WHITE PAPER

Improving Enterprise Performance with Flash on the Memory Bus

Sponsored by: SanDisk Corporation

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IN THIS WHITE PAPER

In this white paper, IDC explores the expanding usage of NAND flash in the enterprise data storage and server market. This white paper discusses the role of solid state drives (SSDs), the impact NAND flash is having on the traditional memory and storage hierarchy — and the benefits of moving NAND flash to the memory bus, closer to where the data is being processed on the server motherboard.

EXECUTIVE SUMMARY

The IT industry is going through a period of transformation on a scale that has not been seen in decades. The emergence of what IDC is calling the Third Platform — driven by Cloud Computing, Social Business, Big Data, and Mobility — is altering the way that business gets conducted, where it takes place, and the speed required to be successful in today's real-time world. Enterprise datacenters and cloud datacenters are at the forefront of this transformation. They act as a foundational platform for many organizations, deciding where data is stored, how it is analyzed and how it is used by a broad range of applications.

To deal with massive quantities of data in a quick and efficient manner, a new way of thinking about the datacenter is needed. For IT managers, this presents both an opportunity and a challenge at a time when IT budgets are limited and IT staffs are shrinking. IDC sees no slowing down in data growth — rather, IDC expects the amount of data being stored to grow in excess of 40% compound annual growth rate over the next five years. Thus, datacenters must improve resource efficiency and focus on application acceleration to deliver the business agility that is required in today's world.

Over the last few years, NAND Flash has emerged as a viable solution for the enterprise to help address some of these storage issues. Enterprise SSDs based on NAND flash technology present an opportunity for IT managers to deliver higher performance and improved responsiveness while lowering costs and increasing overall efficiency. This white paper will provide the reader with a look at the expanding usage of NAND flash in the enterprise market and the role it is having in accelerating application performance. Additionally, this paper will look at the different options to implement the technology. This includes a discussion about moving NAND flash closer to where the data is being processed to provide the lowest latency and quickest access to the data, such as using flash SSDs on the memory bus to provide a more direct path to the central processing unit (CPU).
SITUATION OVERVIEW

For decades, the role of storage and memory within the hierarchy has changed little, with processors (CPUs) having registers, local cache, and main memory (typically DRAM) as temporary storage areas — and the role of persistent storage being handled by high-capacity storage devices like hard-disk drives (HDDs), tape, or optical.

However, technologies rarely stand still. Processing power, thanks to Moore’s law, has increased dramatically over the past decade. Increased core CPU performance, number of cores per processor (i.e., multi-core processors), bus speed, and the growth of virtualization — all of these technologies have fueled the drive to accelerate performance of applications.

Memory (DRAM) has also seen similar improvements with increasing densities, faster interfaces, and more bandwidth. Likewise, Hard Disk Drives (HDDs) have seen a dramatic increase in the storage capacity per drive over the same period enabling the lower cost-per-capacity (or dollar per gigabyte [$/GB]) trend that many within the IT industry have become accustomed to.

Yet, over that same period of time, little has been done to improve HDD performance. In the early 2000s, the HDD industry increased the spin speed or revolutions per minute (rpm) from 10,000rpm to 15,000rpm, but since that time, little else has been done to substantially increase HDD performance.

This growing performance gap between the CPU and storage subsystem has created a bottleneck for data I/O. The traditional way to overcome this gap is through overprovisioning of the number of HDDs or short-stroking a drive (i.e. using the outermost section of the drive) to increase storage performance. While these techniques can be effective, this approach proved to be costly from the perspective of return on investment (ROI) for those workloads requiring high I/O. Today, innovation has positioned NAND flash as a key technology to overcome the gap between CPU performance and storage performance and to help mitigate the I/O bottleneck (see Figure 1).

The Emergence of NAND Flash and SSDs in the Enterprise

NAND Flash was invented 25 years ago as a non-volatile solid state storage media that can be programmed and erased electronically. Today, NAND flash has become the de-facto standard for many consumer devices ranging from memory cards and USB storage to advanced smart phones and tablets. When coupled with technological advancements, such as multilevel cell (MLC) NAND or the ability to store two or more bits per cell, this increasing density improves the economics of flash and makes it a more cost-effective solution for high density storage. As of 2013, a state-of-the-art NAND die could store up to 16GB of data. Some SSD products had up to 2TB capacity, as of the end of 2013.

SSDs take NAND flash a step further by combining a number of raw NAND flash devices and adding sophisticated controller technology that manages the flash devices (or flash management). This includes adding advanced digital signal process (DSP) algorithms, error correction codes (ECC), and data integrity features (e.g., wear leveling, protection against data loss in the event of unexpected power interruption, flash failure, etc.) that improve the endurance, reliability and performance and make it suitable for use in demanding mainstream enterprise applications. SSDs also add the interface to the host interfaces such as the traditional SATA or SAS, but also emerging interfaces such as PCIe or the memory bus.
FIGURE 1

Flash Usage Now in the Majority (% of Respondents)

Q. Is your organization currently using flash and/or SSD in your external disk storage environment?

![Pie chart showing flash usage](image)

- Yes: 51.5%
- No: 46.3%
- Don't know: 2.3%

N = 307 US organizations

Source: IDC, 2014

The New Memory and Storage Hierarchy

The emergence of cost-effective NAND flash and SSDs into the enterprise provides an entirely new way of looking at things. The performance gap between the CPU and main memory and the storage subsystem can be filled with NAND flash as seen in Figure 2. Thus, no longer is it necessary to overprovision HDDs or to short-stroke drives to get performance. The I/O bottleneck can be overcome through the cost-effective use of SSDs to gain much higher performance.
FUTURE OUTLOOK

To deliver higher performance and improved responsiveness while lowering costs and increasing overall efficiency within the enterprise environment, the inclusion of NAND flash is transitioning from niche environments into the mainstream. Conceptually, the insertion of NAND flash into the memory and storage hierarchy makes complete sense now that NAND flash has become more cost effective. However, many IT managers have been left wondering how to get the most out of NAND flash to accelerate application performance in real-world enterprise environments.

The Path to Lower Latency

When first introduced, SSDs 'looked' like an HDD, having a similar form factor (e.g., 3.5", 2.5" drives) and interface (e.g., Fibre Channel, SAS, or SATA). This was the most logical and easiest way to implement SSDs into an existing infrastructure. As a result, IT customers could simply swap out HDDs in their server or storage system for the faster performing SSDs and realize increased performance. No other changes were needed to replace the HDDs with SSDs in these server or storage chassis.
Today, given the long history the industry has had with HDDs, these SSDs utilized many of the traditional storage interfaces that many are familiar with in the enterprise storage environment:

- **SATA SSDs** – SSDs using 3Gbs or 6Gbs SATA interface. For example SanDisk's CloudSpeed SATA SSDs
- **SAS SSDs** – SSDs using the SAS protocol with speed of 6Gbs or 12Gbs. For example SanDisk's Lightning SSDs and Optimus SSDs

These solutions inherently deliver higher performance in terms of IOPs (I/O Operations per second) and lower latency when compared to the rotating HDDs. However, many of these drives now have the capability to saturate the bus speeds of traditional drive interfaces as the technology has advanced. Additionally, much of the traditional architecture was designed for rotating HDD media, and while advancements have been made to the I/O controller to support SSDs, it does add additional latency between the CPU and storage. So, while using traditional form factors and interfaces for SSDs has significant merit, and a wide number of use cases, it ultimately creates another I/O bottleneck in the system for those applications that require the fastest speeds and lowest latency.

Another interface option for SSDs to overcome this challenge has recently emerged leveraging the PCIe (PCIe I/O interface) bus. This interface bypasses the traditional I/O controller and has low latency, high bandwidth (with the ability to support multiple lanes), and it provides even greater performance between the host and the solid state memory. For example, in the first-generation PCIe interface, each lane carries 250MBps, while the second generation (PCIe 2.0, released in late 2007) doubled the rate to 500MBps. The latest generation, PCIe 3.0 (released in late 2010) added next generation signaling at 1GBps.

**Connecting Flash to the Memory Bus**

Yet, innovation and the evolution of flash in the enterprise continues to take place, and another option can provide even lower latency and higher bandwidth – using the memory bus via a server's dual inline memory module (DIMM) slots. The result further narrows the performance gap in current storage infrastructures by placing flash as close as possible to the CPU and applications. Connecting flash to the memory bus also eliminates arbitration and data contention on the I/O hub which further accelerates access to the data stored within the flash media.

This architecture delivers high, scalable performance for the enterprise storage market, with deterministic write latencies near the expected latencies of DRAM and linear performance scaling with additional modules.

**Applications That Can Benefit from Flash on the Memory Bus**

Enterprise applications vary widely, both in their requirements and in their performance characteristics. However, when time equals money, latency is a very important metric. The speed with which the data is accessed can provide a significant performance boost and accelerate application performance. Thus, there are a number of application and use cases that can benefit from implementing flash on the memory bus:

- **In-Memory Compute** – Higher density and lower power than DRAM
- **Financial Trading** – Low predictable latency for fast data transactions
- Databases – Faster transactions per second
- Virtualization – Increased number of virtual machines (VMs) per node and faster response time
- Data Warehouses – Faster response time
- Blade Servers – High density in compact form factor
- Memcached on OpenCompute – More in memory caching
- Server – Page swaps between memory and flash on the memory bus are faster than other types of I/O because of the memory bus’ raw speed – and not needing to go to external storage to access data

**SanDisk’s ULLtraDIMM Flash SSD**

SanDisk's ULLtraDIMM is an example of this type of next-generation device that is an enterprise-class, ultra-low latency, memory channel storage solution that adds flash directly into a server's DIMM slots.

The ULLtraDIMM is the result of a close partnership between SanDisk and Diablo Technologies Inc., utilizing the combined expertise of the two companies around the memory bus and flash storage to create this new type of ultra-low latency storage. Diablo's Memory Channel Storage (MCS) solution combines software and hardware by placing NAND flash on cards that reside alongside DRAM in system memory slots. ULLtraDIMM products began shipping in server products in Q1 2014. The ULLtraDIMM uses the DDR3 protocol and is configurable as a block storage device that can be used in a similar fashion as other block storage devices within the enterprise. A summary of SanDisk's ULLtraDIMM is shown in Table 1.

**TABLE 1**

SanDisk’s ULLtraDIMM Overview

<table>
<thead>
<tr>
<th>Metric</th>
<th>ULLtraDIMM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>19nm MLC</td>
</tr>
<tr>
<td>Form Factor</td>
<td>DIMM</td>
</tr>
<tr>
<td>Size (GB)</td>
<td>200 and 400</td>
</tr>
<tr>
<td>Read Latency</td>
<td>150 usec</td>
</tr>
<tr>
<td>Write Latency</td>
<td>&lt;5 usec</td>
</tr>
<tr>
<td>Random Read (4K transfer)</td>
<td>150K IOPs</td>
</tr>
<tr>
<td>Random Write (4K transfer)</td>
<td>65K IOPs</td>
</tr>
<tr>
<td>Sequential Read</td>
<td>1 GB/s</td>
</tr>
<tr>
<td>Sequential Write</td>
<td>760 Gb/s</td>
</tr>
<tr>
<td>Interface</td>
<td>DDR3</td>
</tr>
<tr>
<td>Endurance</td>
<td>10 Drive Writes Per Day</td>
</tr>
<tr>
<td>Reliability</td>
<td>1 unrecoverable error in 10^17 Bits Read</td>
</tr>
</tbody>
</table>

Source: IDC, 2014
The ULLtraDIMM provides a number of additional benefits:

- **Fits into existing memory slots.** The DIMM form factor allows the ULLtraDIMM to be used in any existing memory slot on the motherboard. This is fully interoperable with RDIMMs, enabling it to be deployed in any server or blade system found in enterprises today. Capacity can be scaled linearly with each additional SSD that is inserted into a memory slot.

- **Ultra Low Latency and Scalable I/O Performance.** Leveraging the DDR3 to SATA memory channel storage (MCS) protocol conversion capability from Diablo Technologies, the ULLtraDIMM is able to connect to the memory bus to provide less than 5 µsec (microseconds) write latency, the lowest in the industry, closing the performance gap between storage devices and system memory. (Many other technologies show I/O speeds in the milliseconds range). The ULLtraDIMM achieves random performance of 150K read IOPS and 65K write IOPS, 1GB/s and 760MB/s of sustained read/write performance and can scale I/O performance linearly while maintaining consistent write latency.

- **Enterprise-Class features.** Leveraging SanDisk’s patented Guardian Technology Platform, the ULLtraDIMM utilizes flash management techniques that deliver enterprise-grade endurance and reliability. The Guardian Technology Platform is composed of three components: FlashGuard, EverGuard and DataGuard:
  - **FlashGuard** includes technologies developed by SanDisk that reliably extract significantly more usable life from MLC flash than provided by the standard specifications published by NAND manufacturers. FlashGuard extends the native endurance of standard MLC flash-based SSDs from less than 1 capacity write per day (Drive Writes per Day, or DWPD) to 50 full capacity writes per day (DWPD) for a period of five years.
  - **DataGuard** technology provides full data path protection, ensuring that user data will be safe throughout the entire data path in the SSD. Dataguard provides the ability to recover data from failed page and NAND blocks.
  - **EverGuard** technology protects and prevents the loss of user data during unexpected power interruptions.

**CHALLENGES/OPPORTUNITIES**

Moving flash to the memory bus may not be for all applications, because not all applications can take advantage of the I/O and latency performance gains associated with this approach. However, for those designs that require extremely fast and low latency storage – including High-Frequency Trading (HFT), Virtual Desktop Infrastructure (VDI), transaction processing, virtualization and cloud computing – flash on the memory bus may be the ideal solution to accelerate application performance.

Yet, there are some things to consider when leveraging flash on the memory bus. While flash is cheaper than DRAM, it is more expensive on a dollar per gigabyte basis than other persistent storage solutions like the HDD. Thus, cost remains a key hurdle for many IT users when evaluating the technology. Although advances in NAND flash technology continue to reduce the cost of flash storage, future improvements promise even lower costs over time, which will make flash on the memory bus more cost effective from a dollar per gigabyte perspective. And, it is worth noting that for many customers, high performance applications’ new metrics that move beyond $/GB may be more appropriate, such as minimum latency, cost per IOP ($/IOP) or cost per watt ($/watt) when considering...
leveraging this solution. Today, when considering these metrics, which center on operational costs for datacenter space, power and cooling, flash far outperforms HDDs on a $/metric basis.

Flash on the memory bus will also require some changes, because many of today’s systems have not been designed for this type of DIMM-slot solution, similar to what the industry has experienced around PCIe-based SSDs over the last few years. Given that flash on the memory is a new approach that moves away from the traditional I/O stack, an ecosystem is needed to fully support its mainstream appeal. As a result, items such as updates to the BIOS and new drivers, will be needed to be used as a block storage device and properly integrated in the enterprise.

In the future, further optimization of the technology can expand its use within the enterprise. With its use as a block storage device, the solution can emulate faster persistent storage for deployments that can take advantage of this innovation. Making flash on the memory bus act as an extension of main memory will further broaden this solution’s mainstream market appeal. Additionally, new solid state media is under development within the industry to complement NAND flash. Early prototypes of some of these media types suggest that they could provide even higher performance and lower latency than NAND flash does today. The use of these new media types over time could further enhance the use of nonvolatile solid state storage on the memory bus.

CONCLUSION

The old adage “time is money” holds true for the enterprise. The ability to extract real-time value from the analysis of enterprise data related to transactional applications and databases is having meaningful impacts in terms of the evolution of enterprise data centers. It does so by improving IT capabilities, business agility and the overall efficiency of the organization.

NAND flash is at the center of the Big Data and Analytics trends, due to its ability to store large datasets, and to support large IOPS rates. By combining a form factor that easily plugs into a server’s existing memory DIMM slots with an interface that moves beyond the traditional I/O stack, flash on the memory bus is poised to fill the need of applications that require high performance and very low latency. This approach is designed to harness the power of real-time data access and real-time analytics to meet the needs of today's business – and to expand its reach to address tomorrow's business opportunities.
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