EXECUTIVE SUMMARY

While the performance requirements of enterprise applications continue to increase rapidly, the performance of hard disk drives (HDDs) has increased more slowly for many years. This disparity has been mitigated by aggregating hundreds or thousands of HDDs to provide higher performance within a given storage system.

More recently, compute performance has eclipsed HDD performance to the point where enterprises are beginning to turn to solid state drives (SSDs) that provide magnitudes faster performance. However, the performance increases of SSDs come with a similar increase in cost; therefore, adoption has been slow.

Seagate has pioneered a new solution, known as a solid state hybrid drive (SSHD), to help bridge the gap between high-capacity HDDs and faster, lower-capacity, but more expensive SSDs. An SSHD is a storage device consisting of magnetic media and a DRAM buffer (similar to a traditional enterprise HDD), plus nonvolatile NAND flash used as a cache and optimized firmware. SSHDs provide high performance and high capacity to fill a void between HDDs and SSDs, creating opportunities for server and storage system vendors to enhance current solutions and to develop new ones.

Performance testing by IBM recognized a 2.3x IOPS improvement over HDDs when using SSHDs. Seagate’s own profiling of storage area networking (SAN) systems found SSHDs provide significant performance improvements over HDDs.

The similarity of SSHDs to HDDs enables server and storage system vendors to embrace these new drive options quickly and seamlessly to enhance the performance of enterprise storage systems, servers, operating systems, and applications for their customers. SSHDs also create new opportunities for further innovation through the leveraging of their large read caches, safe write caching, and other advanced capabilities.

Seagate finds that SSHD latency improvements enhance storage system performance during lower workloads, while higher workloads benefit from improved latency and increased IOPS performance. Moreover, Seagate's technology scales well with larger numbers of SSHDs contributing additional performance.
Early adopters of SSHDs, including IBM, are experiencing significant performance improvements over systems architected with just traditional enterprise HDDs. IDC believes SSHDs represent a significant new opportunity for advancing enterprise datacenter performance economically, especially as it relates to applications with data that is frequently accessed or large amounts of random reads. Database and transaction processing, file serving, virtual desktop serving, and email are among the applications that have shown benefits from SSHDs.

IN THIS WHITE PAPER

This IDC white paper examines the emerging use of solid state hybrid drives as a complementary storage tier for the enterprise and how the technology is being deployed to improve storage performance, increase usable capacities, and lower infrastructure costs. This white paper explores the innovative technology included in enterprise hybrid drives, considers various aspects associated with deploying enterprise hybrid drives within server and storage systems, and highlights the importance of complementing hard disk drives and solid state drives with SSHDs within enterprise environments.

SITUATION OVERVIEW

The magnitude of storage consumption and changes in storage infrastructure design driven by cloud computing, virtualization, and big data applications and data protection or disaster recovery requirements is creating challenging storage performance and capacity demands. Some enterprises are turning to SSDs in an effort to achieve higher storage performance. SSDs are 100% NAND flash-based high-performance storage devices that are now a viable option for many storage system architectures. HDDs and SSDs provide essentially opposite mixes of dollar per capacity and dollar per performance, so they are often combined with tiering software to help balance their differences when addressing a wide range of application workloads. In an ideal implementation, this results in a storage system providing very high capacity with very high performance for all applications at all times.

A few all-SSD storage systems are also available for environments and applications requiring the highest levels of performance. These purpose-built systems generally are deployed and dedicated for specific applications (such as databases) that can benefit from the tremendous performance enabled by storing all data on SSDs. However, extreme performance comes at a significant cost premium — even when the potential benefits of deduplication and compression are considered — so it is not economically feasible to utilize SSD-only storage broadly within enterprise datacenters. Moreover, most applications do not require the elite performance of all-SSD storage systems.

Even in a tiered storage environment, the performance differences between HDDs and SSDs are so dramatic that software alone cannot ensure SSD-like performance for all applications in today's highly dynamic and virtualized environments.

Simply put, storage systems designed with a mix of enterprise HDDs and/or emerging SSDs are challenged to support (in a precise way) every level of price/performance/capacity required by modern enterprise datacenters and applications today and well into the future.
Now more than ever, complementary solutions creating new levels of performance/capacity can
deliver compelling value and be cost-effective alternatives for IT managers working to address the
myriad capacity and performance requirements defined by more stringent enterprise-class service-
level agreements.

**Inherent Challenges with Increasing HDD Performance**

Mechanical speed has been the primary enabler of improved HDD performance – a key reason why
drives with 15K-rpm provide more performance than 10K-rpm or slower drives. Today's fastest HDDs
have remained at 15K-rpm for more than a decade, and product designs with faster rotational spin
speeds bump up against HDD mechanical limitations.

The challenges for achieving significantly better-performing HDDs include:

- **Reliability.** Keeping the head on track reliably at faster rotational spin speeds is a daunting
  challenge for HDD engineers. Mechanical vibration and airflow disturbances introduced to the
  read/write recording head by very high rotational spin speeds make it almost impossible to
  increase HDD rotational spin speeds beyond 15K-rpm.

- **Form factors.** HDD manufacturers have moved to smaller HDD form factors as faster rotational
  speeds have been introduced. This has mitigated technical challenges associated with very
  high rotational speeds such as mechanical vibration, but it has also reduced capacities
  (because of the smaller diameter media used). In the era of cloud computing, virtualization,
  and big data, organizations desire more capacity at lower costs, which is the opposite result
  from adopting HDDs with smaller form factors.

- **Power consumption.** Higher HDD rotational speeds require more electrical power. Spinnin
  disks faster requires the dissipation of more heat and consumes additional power due to
  cooling requirements. Yet organizations worldwide are striving to decrease their environmental
  impact by reducing their energy consumption and carbon footprints.

- **System design.** Enterprise datacenters are adopting software-driven architectures rapidly.
  Server and storage system vendors have responded by standardizing their hardware platforms
  while innovating with software, services, and support. As a result, there is a declining interest
  in engineering and adopting new hardware platforms capable of supporting HDDs with spin
  speeds higher than today's 15K-rpm drives.

Overcoming the rotational speed barrier to achieving higher HDD performance requires an innovative,
new approach.

**The Emergence of Enterprise Solid State Hybrid Drives**

SSHDs are essentially HDDs that incorporate complementary nonvolatile NAND flash and other
 technologies into the HDD to improve performance. A storage system combining SSDs and SSHDs
 (and possibly multi-terabyte HDDs) with tiering software becomes a potential solution for a wide range
 of performance-sensitive applications and creates a new type of tiered storage array solution.
Seagate’s Enterprise Hybrid SSHD Approach

Seagate’s existing performance-optimized enterprise HDDs and its new enterprise SSHDs share proven rotating magnetic media and DRAM buffer technologies to provide reliable long-term storage. Their differences involve the additional NAND flash used as a nonvolatile cache along with other technologies, as shown in Table 1.

**TABLE 1**

<table>
<thead>
<tr>
<th>Comparison of Key Technology Features: HDD Versus SSHD</th>
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</thead>
<tbody>
<tr>
<td>Enterprise HDD</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Magnetic media</td>
</tr>
<tr>
<td>DRAM buffer</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Source: IDC, 2013

The complementary use of magnetic media with a DRAM buffer (similar to a traditional enterprise HDD), plus a NAND flash cache and other supporting technology, defines Seagate's SSHDs and enables unique functionality.

NAND flash enables SSHDs to mitigate the performance-reducing side effects of rotational latency and seek times. For example, during reads, SSHDs and HDDs both move data from magnetic media to a DRAM buffer before data is sent to their drive interfaces, but SSHDs complement the DRAM buffer with a NAND flash cache, providing up to 100x more cache capacity. This allows SSHDs to monitor buffer and cache utilization, keeping infrequently accessed data on the magnetic media and moving hot data to NAND flash. This allows the frequently accessed data to respond at peak performance to deliver SSD-like performance.

The management of read data among DRAM, NAND flash, and magnetic media is a form of tiering, but it occurs automatically and transparently within the SSHD. Including NAND flash within an SSHD has an effect similar to including NAND flash within a storage system or server – performance acceleration. As a result, SSHDs deliver higher performance than HDDs since more reads are serviced from high-performance solid state media (DRAM or NAND flash), and the need to access low-performance magnetic media is significantly reduced.

A unique and powerful performance-enhancing SSHD feature is safe write caching at the drive level. SSHDs protect write cache data against loss in the event of an unplanned power failure by automatically copying write data and any outstanding commands from the DRAM buffer to the NAND flash cache using the spindle motor as a power source. When power resumes, the SSHD immediately processes
outstanding write commands and transfers write data to magnetic media during power-up. HDDs may have write caching features, but they are rarely used since any data an HDD holds in write cache is permanently lost during an uncontrolled power failure.

The safe write caching of SSHDs can have a profound effect on server and storage system performance. When SSHDs are used with servers, operating systems and applications gain access to more responsive storage highly suited to managing the numerous small writes that commonly occur. For storage systems, SSHDs mitigate the performance-reducing effects of RAID protection by allowing storage controllers to complete the flushing of RAID stripes instantly (to the SSHD write caches) and by accelerating the read-modify-write process (the writes are cached by SSHDs and completed instantly) required to maintain RAID consistency. With SSHDs, servers and storage systems immediately complete write operations rather than wait for the multi-millisecond delays caused by seek times and rotational latency.

In the case of Seagate SSHDs, other advanced features are enabled by robust Self-Encrypting Drive (SED) and Instant Secure Erase (ISE) security technologies. SED adds data-at-rest encryption capabilities with autolocking options. ISE renders all data on a drive unreadable via a cryptographic erase of the data encryption key, and this improves total cost of ownership (TCO) by easing data management expenses at time of disposal. Together, these capabilities enable IT managers to support more stringent security policies in the datacenter.

Seagate's own profiling of SAN systems found that SSHDs provide significant performance improvements over HDDs. Additionally, storage vendors now using Seagate SSHDs for network-attached storage (NAS) systems have achieved performance improvements. Moreover, Seagate's technology scales well with larger numbers of SSHDs contributing additional performance.

**Early Adopter Results Using Seagate Enterprise SSHDs**

Seagate has begun to publish performance data that compares HDD and SSHD performance, and the results are noteworthy, as illustrated in Figure 1. In this comparison of single drive performance by IBM, SSHDs delivered up to 2.3x more IOPS and up to 5-15x faster response times than typical enterprise HDDs. Such performance improvement is not possible using HDDs alone, and integrating separate HDDs and SSDs inside servers is challenging. This makes the SSHD an effective and convenient solution for scaling server storage performance to match ever-increasing server CPU and memory speeds.
Seagate finds that SSHD latency improvements (shown as response times in Figure 1) enhance performance during lower workloads, while higher workloads benefit from improved latency and increased IOPS performance. This makes SSHDs ideal for applications with data locality (data that is frequently accessed) or large amounts of random reads. Database and transaction processing, file serving, virtual desktop serving, and email are among the applications that have shown benefits from SSHDs.

Drive performance is one of the major contributing factors to overall system performance, so it is not surprising to learn that the performance benefits of SSHDs extend from servers to storage systems. Recently, Seagate published an SPC Benchmark Full Disclosure Report (see SPC-1C submission C00016 on the Storage Performance Council Web site) documenting the testing results for IBM’s enterprise storage systems. In this case, HDDs and then SSHDs were used as the only drives within the storage system. Table 2 provides a comparison of IBM storage system benchmark performance results for a system with HDDs versus a system with SSHDs.
TABLE 2

SPC Summary of Results: Comparison of IBM Storage System Benchmark Performance Results for a System with HDDs Versus a System with SSHDs

<table>
<thead>
<tr>
<th></th>
<th>Performance-Optimized Enterprise HDDs</th>
<th>Enterprise SSHDs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sponsor</td>
<td>Seagate</td>
<td>Seagate</td>
</tr>
<tr>
<td>Benchmark</td>
<td>SPC-1C</td>
<td>SPC-1C</td>
</tr>
<tr>
<td>Submission identifier</td>
<td>C00015</td>
<td>C00016</td>
</tr>
<tr>
<td>SPC-1C IOPS</td>
<td>448 IOPS</td>
<td>1,027 IOPS</td>
</tr>
<tr>
<td>ASU capacity (total)</td>
<td>1,500GB</td>
<td>1,500GB</td>
</tr>
<tr>
<td>Data protection level</td>
<td>Protected 1 (RAID 5)</td>
<td>Protected 1 (RAID 5)</td>
</tr>
<tr>
<td>System price</td>
<td>$9,213</td>
<td>$11,133</td>
</tr>
</tbody>
</table>

IOPS = input/output per second
ASU = average storage unit capacity, or total storage capacity read and written during the SPC-1 test

Source: Seagate, 2013

The SPC-1C benchmark selected is a component-level benchmark applicable to a diverse range of storage components, including drives. It is intended to demonstrate the performance of a storage component while performing functions typical of the business-critical applications commonly used within enterprise datacenters. This includes online transaction processing (OLTP), database, and email applications characterized by workloads with heavy random I/O operations. The result of this SPC benchmark indicates that the current enterprise storage systems can readily utilize and directly benefit from the performance of Seagate SSHDs.

The Role of Hybrid Drives in Enterprise Architectures

Enterprise storage system engineers designing system architectures are purposefully slow in reacting to revolutionary change and surprisingly agile in adopting evolutionary advancements, especially when they are a result of integrating known and proven technologies. The enterprise SSHD falls into the category of being an evolutionary advancement. As such, SSHDs can be rapidly adopted in numerous enterprise-friendly ways, including:

- **Faster server drives.** Many servers continue to include internal drives for local storage, and while some now offer flash drive options, hard drives remain the most popular choice. SSHDs offer a new and practical alternative for accelerating server storage performance to SSD-like levels without significantly sacrificing HDD-like storage capacities or prohibitively increasing server costs.
\begin{itemize}
  \item **SSHD-only storage systems.** The growing interest in SSD-only enterprise storage systems demonstrates a desire to explore new alternatives to address datacenter requirements. While SSD-only storage systems are cost prohibitive for many applications, the performance benefits of an SSHD-only storage system could make SSHD a popular alternative to traditional HDD-based storage systems for performance-sensitive applications.
  
  \item **SAN, NAS, and DAS enhancement.** Network-based and local storage systems include advanced storage controllers featuring RAID technology to protect data and improve performance. Compared with HDDs, SSHDs include larger read caches and safer write caches that complement storage system controllers to further improve storage performance and enhance data protection.
  
  \item **Faster midlevel storage tier.** Tiered storage systems commonly rely on three types of drives to create storage tiers: SSDs for caching, high-performance HDDs for performance, and high-capacity HDDs for capacity. Assuming that an SSD tier will serve less than 50% of the IOPS in a given architecture, a midlevel performance tier will still be required. Replacing high-performance HDDs with SSHDs can create a much faster midlevel storage tier with capacities and costs similar to those of enterprise HDDs.
  
  \item **Complement to SSD storage.** Enterprises with SSD-only storage are essentially building their own tiered storage infrastructures by complementing traditional enterprise HDD-based storage systems. The introduction of SSHD-only storage systems to these environments adds balance between performance-optimized SSD-only storage and capacity-optimized HDD-based storage.
  
  \item **Virtualized infrastructure optimization.** The fast performance and large capacities of SSHDs create an opportunity for a new storage systems tier between SSDs and HDDs. In this way, vendors can leverage SSHDs to achieve improved performance and capacity optimization for virtualized environments.
\end{itemize}

The accelerating IT industry adoption of flash and growing demand for SSDs within storage systems signal a strong interest in innovative technology-based storage solution alternatives to the performance bottleneck. This indicates that the marketplace is ready for enterprise SSHD adoption.

**The Future of Enterprise Storage Systems with SSHDs**

The acceptance of SSDs within the enterprise virtually guarantees that the use of tiered storage infrastructure will continue. Magnetic storage media such as HDDs and SSHDs will continue to serve the role of high-capacity storage with various levels of performance, and solid state media such as SSDs will continue to provide the highest performance.

Advances in SSHD technology may narrow the performance gap with SSDs over time. Still, NAND flash-only SSDs should continue to outperform SSHDs significantly, albeit at much higher costs.

The similarity between performance-optimized HDDs and SSHDs allows storage system vendors to support SSHDs using the same proven and existing processes they now use for HDDs. Storage systems, particularly those supporting tiering software, can quickly gain new SSHD-based drive options that create an additional (or optimize an existing) tier between SSDs and HDDs.
With more effort, server and storage system vendors can exploit the unique capabilities and features of SSHDs, such as larger read caches or safe and secure write caching, by tuning configuration settings or updating management software.

Broadened availability of SSHDs of various capacity or performance characteristics creates new opportunities for enterprise storage system enhancement. For applications with access patterns that challenge SSDs or HDDs, such as heavy writes that reduce SSD flash endurance or small random reads impacted by HDD access times, SSHDs could become the best alternative.

**CHALLENGES/OPPORTUNITIES**

The promising early results of using Seagate SSHDs within enterprise servers and storage systems suggest there are significant opportunities to further demonstrate the performance advantages of SSHDs over performance-optimized HDDs. Certainly, there is a need for Seagate to continue educating the market about the potential applications for SSHDs, how proven HDD and flash technologies are combined to deliver unique SSHD benefits, and why SSHDs are a necessary complement for HDDs and SSDs within enterprise storage infrastructure.

Seagate will need to work closely with customers to fully take advantage of the unique performance characteristics of SSHDs for various application workloads in order to facilitate SSHD adoption. It took several years for storage system OEMs and customers to learn how to effectively leverage SSD technology in servers and storage systems, and ongoing investments in tiered SSD and HDD storage architecture have built momentum for SSD adoption. Seagate will need to build similar momentum with SSHD solutions.

Broadening the availability of SSHDs to enterprise customers through multiple HDD vendors will facilitate and accelerate SSHD adoption since datacenter managers are known to be cautious when considering the implementation of new products for their critical information strategies. One exception could be IT managers in performance-sensitive environments desiring the fastest and newest technologies to achieve competitive advantage.

An opportunity exists for other types of SSHDs beyond those intended to outperform the fastest 15K-rpm HDDs. Conceptually, future SSHDs could support multi-terabyte capacities and offer faster alternatives to the highest-capacity HDDs unsuitable for some applications because of their lower IOPS ratings. Other opportunities include server and storage system configurations utilizing SSHDs only and next-generation storage controllers optimized for SSHDs.
CONCLUSION

IDC believes that enterprise SSHDs have the potential to deliver remarkable benefits to server and storage system vendors as well as their datacenter customers. It seems obvious that the traditional performance tier between SSDs and capacity-optimized HDDs would benefit from the introduction of an enterprise SSHD. When evaluating SSHDs and their performance-enhancing potential, organizations should consider the following:

- **New storage tier.** The SSHD creates a new and innovative tier between SSDs and HDDs, enabling new capabilities. SSHDs deliver significantly higher performance than HDDs and significantly larger capacities than SSDs. Costs for SSHDs are expected to range between those for HDDs and SSDs in terms of dollar per capacity and dollar per performance.

- **System-level perspective.** The performance benefits of SSHDs are not readily apparent from evaluating specifications or comparisons to SSDs or HDDs. Many advantages of SSHDs are the result of their interaction with storage systems, servers, operating systems, and applications. Organizations should work with vendors to optimize the deployment of SSHDs within datacenters and target workloads that are bound to benefit from the performance characteristics of SSHDs.

- **Server SSHD options.** Already, major worldwide server vendors are adding SSHD options to their supported configurations with impressive performance results. Organizations should investigate whether SSHD options are available during planned server acquisitions and deployments to increase return on investment (ROI).

- **Storage system value.** Vendors have an opportunity to enhance storage system performance quickly by adding SSHD options to their supported configurations. Over time, the SSHD has the potential to become a significant factor in storage system architecture and design, increasing customer value and competitive differentiation.

- **More solution alternatives.** Integrating SSHDs with servers and storage systems increases available solutions. Examples include new or enhanced one-tier (SSD-only), two-tier (SSD/SSHD), three-tier (SSD/SSHD/HDD), and four-tier (SSD/SSHD/SAS HDD/SATA HDD) storage architectures. New alternatives should allow vendors and customers to better match storage, servers, and applications.

SSHDs present practical opportunities for server and storage system vendors to improve the performance and capacity of their products and solutions significantly without compromising costs.

Disclosure statement: IDC takes no responsibility for the benchmark testing results that are referenced in this white paper. IDC does not monitor the testing procedures or validate, verify, or certify the results from associated testing labs.
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