INTEL SSD SOLUTIONS FOR HPC

Darrin Lynch,
BDM NSG, Intel Corp.
Agenda

• Recent product changes and strategy update
• HPC ingredients and opportunities for SSDs
• One problem has many solutions
• NVMe over Fabric (NVMeOF) is here, solutions - on horizon
• Memory Extension – are you ready for this today?
Agenda

• Recent product changes and strategy update
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Technology Driven: Two Breakthrough Technologies

3D MLC and TLC NAND
Building block enabling expansion of SSD into HDD segments

3D XPoint™ Technology
Building blocks for ultra high performance storage & memory
The Future is Here – NVM Express™

What is NVMe?
NVM Express is a standardized high performance software interface for PCI Express® Solid-State Drives

Built for SSDs
Architected from the ground up for SSDs to be efficient, scalable, and manageable

Ready for next generation SSDs
New storage stack with low latency and small overhead to take full advantage of next generation NVM

Developed to be lean
Streamlined protocol with new efficient queuing mechanism to scale for multi-core CPUs, low clock cycles per IO

Industry standard
Software and drivers that work out of the box

TM
NVMe* GETS TO THE RESULT FASTER

SSD NAND delivers ~100X reduction in latency vs. HDD\textsuperscript{25}

NVMe eliminates 20 us of latency\textsuperscript{25}

\textbf{Drive Latency}

\textbf{Controller Latency}

\textbf{(ie. SAS HBA)}

\textbf{Software Latency}

\textbf{Bandwidth (GB/sec)}

\textbf{SATA} \hspace{1cm} \textbf{x4 NVMe} \hspace{1cm} \textbf{x8 NVMe}

>10X the bandwidth of SATA\textsuperscript{25}

Refer to appendix for footnote 25.

*Names and brands of others may be claimed as property of others.
### Intel® SSD DC P3700 Series
- **Capacity**: 400 GB, 800 GB, 1.6 TB, 2 TB
- **Endurance**: Up to 17 DWPD

### Intel® SSD DC P3600 Series
- **Capacity**: 400 GB, 800 GB, 1.2 TB, 1.6 TB, 2 TB
- **Endurance**: 3 DWPD

### Intel® SSD DC P3500 Series
- **Capacity**: 400 GB, 1.2 TB, 2 TB
- **Endurance**: 0.3 DWPD

### Performance

<table>
<thead>
<tr>
<th>Test Type</th>
<th>P3700 Series</th>
<th>P3600 Series</th>
<th>P3500 Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random 4k Read</td>
<td>450k IOPS</td>
<td>450k IOPS</td>
<td>450k IOPS</td>
</tr>
<tr>
<td>Random 4k Write</td>
<td>175k IOPS</td>
<td>56k IOPS</td>
<td>35k IOPS</td>
</tr>
<tr>
<td>Random 4k 70/30 R/W</td>
<td>265k IOPS</td>
<td>160k IOPS</td>
<td>85k IOPS</td>
</tr>
<tr>
<td>Sequential Read</td>
<td>2800 MB/s</td>
<td>2600 MB/s</td>
<td>2500 MB/s</td>
</tr>
<tr>
<td>Sequential Write</td>
<td>2000 MB/s</td>
<td>1700 MB/s</td>
<td>1700 MB/s</td>
</tr>
<tr>
<td><strong>Sequential latency of 20µs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tests document performance of components on a particular test, in specific systems. Differences in hardware, software, or configuration will affect actual performance. Configurations: Intel Core i7-3770K CPU @ 3.50GHz, 8GB of system memory, Windows* Server 2012, IOMeter. Random performance is collected with 4 workers each with 32 QD.
## Intel® SSD DC P3608 Series

New dual controller and PCIe 3.0, x8 architecture delivers increased capacity and read performance compared to the Intel SSD DC P3600 Series

### Performance

<table>
<thead>
<tr>
<th></th>
<th>Up to 850k IOPS</th>
<th>Random 4k Read</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random 4k Write</td>
<td>Up to 150k IOPS</td>
<td></td>
</tr>
<tr>
<td>Random 4k 70/30 R/W</td>
<td>Up to 300k IOPS</td>
<td></td>
</tr>
<tr>
<td>Sequential Read</td>
<td>Up to 5000 MB/s</td>
<td></td>
</tr>
<tr>
<td>Sequential Write</td>
<td>Up to 3000 MB/s</td>
<td></td>
</tr>
<tr>
<td>Avg Active R/W Power</td>
<td>40W, 25-50W configurable</td>
<td></td>
</tr>
<tr>
<td>Idle Power</td>
<td>8-10 W</td>
<td></td>
</tr>
</tbody>
</table>

### Uses

- HPC
- Database

### Features

- One drive volume with Intel RSTe software
- Power loss protection
- End-to-end data protection UBER $10^{-17}$, 2M hours MTBF
- 20nm HET NAND for mixed workload performance at 3 DWPD
- Consistently amazing performance
- Low latency of NVMe®

Results have been estimated or simulated using internal Intel analysis or architecture simulation or modeling, and provided to you for informational purposes.
NEW ADDITIONS TO...

...the most widely adopted PCIe* SSD family

Intel's first active/active dual-port NVMe SSD delivering breakthrough performance\(^\text{19}\) to mission critical data

- Intel® SSD DC D3700
- Intel® SSD DC D3600

Intel's best IOPS value built on the highest density 3D NAND\(^\text{28}\) enabling solutions that are all NVMe

- Intel® SSD DC P3520
- Intel® SSD DC P3320

Break the SAS architecture bottleneck

bringing NVMe drives to the mainstream

*Names and brands of others may be claimed as property of others.

Refer to appendix for footnotes 10, 16, 19, 27.
INTEL® SSD DC P3520 AND P3320 SERIES

Bringing storage out of the cold.

**Performance.**

<table>
<thead>
<tr>
<th></th>
<th>P3320 vs. Intel® SSD DC S3510</th>
<th>P3520 vs. P3320</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random 4K Read</td>
<td>Up to 365K IOPS</td>
<td>Up to 5X faster</td>
</tr>
<tr>
<td>Random 4K Write</td>
<td>Up to 22K IOPS</td>
<td>Up to 1.4X faster</td>
</tr>
<tr>
<td>Random 4K 70/30 R/W</td>
<td>Up to 65K IOPS</td>
<td>Up to 1.9X faster</td>
</tr>
<tr>
<td>Sequential Read</td>
<td>Up to 1600 MB/s</td>
<td>Up to 3.2X faster</td>
</tr>
<tr>
<td>Sequential Write</td>
<td>Up to 1400 MB/s</td>
<td>Up to 3.1X faster</td>
</tr>
</tbody>
</table>

**Performance data available at later date**

**Capacity and Form Factor.**

- **Capacities**
  - 450GB (2.5” only)
  - 1.2TB
  - 2TB
- **Form Factors**
  - 2.5” x 15mm
  - X4 HHHL Add-in-card

**Data integrity and reliability.**

- **End-to-end data protection**
  - Demonstrated 10⁻¹⁷ UBER
  - 100X more reliable preventing SDC

- **PLI**
  - Self-test validated on 2M cycles

- **AFR**
  - Actual AFR consistently better than Intel goal of ≤0.44%

Refer to appendix for footnote 9, 10, 11, 14, 15, 16
Intel® SSD DC D3700 and D3600 series
Always available. Always fast.

Performance. vs. SAS

<table>
<thead>
<tr>
<th>Performance</th>
<th>SSD</th>
<th>SAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random 4K Read</td>
<td>Up to 470K IOPS</td>
<td>Up to 3.9X faster</td>
</tr>
<tr>
<td>Random 4K Write</td>
<td>Up to 95K IOPS</td>
<td>Up to 1.3X faster</td>
</tr>
<tr>
<td>Random 4K 70/30 R/W</td>
<td>Up to 213K IOPS</td>
<td>Up to 2.9X faster</td>
</tr>
<tr>
<td>Sequential Read</td>
<td>Up to 2100 MB/s</td>
<td>Up to 1.8X faster</td>
</tr>
<tr>
<td>Sequential Write</td>
<td>Up to 1500 MB/s</td>
<td>Up to 2.0X faster</td>
</tr>
</tbody>
</table>

Capacity and Form Factor.

<table>
<thead>
<tr>
<th>Capacity and Form Factor</th>
<th>SSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>D3700 Capacities</td>
<td>800GB</td>
</tr>
<tr>
<td></td>
<td>1.6TB</td>
</tr>
<tr>
<td>D3600 Capacities</td>
<td>1TB</td>
</tr>
<tr>
<td></td>
<td>2TB</td>
</tr>
<tr>
<td>Form Factors</td>
<td>2.5&quot; x 15mm</td>
</tr>
</tbody>
</table>

Data integrity and reliability

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</table>

Performance consistency.

<table>
<thead>
<tr>
<th>Performance consistency</th>
<th>SSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOPS consistency</td>
<td>Up to 90%</td>
</tr>
<tr>
<td>Performance degradation</td>
<td>≤5% over product life</td>
</tr>
</tbody>
</table>

High Availability.

<table>
<thead>
<tr>
<th>Availability</th>
<th>SSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual port</td>
<td></td>
</tr>
<tr>
<td>Active-Active</td>
<td></td>
</tr>
</tbody>
</table>

Refer to appendix for footnote 9, 10, 11, 14, 15, 18.
DRIVES WITH INTEGRITY. THE INTEL PCIe* SSD DC ADVANTAGE

Solution

Lasting integrity
≥100X more reliable preventing Silent Data Corruption\textsuperscript{11}
>2M PLI cycles and self-test delivers trusted protection from data loss\textsuperscript{14}

Reliably effective performance
Validated on a massive scale
≤5% performance degradation through product life\textsuperscript{10}

Platform confidence
Complete in-house design of data center solutions
Up to 1 more year in extended platform-level validation

Foundation

Uncompromising supply chain quality
95% delivery to commit\textsuperscript{21}
<100 DPM factory quality\textsuperscript{22}
#4 overall, #1 semiconductor Gartner\textsuperscript{*} 2015 Supply Chain Ranking\textsuperscript{23}

Complete product life cycle support
>2000 engineers optimizing top ISV solutions\textsuperscript{24}
>500 dedicated OEM design-in resources\textsuperscript{24}
Platform-expert post-sales support

Innovation leadership
~1000 researchers in Intel labs
Memory technology innovation leader

Notes to appendix for footnote: FOR PCIE_E612_0215_150407. *Names and brands of others may be claimed as property of others.
3D Xpoint™ on NVMₑ is the next quantum leap

- SSD NAND technology offers ~500X reduction in latency versus HDD
- NVMe eliminates 20 μs of latency today
- 3D Xpoint™ reduces NVM latency offering ~10x reduction in latency versus NAND SSD

Source: Storage Technologies Group, Intel
NAND vs 3D XPoint™ technology: SSD IOPS vs Queue Depth

Comparisons between memory technologies based on in-market product specifications and internal Intel specifications.
• Recent product changes and strategy update
• HPC ingredients and opportunities for SSDs
• One problem has many solutions
• NVMe over Fabric (NVMeOF) is here, solutions - on horizon
• Memory Extension – are you ready for this today?
### HPC ingredients and opportunities for SSDs

**SSDs in local compute nodes (Server side)**

**Purpose:**
- Scratch space to accelerate I/O intensive host workloads.
- Checkpoint restart / Memory snapshot.
- Decrease network utilization.
- Improve KNL/GPU performance.
- Far memory tier for DRAM, Swap.
- Boot drive.

**Technology ingredients:**
- NVMe designs, all product range 3D NAND + 3D XPoint
- SATA / NVMe low power boot drives
- Alignment with Xeon/KNC/OPA feature set

---

**I/O node and Burst Buffer designs**

**Purpose:**
- Accelerating data transfer in-and-out of the compute by scaling I/O nodes in regards to compute nodes.
- Improve small random I/O.
- Cost saving to enable diskless compute noted maintaining close to local I/O latencies.

**Technology ingredients:**
- All NVMe designs performance balanced with high speed fabric
- Great play for 3D NAND NVMe, less often for 3D XPoint
- NVMeOF designs, especially NVMe-over-OPA changes the storage paradigm

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**Improve HPC Storage performance**

**Purpose:**
- Bring NVMe into typical HPC storage ecosystem to improve small I/O performance (HSM).
- Better together story with IEEL (Intel Enterprise Edition for Lustre) for MDS and Lustre DSS.
- Improve cold storage CEPH and parallel FS such as BeeGFS.

**Technology ingredients:**
- Dual Port NVMe designs for Lustre* in MDS and OSS
- Single port NVMe / SATA drives for scratch file systems (no HA)
- Intel CAS DSS for intellectual caching in Lustre*

---

**SSDs in Technical Compute (Workstation)**

**Purpose:**
- Improve overall system performance and critical workloads (CAD, simulations).
- Software development / compilation tasks.
- Enable local cache SSD drive to decrease network utilization.
- Boot drive / Swap.

**Technology ingredients:**
- NVMe designs, all product range 3D NAND + 3D XPoint based on application requirements
- Intel CAS caching solutions
Compute Node optimized architecture

Purpose
Accelerate HPC applications by providing close to memory local storage capabilities.

Architecture Ingredients:
- Attach 1-2 local SSDs to the compute node directly
- Improve workloads characterized by large dataset or swap drive requirements in Genomics, Fluid Dynamics, Computational chemistry, Structural analysis, Finance, HPDA or generic app development.
- Implement Checkpoint restart/Memory snapshot for critical workloads
- Minimize I/O requirements to an external storage
- Opportunity for low power SATA/PCIe boot SSDs
Supercharge Xeon Phi and GPU processing

Purpose
Drive mass parallelism evolution in Many-Core processing by supporting KNL architecture with NVMe tier and close to memory performance.

Architecture Ingredients:
- Direct attach of NVMe SSDs to the KNL standalone node
- Host sharing NVMe SSD between GPUs
- Improve multithreaded workloads by offering direct access to NVMe many queue approach
- Minimize I/O requirements to an external storage

Use Cases
- Cray's Compute cluster architecture with SSD at Chevron
Improving performance of HPC storage

**Purpose**

**Accelerating traditional HPC parallel storage by introducing new features to improve small I/O**

**Architecture Ingredients:**

- Bringing NVMe into typical HPC storage ecosystem to improve small I/O
- Intel SSDs in IEEL (Intel Enterprise Edition), BeeGFS, CEPH
- Enabling NVMe Dual Port drives topologies

**Use cases**

**Lustre:**
- Metadata server (MDS)
- HSM storage tier
- DSS with CAS (in progress)
- All flash scratch or HA solutions

Other alternative solutions:
BeeGFS, CEPH for cold storage

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[Diagram showing Compute Nodes, POSIX, HSM, Storage Controllers, NVMe SSDs over PCIe]
High Availability Storage Systems

Must do. Storage redundancy.

Do it better. Faster results with NVMe*

Accelerate mission critical database workloads

Improve data access for better QoS

Must do.

Do it better.

Refer to appendix for footnote 18

Accelerate mission critical database workloads up to 3.9x faster 4K RR vs. SAS SSD

Improve data access for better QoS up to 3.3x Lower latency vs. SAS SSD
INTEL® SSD DATA CENTER D3700 AND D3600

New features supported for mission critical storage

Reservations
- Controller 1
- Controller 2

Manages who can write to the device and when

Scatter Gather List
- Host Memory
- SSD

Connects scattered data in host memory to reduce IO operations

Multiple Namespace
- Controller 1
- Controller 2
- Name space 1
- Name space 2
- Name space 3

Smaller granularity in managing data across drives

In Controller Memory Buffer
- Host Memory
- I/O Queue
- SSD

Moves IO queue to the SSD to reduce latency
Intel® Cache Acceleration Software (CAS) 3.0 introduced DSS support

- Use CAS with SSD storage to provide a complete DSS-enabled read cache for Lustre*

Lustre “tags” data to identify priority and passes to storage

Intel CAS interprets tag & directs IO to cache or sends to HDD

Data is written to HDD and/or flash, depending on priority
I/O node, Burst Buffer, NVMe over Fabric (NVMeF)

Purpose

Accelerating data transfer in-and-out of the compute by scaling I/O nodes in regards to compute nodes with close to local I/O latencies

Architecture Ingredients:

- PCIe IO rich nodes with balanced input-output configuration, so, the internal IO processing capabilities can scale externally.
- Time to market to OmniPath and Ethernet products.
- Typical attach rate is 30 compute nodes to 1 burst buffer node.
- Optimal NVMe SSD count depends on the used fabrics solution and available bandwidth.
Data Transfer Node “DTN”

Purpose

Enabling the rapid transfer of large datasets (>1TB) across long distances, largely avoiding latency issues.

Architecture Ingredients:

- Nodes with >72 PCIe lanes to support 4 SSDs and 1-3 Ethernet NICs
- Time to market to Ethernet products (100GbE)
- Sold as matched pairs of DTNs installed at each end of file transfer paths

Software:

- Aspera* FASP data transfers
- Globus
- Zettar zx* – Ultra Performance Parallel Data Transfer
• Recent product changes and strategy update
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• One problem has many solutions
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Improving Genome Sequencing at German Cancer Research Center

Goal:
• The genome comparison for individual patients of cancerous tissue with healthy tissue
• Apply the right treatment, new way of “personalized medicine”.

Challenges:
• 70GB of raw data per sequencing run (1.3 PB per year)
• Requires fast processing for compute as well as for storage.
• Data exchange between pipeline steps is done by IO of millions of small files

Solution:
Enable every compute node with 1.6 TB Intel DC P3700 NVMe scratch space
• >= 4 drive writes per day requirements (1.3PB in a year overall)
• Minimize CPU idle time due to the low-latency, high-performance NVMe technology
• IO from and to NAS is limited to a few large files, streams at the start and at the end of the pipeline.

"Intel’s NVMe technology boosts IOPS by avoiding SCSI and SAS interfaces of classic SSDs and opens the full PCIe performance and bandwidth for small file IO."


System configuration: 2 Xeon 2660v2, 512GB DDR3, P3700 -1.6TB, RHEL 6.5, Intel GATK
Qiagen: Analyze Your $1,000 Genome for as Little as $22

- Reference Architecture to improve genome sequencing time by hosting data sets at optimized Lustre (IEEL)
- 700GB data per genome, more than 30TB of data analysis per day using 32-node HPC cluster
- Cost optimized 165TB storage solution is driven by target capacity and required performance. Combination of HDD for the storage and SSDs for metadata.
- Intel DC SSD for NVMe P3600 series meets performance requirements for MDS at data center reliability (2M hours MTBF)


System configuration:
- **HPC cluster**: 2 x Intel® Xeon® processor E5 v3 (14 core, 2.60 GHz), 128GB DDR4, CLC Genomic Server, version 7.1,
- **Storage**: 165 TB usable disk capacity (256 TB total), Intel® Enterprise Edition for Lustre® 2.3, 2 x Intel Xeon processor E5 v3 (14 core, 2.60 GHz), 128 GB DDR4 memory, RAID Controller (RAID 10), 4 x 800 GB Intel® Solid State Drive Data Center P3700 Series

Heavy I/O read and write demands are heavy on the object storage servers
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The Need to Extend NVM Express™ over Fabrics

PCI Express® ideal for in-server and in-rack, but difficult to scale beyond 100’s of nodes:

- Address routing rather than endpoint routing
- Want to converge storage + networking at scale
- Want to leverage standard switch infrastructure

Existing Fabric interface (e.g., iSER / SRP) ecosystem is not well suited for this:

- Inconsistent adoption across OS/VMs
- Protocol is overly complex, adding latency
- Issues even worse when we move to NG-NVM

Delivering < 20 µs across Fabric requires new, simple, efficient protocol
NVMe over Fabrics

Industry standard definition of NVMe over Datacenter Network Fabrics

- Shares same base architecture and NVMe Host Software as PCIe
- Specification defines interface supporting multiple network fabrics

NVMe over Fabrics specification defines how NVMe is extended to support new network fabrics
The back-end of many deployments is PCIe Express® based NVM Express™ SSDs

With 10-100Gb reliable RDMA fabric and NVMe SSDs, the remaining issue is the software necessary to execute the protocol.

Use NVMe end-to-end to get the simplicity, efficiency, and low latency:

- Simple protocol => Simple host and SSD software
- No translation to/from another protocol like SCSI

Standard abstraction layer enables NVMe across range of Fabrics
NVMe over Fabrics

Host Components

Architecture

- Separation of NVMe Core Logic and Transport
- Common NVMe Core across all transports: OS and Block interface
- Common NVMe Fabric agnostic functions: Capsules, Properties, Connect, and Discovery
- Thin transports with limited NVMe awareness that can interoperate with multiple targets

Implementation

- Separate Driver Components
- Components interface with Multi-Q Block layer
- Pluggable Transports

Retains efficiency of PCIe NVMe access over fabrics
NVMe over Fabrics

Target Components

Architecture
- Virtual NVMe subsystem representation of PCIe SSD Subsystem
- Separate NVMe subsystem core components and transports
- Discovery Subsystem and controllers

Implementation
- Creates logical NVMe Subsystems and Controllers that are presented to Hosts
- NVMe Namespaces are logically mapped to physical block device
Linux Host and Target Kernel drivers operational

- Target configured with NVMe PCIe SSD
- To ensure fabrics transport is fabric agnostic it has been tested on InfiniBand™*, iWARP, RoCE RDMA adapters
- Host has been tested with multiple target implementations
- Drivers are still being performance tuned
NVMe over Fabrics

NVMe over Fabrics Standardization and Enabling

- **NVMe over Fabrics Specification complete**
  - In release candidate final review
  - Available publicly on nvmexpress.org: 05/16

- **Host and Target drivers will available in upstream Linux kernel**
  - Upstream Kernel under drivers/nvme/{host/target}
  - Available: shortly after specification released in ~4.8
  - Fabrics supported:
    - Local: PCIe
    - RDMA: Fabric agnostic kernel verbs transport
    - Fibre Channel (under development)
    - Other fabrics transports under evaluation / pathfinding (e.g., kFabric)

  When the specification and Host and Target code is available

  Please download, test with your fabric hardware and environments
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NVME SSD AS A SYSTEM MEMORY BY SCALEMP VSMP

**Transparent:** no need to change OS or applications
- Acts as DRAM, no persistency
- P3700 performance close to 80% of DRAM

**Lower TCO:** NVMe SSD to replace DRAM
- Lower CAPEX: significantly lower cost vs. DRAM
- Lower OPEX: up to 33% lower power vs. DRAM

**Increased Capability:** NVMe for DRAM expansion
- Up to 8TB on 2-socket system, and over 20TB on 4-socket system
- Target in-memory databases and multi-tenant deployments

**Transition from DRAM to Hybrid DRAM-NVM System Memory**
*Breaking the memory-storage barrier*

[Diagram showing transition from DRAM to Hybrid DRAM-NVM System Memory]


System configuration: Motherboard S2600WT, 2x Intel Xeon E5 2690v3, 768GB DDR4 or 256GB + 4x Intel SSD P3700 Series 800GB, ScaleMP vSMP
UNIFIED PROGRAMMING MODEL TO ACCESS ANY MEMORY TIER

https://github.com/memkind/memkind
FOOTNOTES AND DISCLAIMERS

9. IOPS consistency. Source – Intel. Measured performance of Intel® SSD DC S3710 and DC P3700 on 4K Mixed (70/30) workload. Device measured using Iometer. Quality of Service measured using 4 KB (4,096 bytes) transfer size on a random workload on a full Logical Block Address (LBA) span of the drive once the workload has reached steady state but including all background activities required for normal operation and data reliability. Based on Random 4KB QD=1, 32 workloads, measured as the time taken for 99.9(99.9999) percentile of commands to finish the round-trip from host to drive and back to host.

11. Proven end-to-end protection. Source – Intel. Demonstrated 10⁻¹⁷ UBER as compared to JEDEC UBER specification of 10¹⁶.
https://www.jedec.org/standards-documents/focus/flash/solid-state-drives. 100X more reliable in preventing Silent Data Corruption. Test performed on Intel® SSD S3x00 drives, Samsung PM853T and SM843T, Micron P400e, Seagate 600 Pro and SanDisk Lightening drives. Drives were exposed to increasing amounts of radiation. After a drive "hang", a power cycle was performed to determine whether the drive would re-boot. If a drive re-booted it was read, and data was compared to the tester's master copy of the up-to-date data that the drive was expected to contain based on writes the drive had acknowledged as completed prior to the "hang" event. If the drive returned data that differed from the expected data, it was recorded as failing for silent errors. The annual rate of silent errors was projected from the rate during accelerated testing divided by the acceleration of the beam (see JEDEC standard JESD89A).


14. PLI. Source – Intel. Intel® Datacenter Drives provide robust Power Loss Imminent (PLI) circuitry that helps to protect infight data in the event of power loss. Intel drives monitor the health of the PLI circuitry via a Self Cap Test using SMART attributes. Samsung PM853T and SM843T drives were checked for capabilities and flags. No PLI monitoring capabilities (e.g. SMART Attributes) were listed in the Samsung drive specification sheet. Additionally, the drives were tested by powering off a drive and removing one electrolytic (or any other type) capacitor. The drives were then powered up to recollect SMART attribute data to determine is the cap test detected the removal of the capacitor. The Samsung drives did not detect capacitor removal.


16. Intel SSD DC P3320 performance. Source – Intel. Results for Intel® SSD DC P3320 2TB capacity have been estimated or simulated using internal Intel analysis or architecture simulation or modeling, and provided to you for informational purposes. Simulated configuration: Intel Core i7-3770K CPU @ 3.50GHz, 8GB of system memory, Windows1 Server 2012, IOMeter. Random performance simulated for 4 workers with 32 QD. Any differences in your system hardware, software or configuration may affect your actual performance. Comparison to Intel® SSD DC3510 based on that product's spec datasheet for 1.2TB capacity.

17. Intel SSD DC P3320 benchmarks. Source – Intel. Any differences in your system hardware, software or configuration may affect your actual performance. System Configuration: Supermicro 2U SuperServer® 2028U-TNR4T+, Dual Intel® Xeon® Processor E5-2699 V3 (45M Cache, 2.30 GHz), 192 GB DDR4 DRAM, Boot Drive – Intel® SSD Data Center S3710 Series (200GB), NVMe – Intel® SSD Data Center P3320 Series (2TB), SATA – Intel® SSD Data Center S3510 Series (1.6TB). Running Vmware ESXi 6.0 with two identical Windows Server VMs running various workloads housed on two different SSD-backed Datastores.

FOOTNOTES AND DISCLAIMERS


20. Data Center SSD shipments. Source – Gartner, Q4 2015

21. Delivery to commit. Source – Intel. Actual measurement of percent shipments for all Intel SSD products that arrive on committed delivery date.


24. ISV enabling, OEM design-in support. Source – Intel Software and Solutions Group, Intel Non-volatile Memory Solutions Group, Intel Influencer Sales Group, Intel Direct and Channel Sales.

25. NVMe gets to results faster. Source - Storage Technologies Group, Intel. Comparisons between memory technologies based on in-market product specifications and internal Intel specifications.
