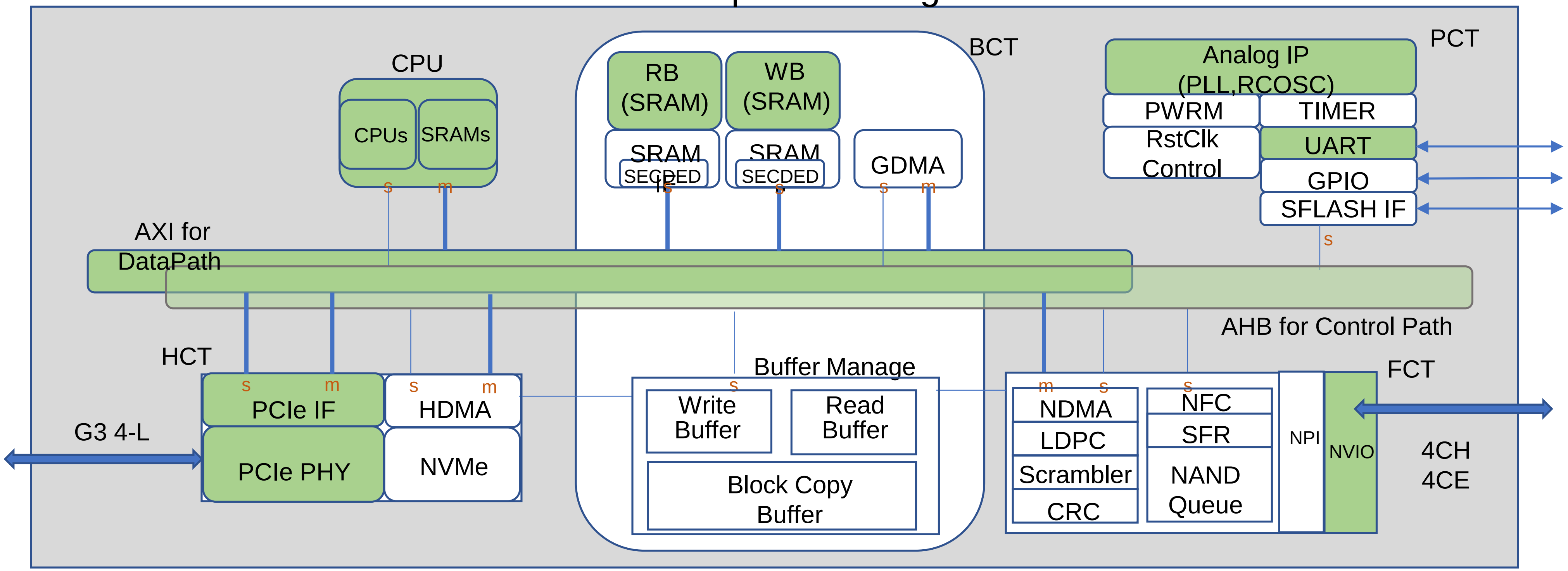
- Open-Channel SSD (OCSSD)
  - Standard NVMe based protocol
  - Facilitates host FTLs and good fit for cloud providers
- Optimized protocol translation between host and NAND interface
- Performance acceleration and reliability enhancement features for 3D NAND TLC/QLC
- Cost and power efficient ASIC design

CBBridge™ OCSSD Controller

Simple but robust SoC handling essential NAND media functions

- Open-Channel SSD spec and additional features for cross layer optimizations
- 28nm process technology accommodates 96+ layer 3D toggle3 TLC/QLC NAND with LDPC

SoC Chip Block Diagram



System Performance : G3 2-L

🟩 3rd Party IPs

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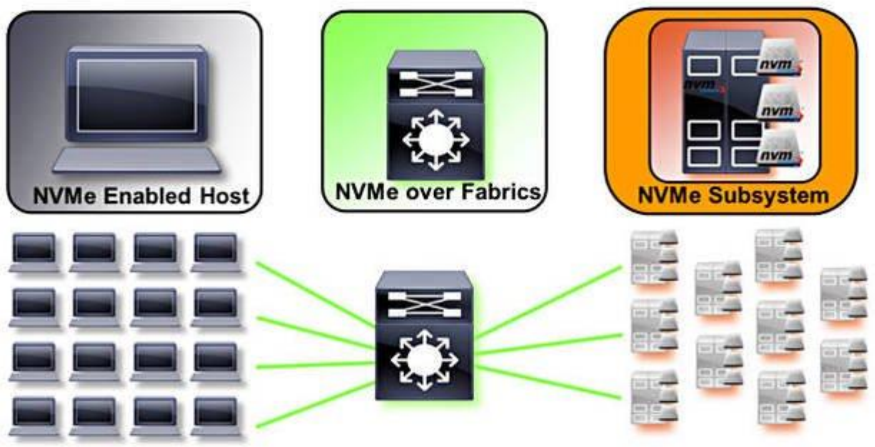
Network Interface

Leverage New Standard for Networked Storage Interfaces



- NVMe-over-Fabrics (NVMe-oF)
  - Faster access between hosts and storage systems
  - Much lower latency than iSCSI
- Flexible system design to support various fabrics of NVMe-oF standard (Ethernet, Infiniband, etc.)
- Open architecture allows incorporating new system technologies (e.g. SmartNIC, FPGA acceleration, SDN)
- Seamless integration with Open-Channel SSDs

Software Design

Advanced Open Source Software Optimized for All Flash Array

Latest Open Source SW Solution

Linux LightNVM
SPDK/DPDK
RocksDB
OpenStack
Ceph
Docker
Kubernetes

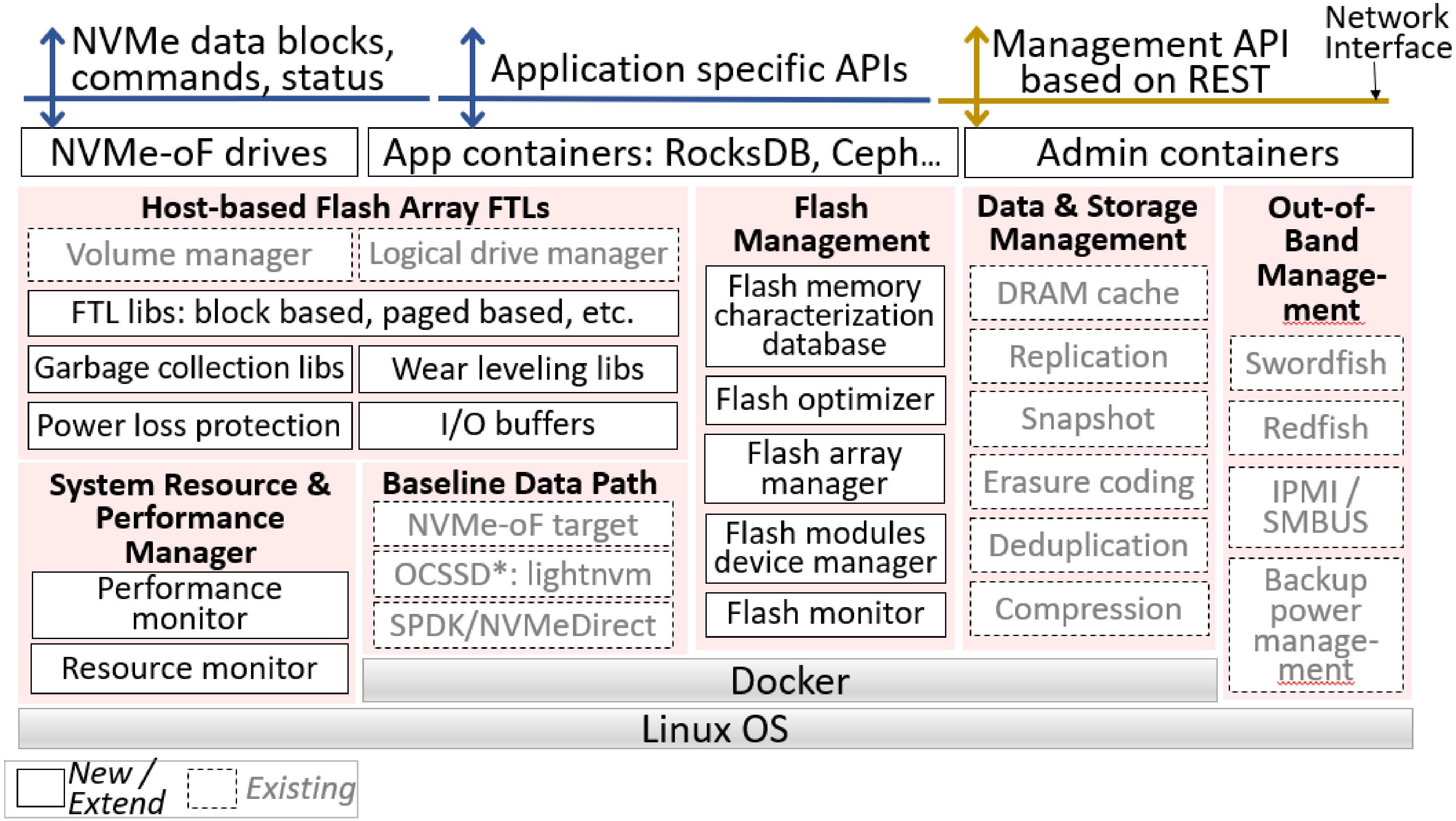
SPDK

- Host-managed array FTLs
- User-level device driver configurable/adapting to various workload
- Scalable design to manage array of NAND modules
- Leverage multi-core/multi-processor CPU to maximize parallelism
- Data center friendly orchestration utilizing Linux Containers and Kubernetes Ready design

CBOS™ Software Architecture

Container based storage and application software modules

- Host based Flash Array FTLs come with libraries that apps can pick and choose



NVMe data blocks, commands, status

Application specific APIs

Management API based on REST

Network Interface

NVMe-oF drives

App containers: RocksDB, Ceph…

Admin containers

Host-based Flash Array FTLs

Volume manager

Logical drive manager

FTL libs: block based, paged based, etc.

Garbage collection libs

Wear leveling libs

Power loss protection

I/O buffers

Flash Management

Flash memory characterization database

Flash optimizer

Flash array manager

Flash modules device manager

Flash monitor

Data & Storage Management

DRAM cache

Replication

Snapshot

Erasure coding

Deduplication

Compression

Out-of-Band Manage-ment

Swordfish

Redfish

IPMI / SMBUS

Backup power manage-ment

System Resource & Performance Manager

Performance monitor

Resource monitor

Baseline Data Path

NVMe-oF target

OCSSD*: lightnvm

SPDK/NVMeDirect

Docker

Linux OS

□ *New / Extend*

⬚ *Existing*

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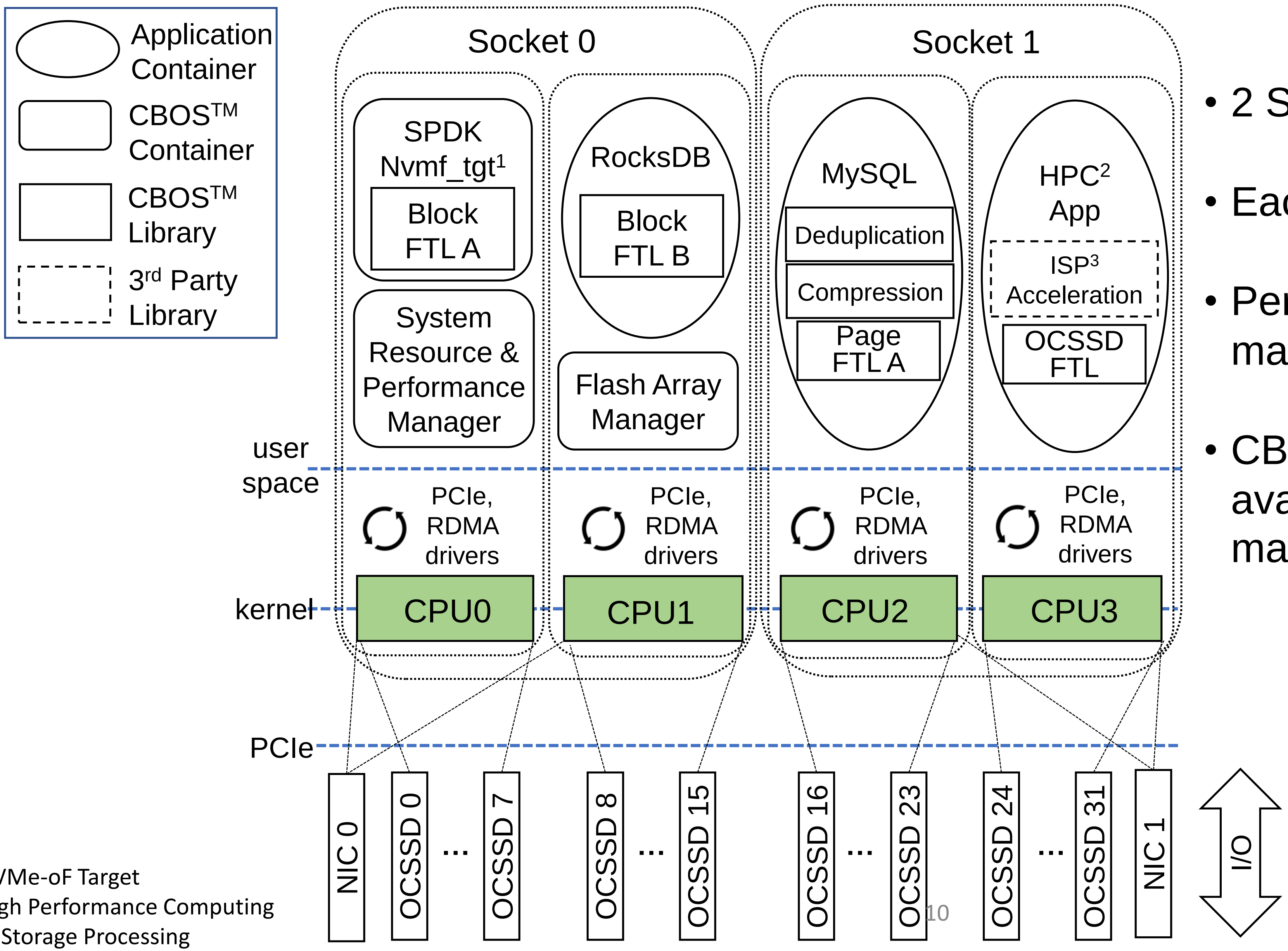
* OCSSD: Open-Channel SSD

CBOS™ Container Example



- 2 Socket, 4 Core System
- Each CPU core handles 8 OCSSD
- Per different application needs, matching FTL container is deployed
- CBOS storage containers run on available CPU cores executing managerial tasks

1. NVMe-oF Target
2. High Performance Computing
3. In Storage Processing

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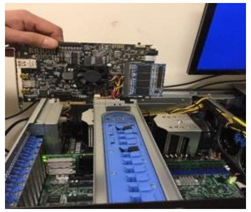
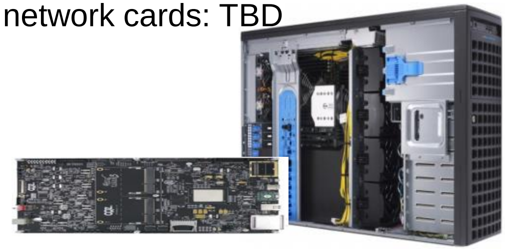
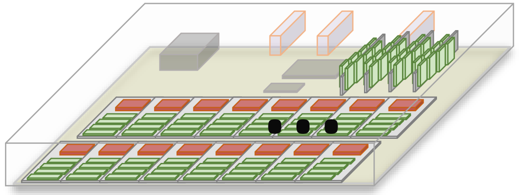
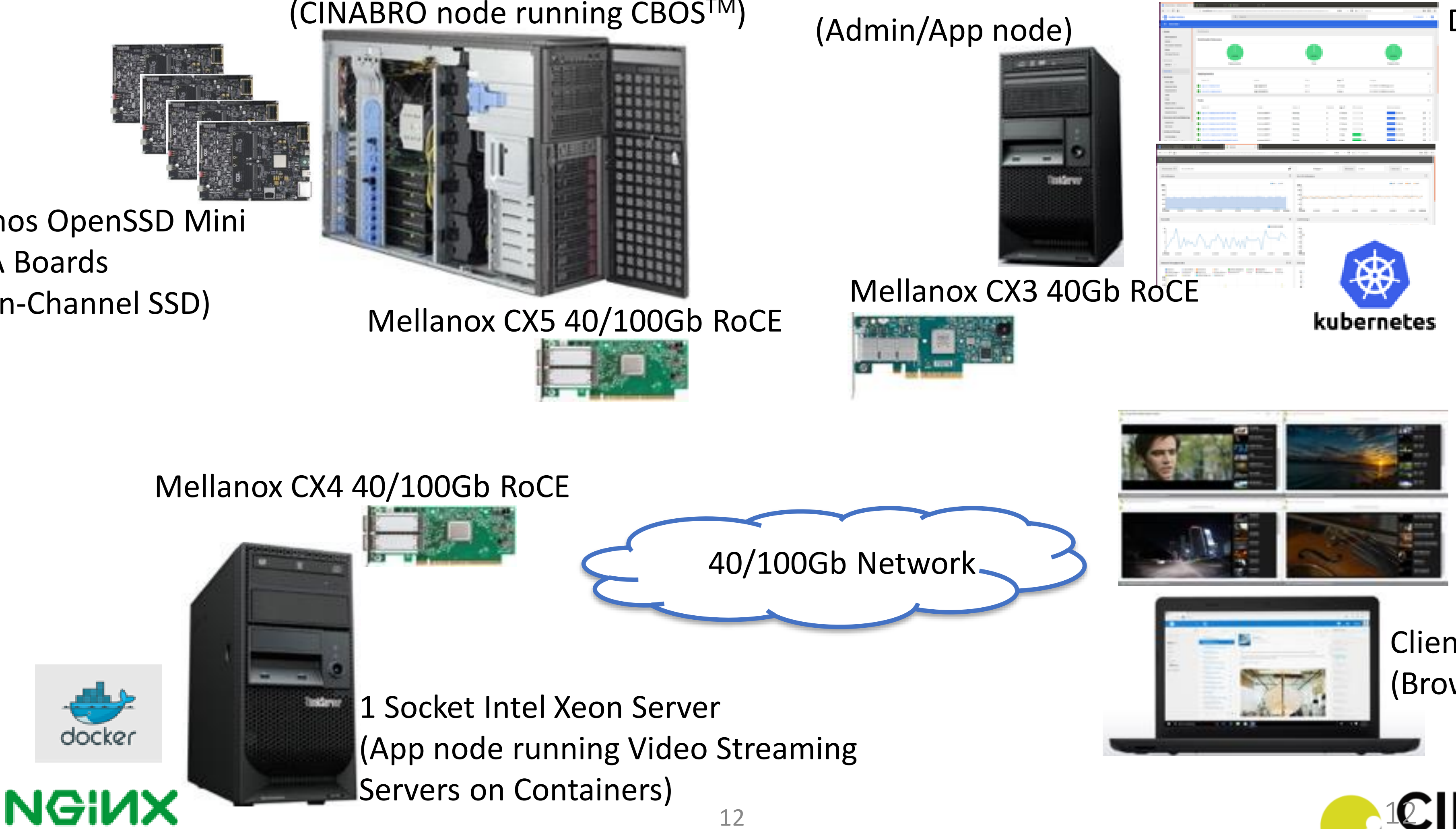
Development Milestones

	Phase I (-Dec. '17)	Phase II (-Dec. '18)	Phase III (-Dec. '19)
CINABRO™ Appliance	**First Working Prototype** • Commodity x86 server • x4 Cosmos OpenSSD Mini PCIe cards • Mellanox RDMA network cards 	**Alpha** • Commodity x86 server • x8 Cosmos OpenSSD Ultra PCIe cards • NVMe-oF network cards: TBD 	**Beta** • Customized PCIe fabrics • Commodity CPU, DRAM, PCIe • BMC: ready; Backup power: TBD 
CBBridge™	**FPGA1** • FPGA code with OCSSD compliant FW • 16nm 2D MLC NAND w/ BCH	**FPGA2** • RTL release: CBBridge™ SoC ready. Runs on FPGA • 64L 3D TLC NAND w/ LDPC	**ASIC** • SoC tape-out (mid '19) • 96L 3D TLC/QLC NAND w/ LDPC
CBOS™	**Prototype release** • NVMe-oF drive interface • Baseline data path working: • OCSSD pblk / lightnvm, NVMe-oF, SPDK/DPDK	**Alpha release** • Host-based flash array FTLs • Storage management layer • Application plugins • System resource & performance manager design complete	**Beta release** • Core feature complete • OpenStack compliant • Data management beta • System resource & performance Manager beta • Out-of-Band management beta
Open Source	**SPDK contribution** • Functions to help writing OCSSD access from user level • Included in SPDK v17.10, v18.01	**R&D version alpha** • OpenSSD FPGA RTL codes v1.2 • Developer edition CBOS™ alpha: includes device drivers, user level libraries, and pilot apps	**R&D version beta** • OpenSSD FPGA RTL codes v1.3 • Developer edition CBOS™ beta

Current Prototype

Multiple FPGA based OCSSDs running in our lab



2 Socket Intel Xeon Server
(CINABRO node running CBOS™)

1 Socket Intel Xeon Server
(Admin/App node)

Dashboards

Cosmos OpenSSD Mini
FPGA Boards
(Open-Channel SSD)

Mellanox CX5 40/100Gb RoCE

Mellanox CX3 40Gb RoCE

Mellanox CX4 40/100Gb RoCE

40/100Gb Network

Client PC
(Browsers)

1 Socket Intel Xeon Server
(App node running Video Streaming
Servers on Containers)

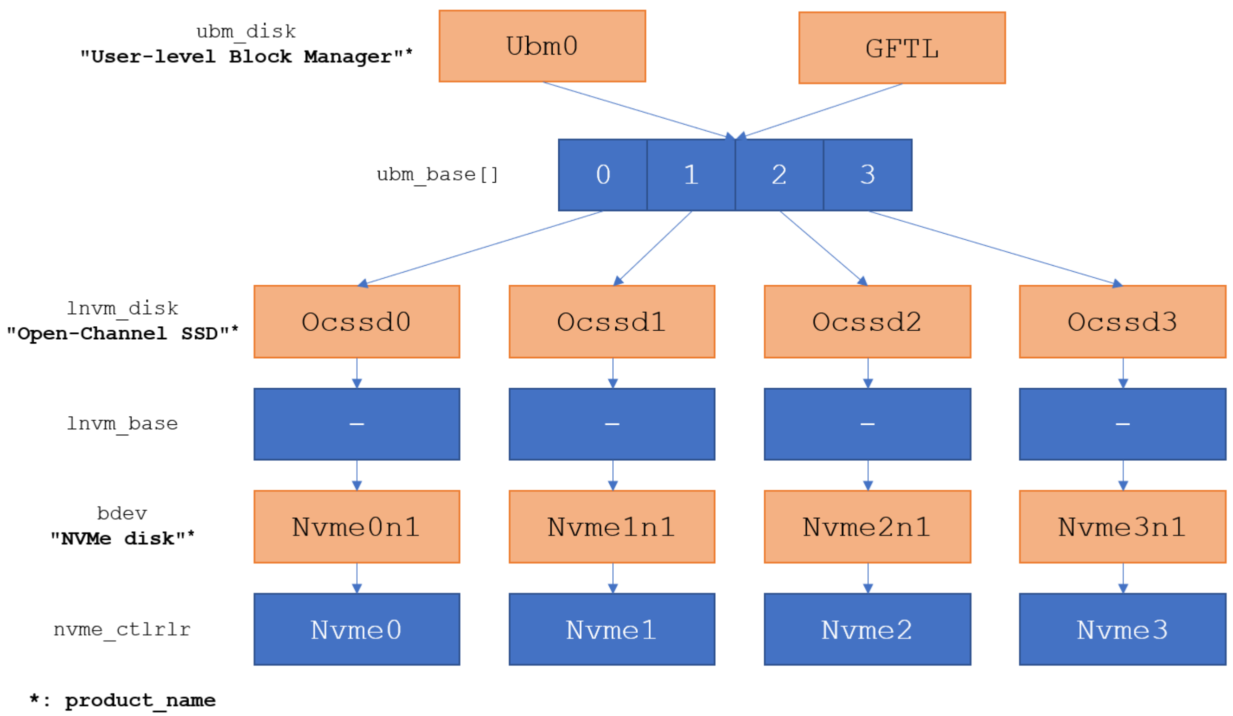
Prototype FTL Evaluations

Our 1st host FTLs, UBM and GFTL*, have been implemented in SPDK.

Access

Local (SPDK API)

Remote (NVMe-oF)



ubm_disk
"User-level Block Manager"*
Ubm0
GFTL
ubm_base[]
0
1
2
3
lnvm_disk
"Open-Channel SSD"*
Ocssd0
Ocssd1
Ocssd2
Ocssd3
lnvm_base
–
–
–
–
bdev
"NVMe disk"*
Nvme0n1
Nvme1n1
Nvme2n1
Nvme3n1
nvme_ctlrlr
Nvme0
Nvme1
Nvme2
Nvme3
*: product_name

(1) Array with up to 4 units of FPGA OCSSDs

: showing reasonable performance for FPGA based SSDs

(2) Array with up to 24 units of OCSSD Qemu-nvme emulators

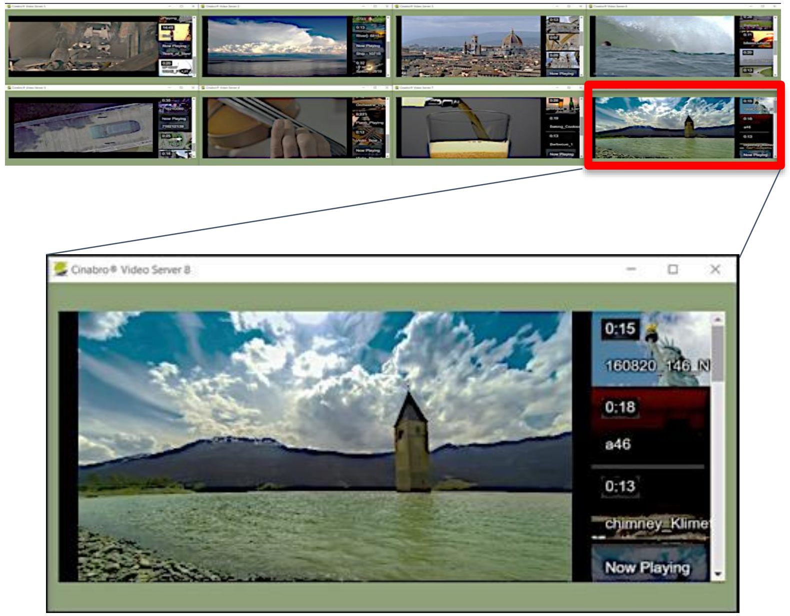
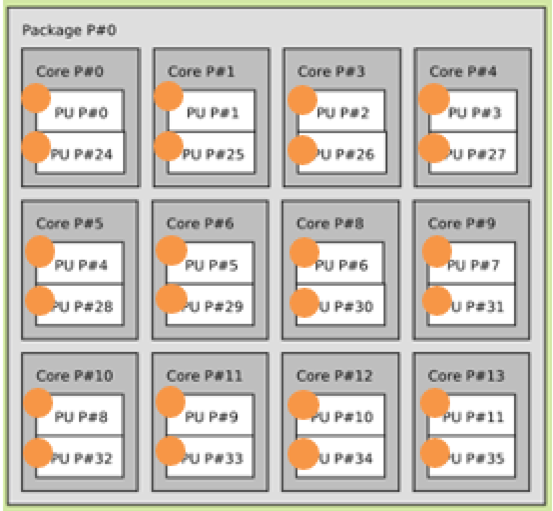
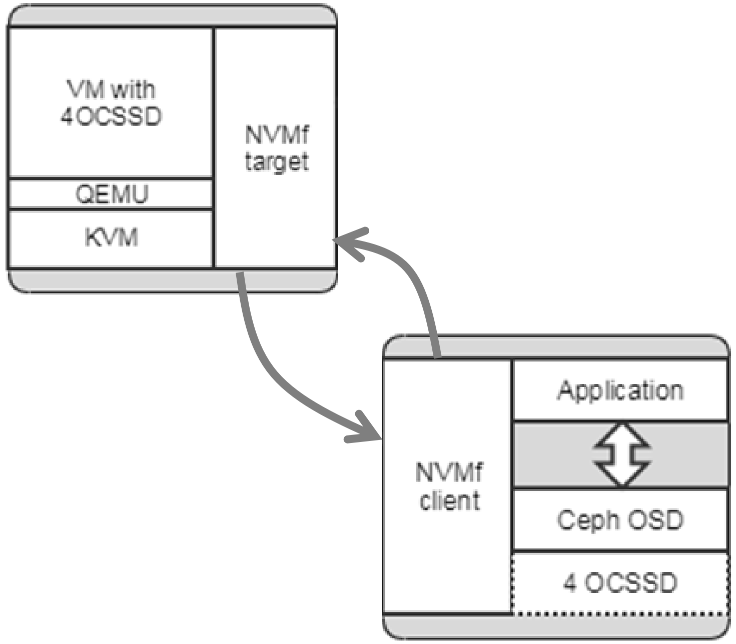
: used for qualitative test of multiple applications

: 24 copies of GFTL working correctly over same number of emulated OCSSDs

* *GFTL is based on Hanyang University's Greedy FTL.*

Prototype Applications

End-to-end integration tests with multiple applications

Containerized Video Server	Containerized RocksDB	SK telecom's AF Ceph
- OCSSD arrays host movie files and are exposed via SPDK nvmf_tgt containers - Video servers run inside containers, made of Nginx web server with RTMP module	- Containerized RocksDB, both local and remote (over NVMe-oF) - Local: SPDK's RocksDB plugin over CBOS^{TM} GFTL - Remote: SPDK's nvmf-tgt over CBOS^{TM} GFTL	- All Flash Ceph is flash optimized version of Ceph. - Initial data verification test over 4 FPGA OCSSDs ran successfully.
 Cinabro® Video Server 8 0:15 160820_146_N 0:18 a46 0:13 chimney_Klime Now Playing [8 concurrent video server example]	SPDK: STORAGE PERFORMANCE DEVELOPMENT KIT RocksDB  Package P#0 Core P#0 PU P#0 PU P#24 Core P#1 PU P#1 PU P#25 Core P#3 PU P#2 PU P#26 Core P#4 PU P#3 PU P#27 Core P#5 PU P#4 PU P#28 Core P#6 PU P#5 PU P#29 Core P#8 PU P#6 PU P#30 Core P#9 PU P#7 PU P#31 Core P#10 PU P#8 PU P#32 Core P#11 PU P#9 PU P#33 Core P#12 PU P#10 PU P#34 Core P#13 PU P#11 PU P#35 [24 RocksDB plugin per CPU core example]	 VM with 4OCSSD QEMU KVM NVMf target NVMf client Application Ceph OSD 4 OCSSD [AF Ceph over 4 OCSSDs example]

Summary

Solution Benefits

- Flexibility to accommodate NAND generations from various vendors
- Adaptable to various Cloud Data Center network infrastructure
- Customizable SW architecture to meet ever-evolving cloud data center requirements

Communities

- OpenSSD, OCSSD, SPDK: Our work has been integrated
- OCP: open to collaboration about making our hardware design available to the community

Resources

- OpenSSD FPGA SSD available at: http://openssd.io
- SPDK OCSSD contributed codes: https://github.com/spdk/spdk.git (SPDK v17.10, v18.01)
- CBOS^{TM} development edition codes: TBD

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