Increasing SSD Performance and Lifetime with Multi-stream Technology

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Agenda

- NAND flash characteristics
- Multi-stream
  - Multi-stream concept
  - Multi-stream system architecture
  - Multi-stream operation
- Performance benefit
- Standards
- Summary
- Q&A
NAND Flash Characteristics

- **Operation**
  - Read/Program/Erase

- **Operation unit**
  - Read/Program: Page
  - Erase: block (= multiple pages)

- **Out-of-place update**
  - In-place update(=overwrite) NOT allowed
    - Invalidate overwritten data
  - Page MUST be erased before programming(writes)
    - Program/Erase (P/E) cycles
  - Need garbage collection operation

Efficient data placement increases performance with reduced garbage collection overhead
NAND Flash Characteristics (Cont’d)

- Limited number of Program/Erase cycles

Efficient data placement increases lifetime of SSD (endurance)
Multi-stream

- Provide better endurance, improved performance, and consistent latency
  - Allow host to associate each write operation with a stream
  - All data associated with a stream is expected to be invalidated at the same time (e.g., updated, trimmed, unmapped, deallocated)
  - Align NAND block allocation based on application data characteristics (e.g., update frequency)

**Diagram:**
- Legacy: Without Stream
  - Data is written in order writes are processed
- Multi-stream
  - Data is grouped according to stream
  - Streams 1, 2, 3

**Legend:**
- User data
- Meta data
- tmp data
Multi-stream Operation

- Mapping data with different update frequency to different streams

Host

Data1  Data2
Data3  Data4
Data5  Data10

Kernel/Application

StreamID

Multi-stream interface

SSD

FTL

NAND Flash Memory

Block

Stream ID = 1
1 Data1
1 Data3
Page
Page

Stream ID = 2
2 Data2
2 Data7
Page
Page

Stream ID = 3
3 Data10
3 Data12
Page
Page

Place data with similar update frequency into same erase unit

Provide hint about data update frequency

- Meta data
- tmp data
- User data

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Operation Example

- Efficient data placement with multi-stream
  - Reduce GC overheads -> better performance and lifetime!

Legacy: Without Stream

Multi-Stream

For effective multi-streaming, proper mapping of data to streams is important!
FIO Performance Measurement System

- **Hardware**
  - Quad Core Intel i7-4790 CPU 3.60GHz
  - 16GB memory

- **Software**
  - Ubuntu 14.04 LTS, v4.0.3 Kernel with multi-stream patch
  - FIO 2.2.5 with multi-stream patch

- **Device**
  - Multi-stream enabled NVMe SSD
Performance Measurement Configuration

- Four sequential writes jobs 1+ random read job
  - Different data lifetime: 1x, 10x, 33x, 55x
- Precondition
  - 2 hours with four-write jobs
Four Streams – Read/Write(70%/30%)

- Reads
  - Jobs: 6
  - Block size: 4k
  - Iodepth: 64

- Writes
  - Jobs: 4
  - Block size: 128k
  - Iodepth: 1

Read IOPS

Write Throughput

WAF

2x lifetime
RocksDB

- Embedded NoSQL database
  - Storage directly attached application servers
  - Persistent Key-Value Store
- Optimized for fast storage (e.g., SSD)
- Uses Log Structured Merge (LSM) Tree architecture
- Server workloads
RocksDB Performance Measurement Configuration

Hardware environment

<table>
<thead>
<tr>
<th>Processor/Memory Details</th>
<th>Operating System</th>
<th>SSD Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Processor Dual Socket</strong>: Intel(R) Xeon(R) CPU E5-2640 v3 @ 2.60GHz.</td>
<td><strong>Distro</strong>: Ubuntu 14.04.1 LTS, <strong>Kernel</strong>: 3.19.0-11-generic with multi-stream patch <strong>Arch</strong>: x86_64</td>
<td><strong>SSD</strong>: Multi-stream enabled NVMe SSD</td>
</tr>
<tr>
<td><strong>Total Logical CPU</strong>: 32</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total memory</strong>: 128 GB</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Software

<table>
<thead>
<tr>
<th>Software</th>
<th>Functionality</th>
<th>Version/Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>RocksDB</td>
<td>Persistent Embedded Key Value Store</td>
<td>Modified to add Multi-stream support</td>
</tr>
<tr>
<td>YCSB</td>
<td>Yahoo Cloud Benchmark Tool</td>
<td>0.1.4</td>
</tr>
<tr>
<td>SSDB-Rocks</td>
<td>Provides an interface to RocksDB for YCSB</td>
<td>1.6.6</td>
</tr>
</tbody>
</table>

Workload

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read/Update Mix</td>
<td>50%/50%</td>
</tr>
<tr>
<td>Pre-inserted records</td>
<td>370 Million</td>
</tr>
<tr>
<td>No of Operation</td>
<td>1.2 Billion</td>
</tr>
<tr>
<td>No of YCSB Threads</td>
<td>32</td>
</tr>
</tbody>
</table>
RocksDB Architecture

- Level-tiered compaction
RocksDB in Legacy SSD

- Legacy SSD (same as a single stream ID case)
RocksDB with Multi-stream

- Assign stream IDs according to SSTfile levels

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Write-Ahead Log</td>
</tr>
<tr>
<td>2</td>
<td>L0</td>
</tr>
<tr>
<td>3</td>
<td>L1</td>
</tr>
<tr>
<td>4, 5, 6</td>
<td>L2</td>
</tr>
<tr>
<td>7, 8, 9</td>
<td>L3</td>
</tr>
<tr>
<td>10, 11, 12</td>
<td>L4</td>
</tr>
<tr>
<td>13, 14</td>
<td>L5</td>
</tr>
<tr>
<td>No data on Level 6 due to dataset size</td>
<td>L6</td>
</tr>
</tbody>
</table>

1. Write-Ahead Log
2. Flush data Write
3. Compaction data Write
4, 5, 6

Level L0

Level L1

Level L2

...
RocksDB:
15%+ Performance and 54% Lifespan
RocksDB: 10%+ Better Average Latency

- **Avg Read Latency**
  - Legacy: 9492 us
  - Multistream: 8261 us
  - Improvement: -12.96%

- **Avg Update Latency**
  - Legacy: 458 us
  - Multistream: 386 us
  - Improvement: -15.72%
Standards

- SCSI/SAS: Completed in May, 2015
  - Standard spec: [Link to standard spec](http://www.t10.org/cgi-bin/ac.pl?t=f&f=sbc4r10.pdf)

- NVMe: standardization ongoing
- SATA: standardization ongoing
Summary

- With multi-stream, SSDs can be more efficiently used for
  - Consistent better performance
  - Better endurance (=better SSD lifetime)
- With multi-stream
  - FIO: more than 2x SSD lifetime in addition to the decent I/O performance enhancement
  - RocksDB: more than 50% SSD lifetime as well as more than 15% I/O performance improvement
THANK YOU

Q&A