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Benchmarking SSD-Based Lustre File System Configurations

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Introduction

- Application Acceleration Center of Excellence (AACE) is a partnership with NICS, Cray, and Intel established in 2011
- AACE's Beacon Project
  - Funded by NSF and the State of Tennessee
  - Acquired two Intel Xeon Phi clusters for the exploration of MIC technology
  - #1 on the Green 500 (Nov 2012)
  - Nodes with SSDs for I/O experimentation
- How should the SSDs be used?
  - Allocate nodes to batch jobs?
  - Layer storage technology on top of SSDs?

ZFS/Lustre on SSDs

- Lustre is a good choice for users
  - Users are familiar with using it
  - Can use all I/O nodes to boost performance
  - Easy to share among multiple users
- ZFS is a good choice for SSDs
  - Copy-on-write provides wear leveling benefits
  - Potentially use compression to increase performance/capacity
- Lustre 2.4 adds ZFS support
  - Opportunity to compare ZFS vs. mdraid and ZFS vs. ldiskfs

Beacon Hardware

- 48x Compute Nodes
  - 2x 8-core Intel Xeon processors
  - 4x Intel Xeon Phi coprocessors
  - 256 GB RAM
  - 960 GB of local SSD
- 6x I/O Nodes
  - 2x 8-core Intel Xeon processors
  - 256 GB RAM
  - 16x Intel 710 SSDs (300 GB each)
  - 4x LSI SAS9211-4i RAID cards (4 disks each)
- FDR Infiniband Fabric
  - Bandwidth of 56 Gb/s

Beacon I/O Node Software

- CentOS 6.2
- Kernel 2.6.32-358.23.2.el6_lustre
  - Standard patched kernel supplied by Intel
- Lustre-2.4.3 (server)
- Lustre-1.8.9 (client)
- zfs-0.6.1
- e2fsprogs-1.42.7.wc2-7
- mdadm-3.2.2-9

Benchmarking Methodology

- Goals
  - Test hardware/software performance
  - Verify vendor claims
  - Gauge real-world performance
  - Identify bottlenecks or misconfigurations
- Need a systematic approach
  - Bottom-up testing (disk → Lustre)
  - Test individual components before testing combinations
  - Build up layer-by-layer

Benchmarking tools

- xdd-6.5
  - SSD and RAID benchmarking
  - Use multiple threads to saturate targets
- IOzone-3.420
  - ext4 and ZFS benchmarking
- ib_write_bw-2.6 (perftest-1.3.0-2.el6 rpm)
  - Benchmark RDMA over Infiniband
- lnet_selftest (Lustre 2.4.3)
  - Benchmark LNet performance
- IOR-3.0.1
  - Lustre benchmarking

SSD Benchmarks

- **Test individual drives**
  - Verify vendor claims and consistent performance
- **Test multiple drives**
  - Check scaling behavior and potential bottlenecks
- **Sequential I/O xdd flags:** -timelimit 60 -blocksize 512 -reqsize 2048 -passes 3 -dio -queuedepth 3 -seek sequential
- **Random I/O xdd flags:** -timelimit 60 -blocksize 4096 -reqsize 1 -passes 1 -dio -queuedepth 32 -seek random -seek seed $TIME
    - Before writes, issue PURGE command to reset drive
    - Add appropriate “-seek range” option base on SSD size
    - Run write command ~2hrs to precondition drive

SSD Benchmarks (Single Drive)

Test Type	Intel Specs	Benchmark Results
Sequential Read	270 MB/s	281 MB/s
Sequential Write	210 MB/s	219 MB/s
Random Read	38,500 IOPS	39,287 IOPS
Random Write	2000 IOPS	2260 IOPS

- **Drives perform slightly better than vendor specs**

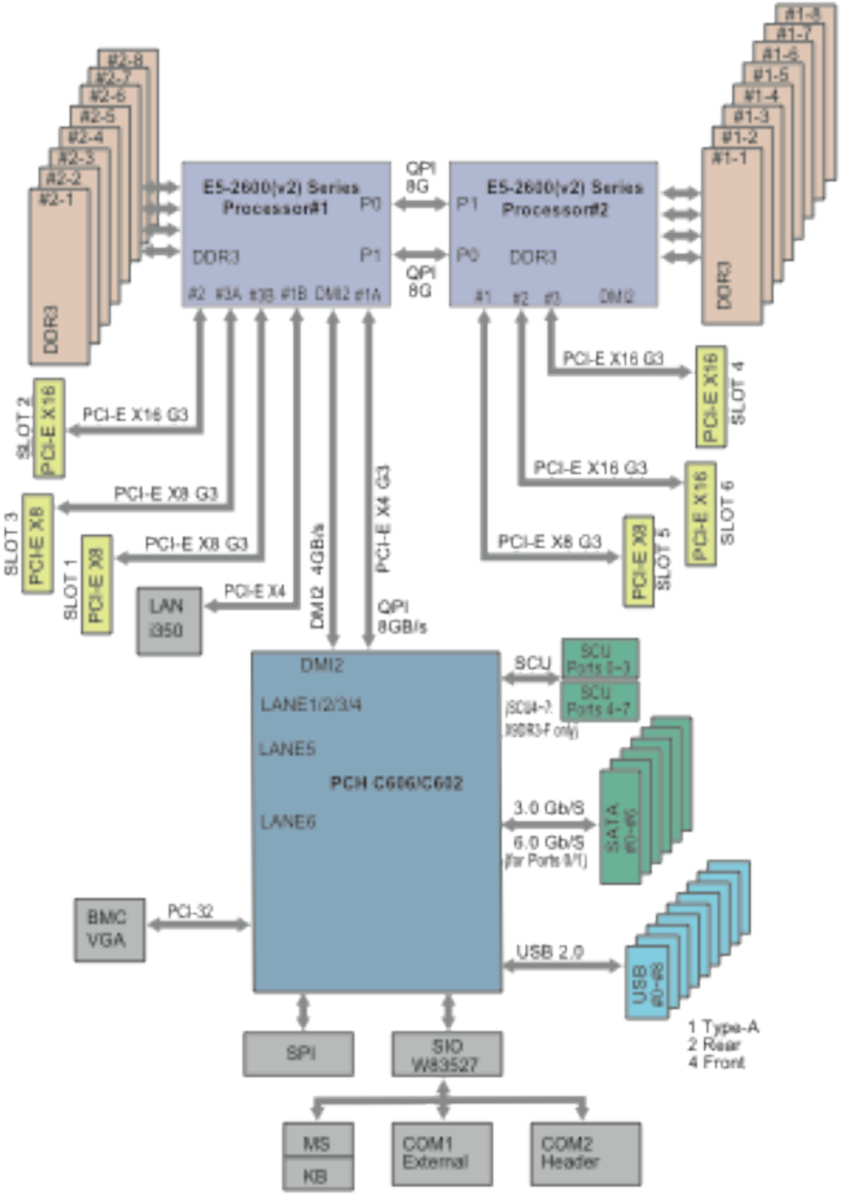
SSD Benchmarks (Multiple Drives)

- Scaling per RAID card
  - Test groups of 4 drives simultaneously
  - Results show good scaling
    - Single host example: 879 MB/s, 878 MB/s, 874 MB/s, 878 MB/s
- Scaling across all RAID cards
  - Test all 16 drives simultaneously
  - Write tests: 3542 MB/s ≈ 16 x 219 MB/s
  - Read tests: 3633 MB/s ≠ 16 x 281 MB/s (4496 MB/s)
  - Read speeds per drive vary from 134 MB/s to 285 MB/s

Sample xdd Results (16 SSDs)

T	Q	Bytes	Ops	Time	Rate	IOPS	Latency	%CPU	OP_Type	ReqSize
0	3	10148118528	9678	60.013	169.098	161.26	0.0062	0.01	read	1048576
1	3	10152312832	9682	60.016	169.160	161.32	0.0062	0.01	read	1048576
2	3	10149167104	9679	60.015	169.111	161.28	0.0062	0.01	read	1048576
3	3	11326717952	10802	60.016	188.729	179.99	0.0056	0.01	read	1048576
4	3	16871587840	16090	60.009	281.152	268.13	0.0037	0.01	read	1048576
5	3	16871587840	16090	60.009	281.153	268.13	0.0037	0.01	read	1048576
6	3	16885219328	16103	60.010	281.373	268.34	0.0037	0.01	read	1048576
7	3	16885219328	16103	60.009	281.378	268.34	0.0037	0.01	read	1048576
8	3	16873684992	16092	60.008	281.193	268.17	0.0037	0.01	read	1048576
9	3	16870539264	16089	60.011	281.126	268.10	0.0037	0.01	read	1048576
10	3	16883122176	16101	60.007	281.351	268.32	0.0037	0.01	read	1048576
11	3	16864247808	16083	60.010	281.022	268.00	0.0037	0.01	read	1048576
12	3	13420724224	12799	60.011	223.638	213.28	0.0047	0.01	read	1048576
13	3	13417578496	12796	60.012	223.583	213.23	0.0047	0.01	read	1048576
14	3	13407092736	12786	60.012	223.406	213.06	0.0047	0.01	read	1048576
15	3	13425967104	12804	60.010	223.729	213.36	0.0047	0.01	read	1048576

I/O Node Block Diagram



- "Slow" drives match the x16 PCI slots
- Tried moving IB and RAID cards
- Solution: Change BIOS settings
  - Configure x16 slot as 2-x8 slot
  - This works, but not sure why

RAID & File System Testing

- For different RAID levels, compare:
  - Standard Linux mdraid (RAID-0/5/6)
  - mdraid with ext4 file system
  - Equivalent ZFS configuration (zpool / raidz / raidz2)
- Focus on sequential read/write speeds
  - xdd for mdraid tests
    - Same command used for SSD testing except that queuedepth is 6 for writes and 10 for reads
  - IOzone for ext4/zfs tests
    - `iozone —ec -t8 -r1M -s100g -+n -i0 -i1`
- All RAID devices composed of 8 SSDs
  - Chosen to allow uniformity of OSTs and MDT

RAID & File System Results

	RAID-0	RAID-0 / ext4	zpool
Seq. Write	1701 MB/s	1406 MB/s	1466 MB/s
Seq. Read	2159 MB/s	1962 MB/s	1859 MB/s

	RAID-5	RAID-5 / ext4	raidz
Seq. Write	400 MB/s	338 MB/s	1236 MB/s
Seq. Read	1786 MB/s	1581 MB/s	1568 MB/s

	RAID-6	RAID-6 / ext4	raidz2
Seq. Write	319 MB/s	243 MB/s	1059 MB/s
Seq. Read	1773 MB/s	1532 MB/s	1401 MB/s

- **Based on these results, raidz was selected.**

Infiniband Testing

- Before testing Lustre, need to make sure interconnect is working as expected
- Use ib_write_bw to test IB RDMA speed
  - 5.9 GB/s compared to 6.8 GB/s (theoretical)
- Use lnet_selftest to check LNet performance
  - 5.4 GB/s (single client to single server)
  - Possibly higher with other Lustre tuning

Lustre Testing

- One MDS server, four OSS servers
  - MDS server has one MDT and one OST
  - OSS servers have two OSTs
  - Each OST is 8-disk raidz setup
  - MDT has 8 drives configured as a mirrored zpool
- Use IOR to test speeds
  - POSIX, file-per-process, 1 MB requests, 60 secs duration, stripe_count=1
  - Best performance: 9 clients, 3 processes per client, files evenly distributed over OSTs
- Results: 12.2 GB/s (writes), 12.1 GB/s (reads)

Future Work

- Metadata testing
- Random I/O benchmarking
- Compare Lustre/ZFS with Lustre/ldiskfs
- RAID-10 vs mirrored zpool
- ZFS compression/deduplication
- Investigate optimal tuning for mdraid
- System load monitoring
- Re-run tests with Lustre 2.5 clients

Conclusions

- Proper benchmarking requires:
  - Systematic approach
  - Time
- ZFS is the best choice…..for this case
  - Provides reliability with less performance loss
  - Hardware drives the software choice
- ZFS flexibility and features make it promising for Lustre deployments
- More work to be done

Questions?

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