What's the Story in EBS Glory: Evolutions and Lessons in Building Cloud Block Store

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Elastic Block Storage

- A Storage Service of ALIBABA CLOUD
  - Services in the form of virtual block devices with
    - High performance
    - High availability
    - High elasticity

  The Goals of EBS

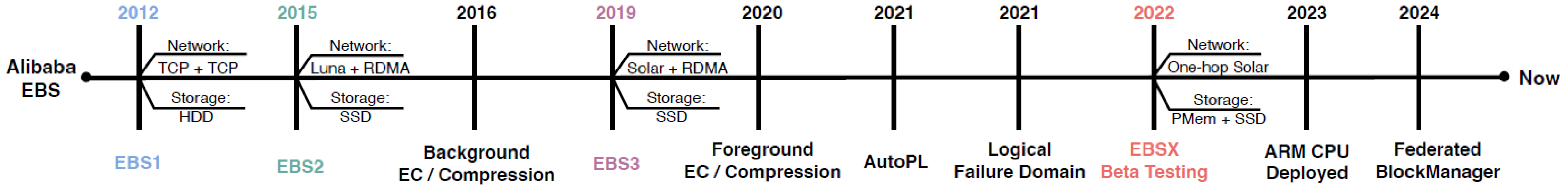
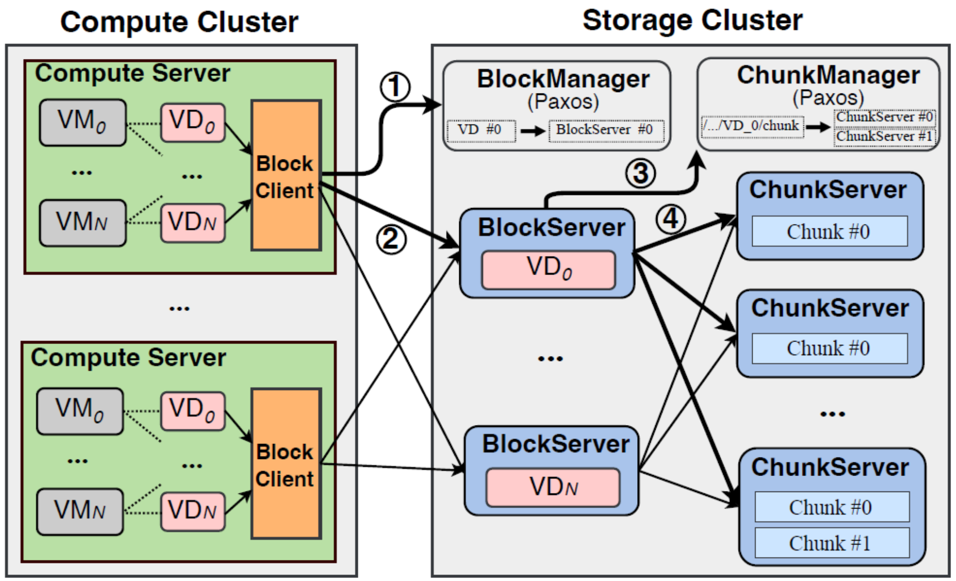


Figure 1: Alibaba EBS Timeline

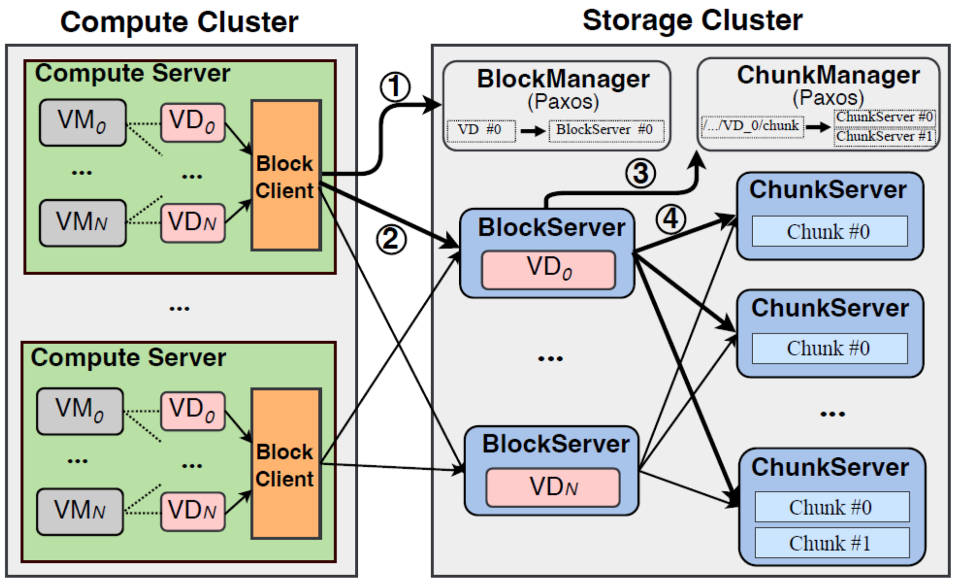
EBS1: An Initial Foray

- Based on a simple disaggregated architecture
  - Compute cluster
  - Storage Cluster
    - Three-way replicates each chunk and stores it as a 64MiB Ext4 file
    - Divides a VD into 64MiB chunks
    - Performs in-place update to the chunk
  - Network
    - Frontend: Compute Cluster-Storage Cluster
    - Backend: BlockServers-ChunkServers
    - Both rely on 10 Gbps TCP/IP network



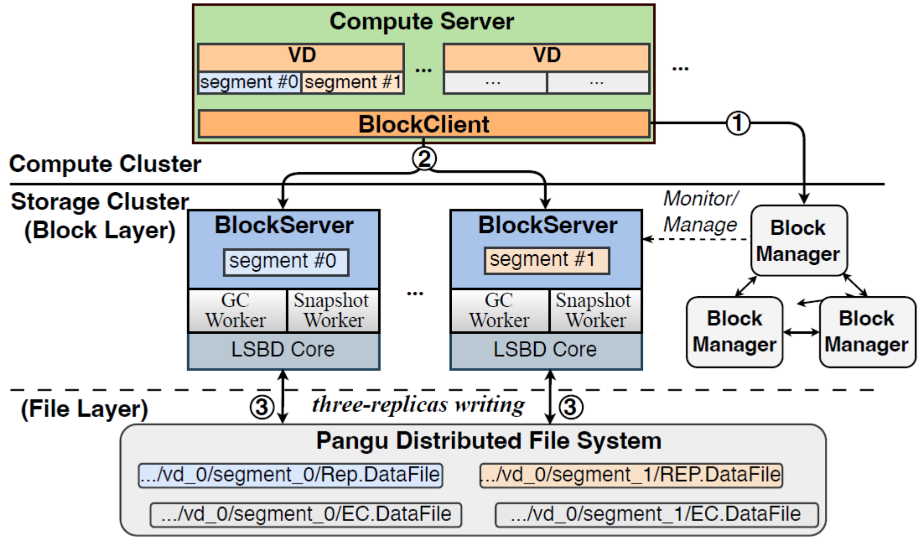
EBS1: An Initial Foray

- Limitations in the aspect of
  - Efficiency due to in-place update
    - Unable to use data compression and EC(Erasure Coding)
    - Compression non-deterministically alters the size of data
    - EC has a minimum size requirement
  - Performance due to the N-to-1 mapping
    - BlockServer can suffer from hotspot issues



EBS2: Speedup with Space Efficiency

- High performance and space efficiency
  - Builds on top of the Pangu(a distributed storage system)
  - BlockServer employs log-structured Design
    - Enables data compression and EC during GC
  - Disk segmentation
    - Alleviate the hotspot accessing in VDs
  - Network (2x25 Gbps)
    - Frontend: Luna(user-space TCP implementation)
    - Backend: RDMA network



EBS2: Speedup with Space Efficiency

- Disk Segmentation
  - A VD is divided into 128 GiB segment groups
  - A segment group comprises 32 GiB segments
    - Allocated in a round-robin fashion
  - Associates one segment with multiple DataFiles
    - Supports concurrent write

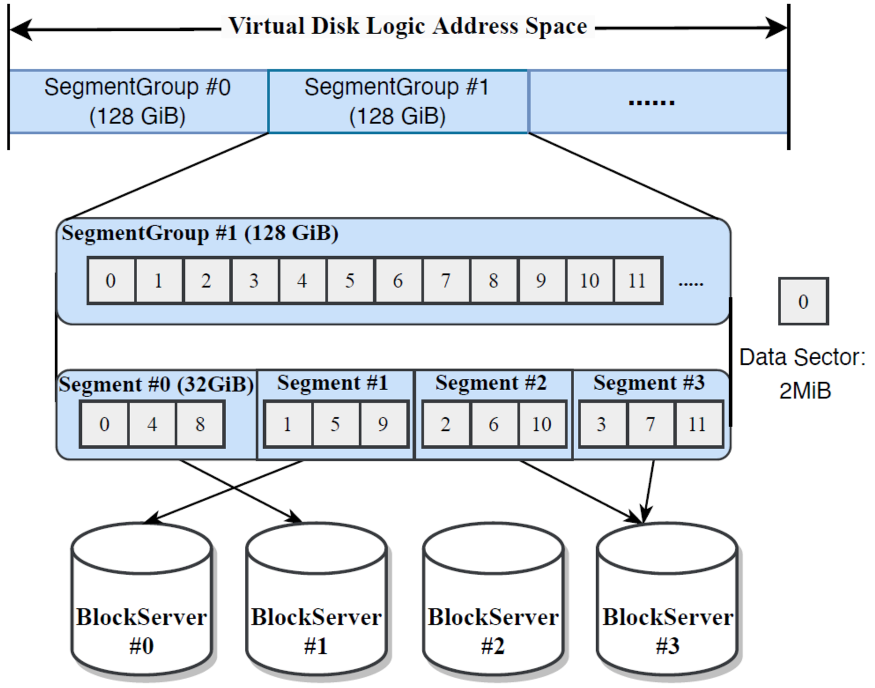
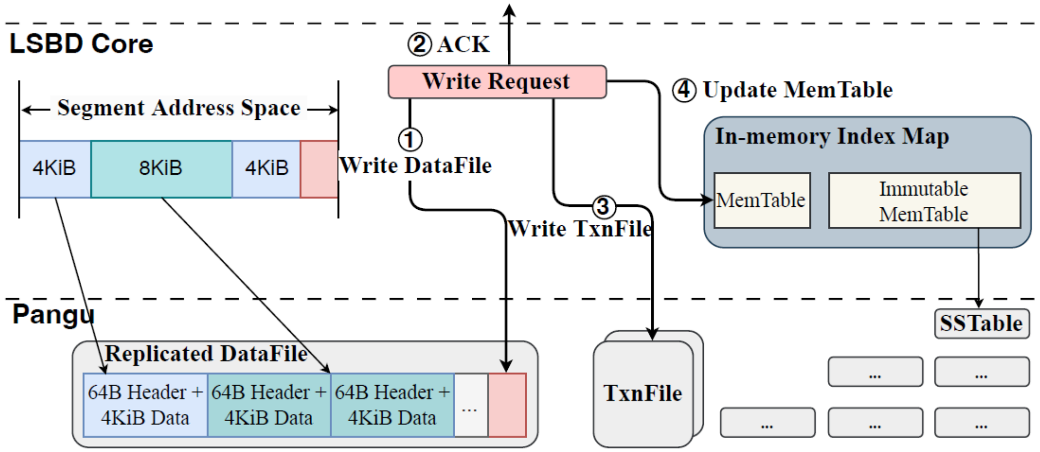


Figure 4: The Disk Segmentation Design of EBS2 (§2.2).

EBS2: Speedup with Space Efficiency

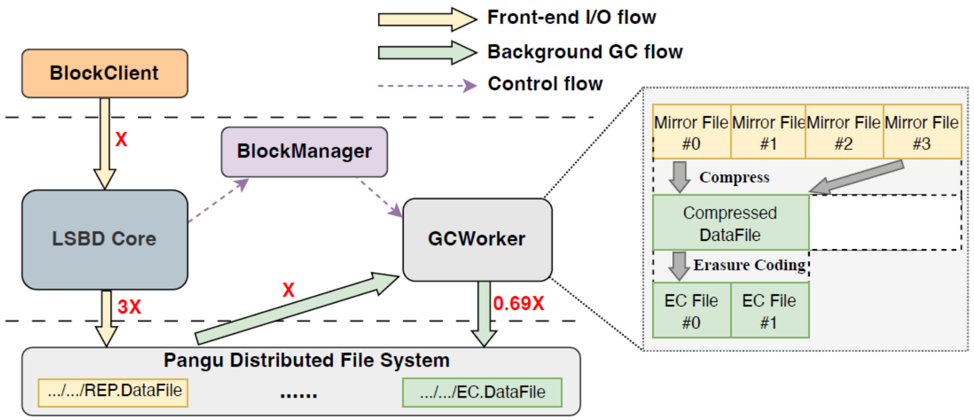
- Log-Structured Block Device
  - Supports the append-only semantics
  - Splits traffic into frontend and backend
  - Index Map(an LSM-tree)
    - Speeds up the locating process
    - Maps the VD's LBA to the DataFile ID, offset and length
  - TxnFile accelerates the index map rebuild



EBS2: Speedup with Space Efficiency

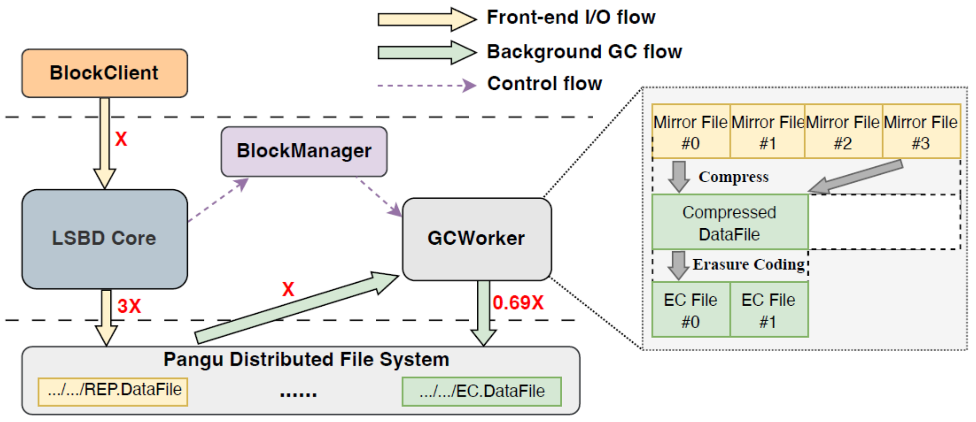
- GC with EC/Compression(LZ4/ZSTD)
  - Runs at the granularity of DataFile
  - Triggered when stale data within DataFiles reaches the threshold
  - Update the TxnFile and the in-memory index map

  - Avg. compression ratio ≈ 50.1%
  - Avg. # of replicas ≈ 1.29



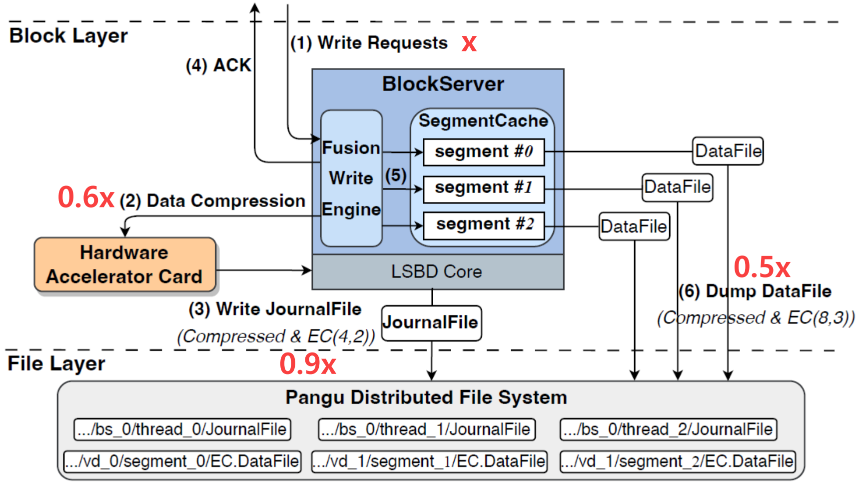
EBS2: Speedup with Space Efficiency

- Limitations
  - Heavy traffic amplification
    - Increased the overall traffic from 3 to 4.69
    - 3 from three-way replication + 1.69 from backend GC
    - Yields only 15.5% of the network bandwidth
  - Unable to adopt online EC/Compression
    - EC requires the data block to be at least 16 KiB
    - 70% of write request are smaller than 16 KiB



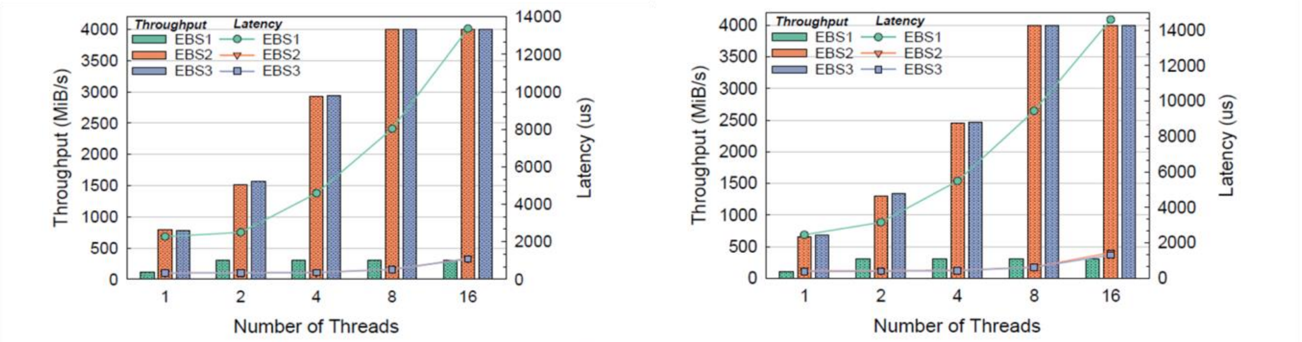
EBS3: Foreground EC/Compression

- Reducing network traffic amplification
  - Fusion Write Engine
    - Merge small writes until forms a 16 KiB DataBlock
    - Infrequent small writes are directly appended with three-way replication
  - FPGA-based compression offloading
    - Comp. data is verified with end-to-end CRC check
  - Network (2 x 100 Gbps)
    - adopts Solar(a UDP-based protocol) for both
  - Traffic amplification reduced to 1.59



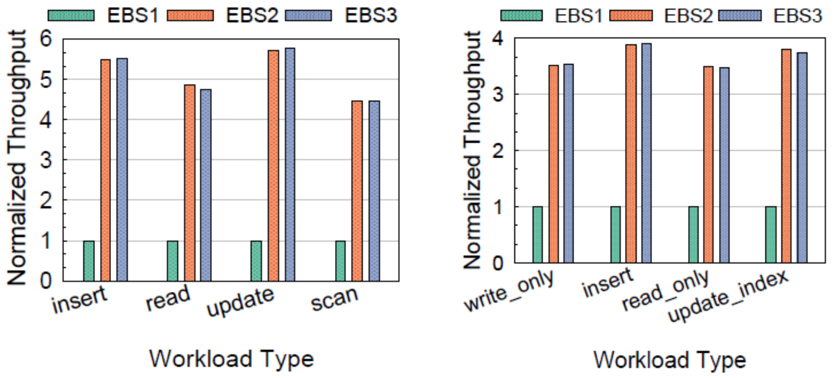
Evaluation

- Throughput under
  - Microbenchmark(by stressing the VD using FIO)
  - Application-based microbenchmark(RocksDB with YCSB / MySQL with Sysbench)



(a) Throughput and Latency of Random **Write** on Thread-to-core Pinning (b) Throughput and Latency of Random **Read** on Thread-to-core Pinning

Figure 9: Random Write/Read Latency of Each Generation EBS under Multiple Threads and 4 KiB-sized I/O. Thread-to-core pinning means that each thread occupies one CPU core exclusively.



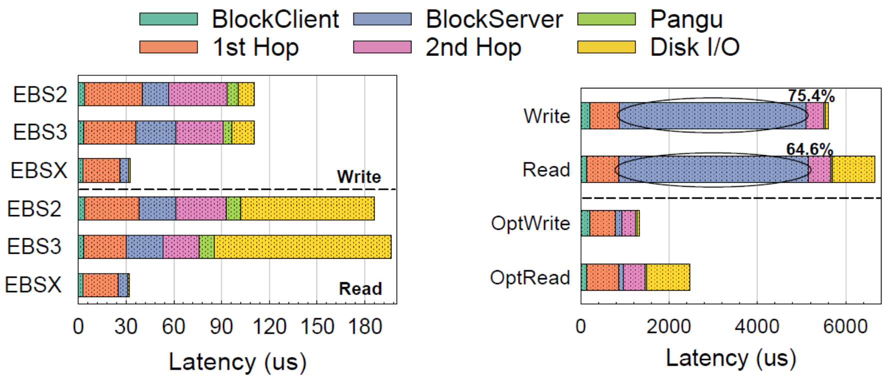
(a) Throughput Comparison of each EBS with **YCSB**

(b) Throughput Comparison of each EBS with **Sysbench**

Figure 10: Throughput Comparison (Normalized with EBS1).

Achieving Elasticity: Latency

- Is determined by the architecture
  - Networks: frontend(1st Hop) and backend(2nd Hop)
  - Software stacks: BlockClient, BlockServer and Pangu
  - Hardware: SSD I/O
- Optimizing hardware is straightforward
  - EBSX: BlockServer stores the data in PMem
- Tail latency by software stack may noise
  - OPT: Segregate the I/O flow from other tasks



(a) Average Latency Breakdown of EBS2, EBS3 and EBSX

(b) 99.999th Tail Latency Breakdown of EBS3

Figure 11: 8 KiB-Sized Avg. and Tail Latency Breakdown of EBS. ***1st hop:*** *network latency from compute to storage end.* ***2nd hop:*** *network latency from BlockServer to Pangu.*

Achieving Elasticity: Throughput and IOPS

- The upper bound is determined by the BlockClient
  - Backend can easily scale with parallelism
  - In EBS1: implemented as a kernel module
  - In EBS2: move to the user space (with user-space TCP stack)
  - In EBS3: offload to hardware (FPGA)
- High performance is not always needed
  - Base+Burst strategy
    - BaseIO: pre-defined
    - BurstIO: allocated based on available capability

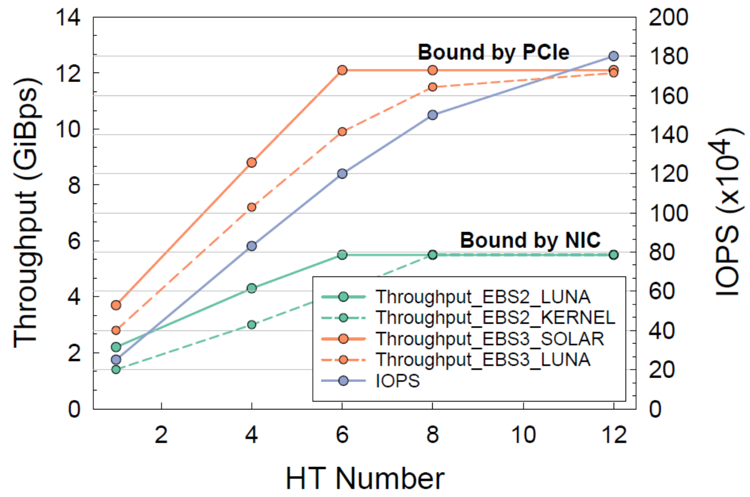


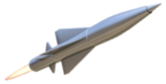
Figure 12: The maximum throughput and IOPS changes of Block-Client with different HT numbers.

Achieving Elasticity: Capacity

- Flexible space resizing
  - Segmentation design enables seamless support for VD resizing
  - Supports VD size ranging from 1 GiB to 64 TiB

- Fast VD cloning
  - Needs for a large volume of resources to be allocate in a short time
  - Uses the Hard Link of Pangu files
  - Enables the creation of up to 10,000 VD(each 40 GiB) in 1 min

Improving Availability

- Blast Radius
  - Individual 
    - When only one VD is influenced
    - e.g., An uncorrectable error inside the disk and a software bug
  - Regional 
    - When incurs deny of service for several VDs (e.g., BlockServer crash)
  - Global

Minimize Blast Radius: Control Plane

- BlockManager in EBS2
  - Single leader serves all the VDs in the cluster
  - Single metadata table hosts the metadata of VDs in the cluster

- Federated BlockManager
  - Multiple BlockManager for each cluster
  - Manages hundreds of VD-level partitions

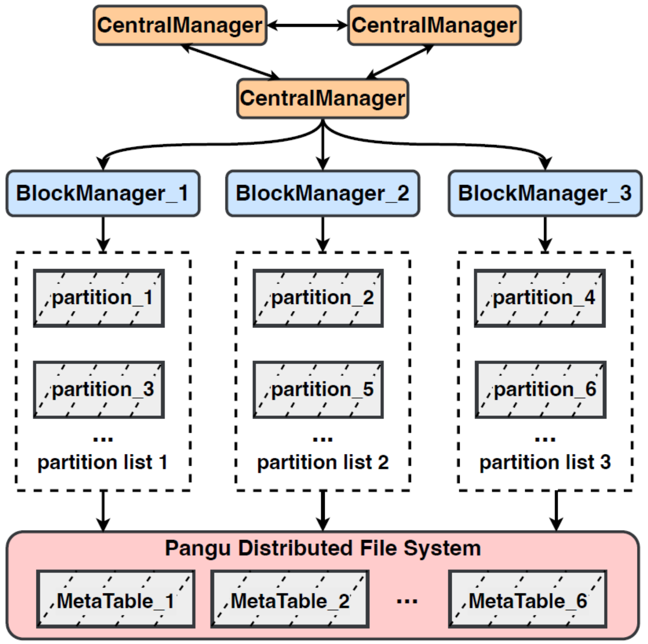


Figure 13: The architecture of Federated BlockManager.

Minimize Blast Radius: Data Plane

- When BlockServer in EBS2 crash
  - BlockManager migrates the segments to other BlockServer
  - Resume and crash again if the crash is caused by an error segment
  - Lesson learned
    - Failure typically originates from a single VD or segment
    - The root causes of the failure are mostly due to software errors
    - Cascading failure can propagate to the whole cluster

- Logical Failure Domain
  - Isolate suspicious segments into a small set of BlockServers

To Whom the EBS offloads

- Offloading BlockClient
  - BlockClient in EBS2 has become bottleneck
    - Calculating CRC
    - Encryption
    - Performing per-I/O table lookups
  - Using FPGA-based solution?
    - 37% of data corruption incidents was identified by CRC mismatches
    - Overheating, signal interference, timing issues
    - Later move on to adopt the ASIC-based solution

To Whom the EBS offloads

- Offloading BlockServer
  - To reduce costs while maintaining performance
  - Still remains 25 us latency with latency-optimized LZ4 compression
  - Using FPGA-based solution?
    - Faces similar instability issues
    - Reorienting the target of offloading toward server ARM CPUs

What if?

- The log-structured design was never adopted?
  - Foreground EC/compression necessitates a sufficient amount of data
- Built EBS with open-source software?
  - Tailored software stacks are needed to achieve low I/O latency
- Pangu and EBS were never separated?
  - Exceedingly complexed interfaces

Conclusion

- EBS: Cloud block store serviced by ALIBABA
  - Revisiting architecture evolutions
    - EBS1 → EBS2 → EBS3 → EBSX
  - Summarize develop lessons
    - High elasticity in latency, throughput, IOPS and capacity
    - Improving availability
    - Identifying the motivations and key tradeoffs in hardware offloading solutions
    - Identifying the pros/cons of alternative solutions

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Thank You !

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