Technical Overview

Enterprise SSD Storage Solutions: Engineered for Reliability, Speed, and Predictable Endurance for Maximum Application Value

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Executive Summary

Speed, Reliability, and When to Change Your Sneakers

NetApp® storage arrays with SanDisk® enterprise solid-state drives (SSDs) deliver space and energy efficiencies, reliability, and performance for data centers running applications with high input/output operations per second (IOPS) requirements. Ideal usage applications include data warehousing and mining, online transaction processing (OLTP), real-time analytics, high-performance computing (HPC), media editing, and virtualized environments.

Like high-performance running shoes, enterprise SSDs are designed for reliability and speed—but they won’t last forever. Flash memory devices such as SSDs have a use-based consumable lifetime. An SSD stores data in memory cells with charge-trapping characteristics that cause the device to degrade gradually with increasing write/erase cycles—eventually it wears out and requires replacement. But experienced storage vendors, akin to veteran runners, know which factors affect SSD lifespan and are adept at designing devices and matching the right devices with the right workloads to maximize both performance and endurance in business-critical application environments. SSD wear-out should not be a cause for avoiding the technology, but rather a consideration in choosing where best to leverage SSDs for maximum reliability and performance.

NetApp storage solutions allow businesses to take advantage of the benefits of SSDs—including high-speed data access and cost-per-capacity value—while minimizing the impact of the wear-out inherent in flash memory technology. NetApp and SanDisk engineering teams design to stringent workload-specific criteria and utilize technologies such as wear leveling that increase the endurance of SSDs to deliver a predictable and economically viable lifespan for enterprise environments. Expectations for a five-year useful life of SSD products—regardless of workload—attest to the field-proven reliability of the devices. Usage and wear monitoring, combined with well-understood endurance characteristics, also help NetApp OEM partners and enterprise customers plan for orderly SSD replacement as devices reach endurance limits.
1.0 Get the Performance Running Shoe Edge

Use SSDs for Speed, Value, and Reliability

1.1 Use SSDs for Speed

Walking shoes have their place, but sprinters need performance running shoes designed for speed. The same can be said of hard-disk drives (HDDs) and SSDs. HDDs have long served as a primary storage medium for enterprise data centers. With the ability to perform hundreds of IOPS and excellent per-gigabyte value for average workloads, the HDD has earned its place in corporate computing environments. Increasingly, however, IT managers must deliver greater performance for data-intensive applications such as data warehousing, analytics, virtualization, and other workloads that can overutilize traditional HDD solutions. Delivering adequate IOPS performance is especially challenging in environments that leverage the most current Intel® microprocessors featuring multiple hyperthreaded cores. Keeping such processors busy and wringing full value from server platforms require extremely high IOPS performance.

BEST RANDOM IOPs PERFORMANCE

Typical enterprise-class HDDs can perform 150 to 200 random reads or writes per second—but data-intensive applications often require IOPS that are orders of magnitude faster. To approach that level of performance with HDD solutions, IT managers have traditionally had to resort to buying more HDDs and using techniques such as data striping or short stroking, which reduce the number of tracks used per hard drive, to minimize average seek distance, which can otherwise consume an average of 2 milliseconds for every repositioning. Buying more drives and using less of their capacity are expensive, not just in terms of capital outlay, but also in attendant footprint and energy costs.

In contrast, SSDs store data in memory cells, not on magnetic fields on spinning disks, and deliver extremely fast access. A Lightning® Write-Intensive SAS SSD solution, for example, can perform up to 118,000 read IOPS (as compared to the 150-200 reads of a typical HDD) and data transfer rates of up to two to three times HDD rates, all in a highly efficient form factor. Depending on the configuration and storage management software, SSDs can enhance overall performance, provide near-instantaneous access to “hot” or frequently used applications and data, or both.

For applications that require extremely high IOPS, enterprise SSDs inside high-performance storage arrays offer distinct advantages in both performance and value. Because of these benefits, organizations are increasingly deploying SSD or hybrid HDD/SSD solutions that can deliver tens of thousands of IOPS per SSD device and consume far fewer data center resources in the process. Lightning Write-Intensive SAS SSDs, for example, typically consume less than six watts per drive. In some system deployments, three- to five-year electrical cost savings alone (from the reduced HDD footprint and low-power-consumption SSDs) can justify SSD purchase.

1.2 Use SSDs for Value

Although SSDs remain more expensive per gigabyte than HDDs, SSDs actually provide the better value for many high-IOPS workloads. For data-intensive applications, enterprises can replace as many as 20 HDDs with a single SSD that delivers equivalent or greater performance in a dramatically smaller footprint.

For a required level of I/O intensity (represented by the x-axis in the diagram in Figure 1), there is an optimal disk drive solution, either hard disk or flash. As Figure 1 illustrates, performance intensity requirements determine the point at which single-level cell (SLC) SSDs deliver greater value than either serial-attached SCSI (SAS) or serial advanced technology attachment (SATA) HDDs.

Because significantly more HDDs would be required to satisfy the higher IOPS (workload) needs, SSDs provide the better value when requirements hit roughly 120 IOPS/GB. For simple IOPS/$ value, the orange line in Figure 1 represents the maximum value achievable when SATA drives are used. But as application workloads demand greater IOPS/GB (for example, in data warehouse applications) SSD media represent the best value.

In contrast, for an archive application that requires only 0.1 to 0.5 IOPS/GB, the lowest cost solution is SATA disk. For applications that require between 0.5 and 0.8 IOPS/GB, 10K SAS is optimal.
Figure 1: The value of SSDs exceeds that of both 10K SAS HDD and SATA HDD in performance-intense applications.

Although SSDs do have a use-based consumable lifetime, the devices work harder during that lifespan, on average delivering 200 times more writes than an HDD supports over its expected lifetime, even though its lifetime is typically longer in calendar time. Expressed in real numbers, writes per lifetime can total approximately 226TB written (TBW) for a 15K HDD and approximately 20PB written (PBW) for a Lightning Write-Intensive SAS SSD. HDDs are performance limited and not endurance limited. SSDs write much faster than HDDs, but the technology’s overall write performance is limited by its endurance—that is, the device supports only a fixed number of writes to flash.

SSD VALUE IN THE REAL WORLD

Flash memory SSDs offer the best value for applications with high IOPS intensity. Platform and storage vendors use flash memory SSDs for persistent storage or directly to create expanded caching devices. Flash memory technology can help eliminate I/O bottlenecks and boost overall performance.

NetApp, for example, uses an SSD cache to accelerate read I/O performance. In the NetApp E-Series platform, a Lightning SSD-based cache moves data from HDD volumes to the SSD cache (configurable up to 5TB) following host reads or writes. Subsequent host reads of the same logical block address can be read directly from the SSDs with a much lower response time than could be achieved by rereading the data from the HDD volume.

1.3 Use SSDs for Reliability

With SAS and SATA interface and form-factor compatibility, SSDs can also be used with existing disk backplanes, storage controllers, and protocols.

SSDs contain no moving parts—no electromechanical arms, no spinning platters, and no motors—and they boast a higher mean time between failure (MTBF) with inherent resistance to vibration, shock, and temperature variances. Parts stress analysis indicates a MTBF of 2 million hours for Lightning Write-Intensive SAS SSDs. An HDD vendor might typically claim a MTBF of 1.2 million hours, yet acknowledge that in practice that number might be considerably lower.

SSDs can, however, experience a second failure mode that is wear-related. Because wear-out is inherent in flash memory, SSDs should be treated as consumables to be replaced as they approach the end of their usable lifespan. It is important to realize, however, that NetApp storage arrays with Lightning Write-Intensive SAS SSDs have been engineered to maximize endurance, and wear-out is graceful, with devices providing good visibility of approaching end of life.
2.0 Choose the Right Shoe

Key SSD Design and Implementation Considerations

Not all running shoes—or SSDs—are created equal. Good design and good materials can make a world of difference in the data center. SSD performance and lifespan depend on the grade of negated AND or not AND (NAND) flash memory, as well as on the sophistication of the controller and the firmware. Some characteristics of SSD devices can affect applications:

- **Performance.** How fast the device can read, write, and erase data
- **Data retention.** How long the device can read data
- **Endurance.** How many times the data can be written and erased (versus the reliability of the device, which is measured in MTBF, as discussed in section 1.3)
- **Accuracy.** How consistent and correct is the existing stored data

The design and implementation of Lightning Write-Intensive SSDs inside NetApp storage arrays maximize performance, data retention, endurance, and accuracy, making the platform distinctly suited to enterprise data management applications. Key characteristics contribute to the enterprise-class performance and endurance that differentiate NetApp and SanDisk solutions:

**Lightning Write-Intensive SSDs are constructed with nonvolatile NAND flash memory.**

Nonvolatile flash memory can be electronically written or erased very quickly. There is no seek or latency time as with HDDs, and it retains data even when the device loses power.

NAND flash memory stores data in blocks made up of pages, and pages are usually 4KB or 8KB in size. Pages are the smallest writable unit; however, NAND memory cannot be erased at the single page level and must be erased as a block.

Unlike disk sectors, NAND pages cannot be overwritten without first being erased—which means erasing the entire block. To write new content to a page, the firmware on the SSD controller must first relocate any valid data in the entire block, then erase the entire block, and then write in the new data. NAND memory cell charge-trapping characteristics cause the device to degrade gradually with increasing write/erase cycles. The SLC NAND used in the Lightning Write-Intensive SAS SSD is rated at 300,000 erase/write cycles for 3x nm technology.

SanDisk flash management does include algorithms for minimizing the number of erase operations and optimizing operations that enable “garbage collection” for future use of blocks that no longer contain valid data. Space reclamation is performed during garbage-collection operations. SSD devices themselves are aware of the percentage of lifespan or endurance used and remaining, and the firmware on the SSD controller tracks that information to provide visibility for device-replacement planning.

**SanDisk employs wear-leveling and overprovisioning technologies to boost endurance and data retention**

Flash memory inevitably wears out over time, but proper flash management slows the process. SanDisk flash management functionality resident in the SSD firmware uses both dynamic and static wear leveling:

- **Dynamic wear leveling** is performed on newly written data based on statistical allocation, so that blocks are used evenly without affecting high performance levels. Dynamic wear leveling is only performed on blocks to which data is actively being written.
- **Static wear leveling** is applied on static data, forcing data transfer across the entire medium to provide high data-retention levels for cases in which flash memory contains large static areas. Static wear leveling is done in the background and for all data blocks, including both static and active blocks.
Overprovisioning means that each SSD has more storage blocks (that is, extra hidden capacity) than are specified for a drive so that the extra flash memory can be used in the place of worn-out blocks. Think of overprovisioning as spare memory blocks that stand in for those that expire, helping to extend the long lifetime of the device. SanDisk's proprietary algorithms and software in the flash firmware optimize performance and endurance, enabling more reads per second and minimizing wear from repeated writes to the same page, block, or device.

SanDisk offers workload-optimized enterprise SSD products.

To optimize performance and endurance in a variety of applications, SanDisk has developed SSDs across multiple categories:

- Write-intensive applications, such as data warehousing and real-time analytics in which hot data changes often, characterized by a 50/50 read/write mix.
- Read-intensive applications, such as video on demand (VOD), media streaming and web applications, characterized by a 90/10 read/write mix.
- Mixed-use applications, including electronic mail and financial systems characterized by a 70/30 read/write mix.

SanDisk uses intensive error-correction technologies designed specifically for NAND flash.

SanDisk flash management implements sophisticated mathematical algorithms to provide high data reliability and resolve errors (such as bit flips) without degrading performance. Error detection is implemented in hardware by the SSD firmware to avoid performance impact to user I/Os.

SanDisk products are characterized by superior reliability, predictable-sustained performance, and value for enterprise environments.

### 3.0 Go for High Performance

**All Disk Array Controllers Are Not Created Equal**

To be deployed effectively in real-world application settings, enterprise SSDs require complementary high-performance storage array controllers. The NetApp E2600 array controller, for example, is capable of very high throughput and low latencies, so it does not become a bottleneck for high-performance Lighting Write-Intensive SAS SSDs. Without equivalent performance, another disk array controller could be overwhelmed by 20 SSDs flooding data into the server simultaneously. High-throughput workloads such as video transfer and data warehousing, for example, would slow down significantly without the NetApp E2600 array controller.

The NetApp controller also collects (that is, queries the devices), displays, and passes SSD usage and wear statistics to applications or database systems as required. The server or database vendor can report SSD statistics to the data center manager or customer support representative for planning purposes.

When wear-out is detected on an SSD device, the NetApp controller automatically evacuates data and copies it to a new storage device in preparation for replacement of the worn-out SSD unit. The NetApp array controller also supports SSD RAID groups for enhanced reliability.

To confirm that the technology performs as expected for real-world application environments, NetApp collaborates with SanDisk to qualify and test SSDs for intense application workloads. NetApp acceptance processes require all devices to demonstrate conformance to specifications.
4.0 Know When to Change Your Running Shoes

Replacement Planning

Organizations building application solutions on NetApp and SanDisk storage platforms can be confident that the solutions have been designed and built to operate in the most demanding of enterprise environments and to provide accelerated performance for a broad range of applications, from high-performance computing (HPC) to data warehousing, analytics, virtualization, and much more. NetApp and SanDisk bring to the architecture of these storage solutions an extensive knowledge of real-world computing workloads and a deep understanding of the inherent reliability and wear-out characteristics of SSDs to confirm the viability of their use in enterprise data centers.

Two metrics help determine wear-out:

- Expected lifetime
- Spare blocks available

Expected lifetime is a calculated number based on both theoretical and demonstrated flash endurance limits. When this metric reaches zero, the device still meets its specified error rate after being powered off for three months. The SSD continues to operate past this point, but there is an unknown data hazard, and the device warranty has expired.

Spare blocks are part of the SSD design because as flash cells age, they can experience fatal program or erase errors that prevent further writing to the device. The SSD reserves a number of spare blocks to address this state. As spares are consumed below a given threshold in Lightning SSDs, write performance suffers, and spares are eventually consumed. At that point, the device becomes read-only. However, well in advance of that condition, the Lightning Write-Intensive SAS SSD generates a SMART alert, and the array controller copies the data to a new SSD. For most of an SSD’s life, only the expected-lifetime metric changes, and that measure can be used to project end of life. Nearer the end of the device’s useful life, the number of spare blocks remaining becomes much more important in determining wear-out. SSDs used by NetApp are selected to reach the end-of-warranty support period—assuming worst-case workloads—with both metrics in the green.

The NetApp workload-agnostic warranty on SSD-based solutions attests to the field-proven reliability of Lightning Write-Intensive SAS SSDs. Beyond the warranty period, enterprises and OEM partners can take advantage of SSD usage and wear monitoring and known endurance characteristics to plan for orderly SSD replacement as devices reach endurance limits. The usage and wear data that SanDisk tracks enable highly accurate calculation of remaining usage and lifecycle and can be used to trigger alerts as devices approach end of life. Some vendors track the wear-out statistics in each SSD to determine the probable wear-out date, helping customers and support organizations to proactively plan for replacements.

NetApp works closely with OEM partners to provide needed device-replacement guidance, as well as information related to expected data retention (that is, how long the flash media can retain data before it becomes unreliable). It is important to be aware that there is a limited data retention period once SSDs have been removed from service (that is, powered off). Retention is also dependent on operating and storage temperatures and the endurance remaining on the device when it was taken out of service. Although the data retention period for some HDDs can be measured in years, SSD retention is more typically measured in weeks or days once the device is powered off. The Lightning Write-Intensive SAS SSDs are capable data retention of 90 days at end of life.
SSDs FOR APPLICATION VALUE

The Teradata Active Enterprise Data Warehouse is built on a NetApp E-Series solution with SanDisk enterprise flash memory technology in a hybrid storage approach. Combining SSDs and HDDs helps Teradata deliver both blazing speed and cost efficiency. Teradata reports that customers use up to 18 fewer HDDs for each SAS SSD installed and are able to dramatically reduce solution footprint and energy consumption.

The hybrid storage solution is enabled by the Teradata Virtual Storage software, which optimizes the use of storage by automatically placing often-used “hot” data on high-speed SSD storage and less-used “cold” data on HDD. In Teradata customer data warehouse application environments, approximately 80% of storage access is to 20% of data, so there is substantial payoff from putting frequently accessed data into SSDs. Using SSDs and a sophisticated hash-based storage scheme for all data objects, Teradata delivers extremely fast access to individual data objects, achieving as much as 22 times more random reads per second than would be possible with a high-performance HDD. Hashing also spreads accesses and writes evenly across all drives in the system, creating even wear across the system and avoiding early wear-out of more frequently used drives.

Teradata stipulates rigorous specifications and strict endurance requirements for SSDs. Teradata software also helps extend SSD endurance by writing only hot data into the flash devices. In addition, customers can take advantage of the Teradata ServiceConnect service offering, which automatically collects SSD device wear-out data. Wear statistics are kept in a data warehouse and used to inform the customer support representative (CSR) when SSDs near the end of useful life. The CSR can then advise the customer in SSD replacement planning.

SSD solution value, combined with Teradata expertise for planned replacement, helps make the hybrid SSD/HDD storage an enabler of Teradata's high-performance enterprise data warehouse solution.

5.0 Cover More Ground

Use SSDs to Do More, Reliably, Faster, and Using Less Energy

NetApp storage solutions allow businesses to take advantage of the benefits of SSDs, including high-speed data access and cost-per-capacity value, while minimizing the impact of the wear-out inherent in the flash technology. NetApp array controllers feature the essential rapid response times and fast data transfer rates required by Lightning SAS enterprise SSDs. In NetApp platforms, both storage array controllers and SSD technologies have been architected to deliver the best performance, reliability, and value over the longest possible lifetime.

NetApp OEMs and enterprise customers are taking advantage of SSD storage solutions to optimize performance in a broad array of applications, finding that for data-intensive workloads, SSDs deliver unique reliability and performance combined with space, energy, and cost efficiencies. Potential users should not hesitate to deploy the technology in demanding data center environments, understanding that although SSD wear-out is inevitable at some point after five years of heavy use, Lightning Write-Intensive SAS SSDs in NetApp E-Series storage solutions have been engineered to enterprise-class reliability and performance specifications, and that within the expected wear-out periods the application workload should not concern the enterprise user. Like performance running shoes, NetApp and SanDisk SSD storage solutions can help you run your application course faster and more reliably, while using less energy in the process.

This document was created in collaboration with SanDisk.