White Paper

Intel Information Technology

Computer Manufacturing

Mobile Computing

Improving the Mobile Experience with Solid-State Drives

Intel IT is evaluating solid-state drive (SSD) technology to better understand the benefits to users and the impacts on the enterprise. We have initiated a proof of concept (PoC) study that includes extensive benchmark testing as well as deployment of notebooks with SSDs to the Intel workforce. Our PoC is demonstrating some significant advantages of SSDs over traditional hard disk drives for both users and IT—including faster system performance, lower energy consumption that extends battery life, and the potential to reduce IT support costs. Based on these results and our expectation of improved reliability, we see SSD technology as a logical next step in improving users' experiences with mobile computing at Intel.

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IT@Intel

Executive Summary

Significant benefits for IT include an anticipated reduction in support costs, the performance required to support emerging technologies, and better service to our users.

Intel IT has initiated a proof of concept (PoC) study that includes extensive testing of solid-state drives (SSDs) against traditional hard disk drives (HDDs) and deployment of SSDs to the Intel workforce. Results show that SSDs deliver a better mobile computing experience, with increased system performance and improved battery life.

In formal tests of performance and battery life, we ran industry-standard benchmark suites on several models of notebooks. We also performed Intel IT-developed tests for common user tasks and disk-intensive tasks.

We found that SSDs offer significant benefits for both our users and IT. User benefits include:

- An 18 to 33 percent overall system performance improvement over HDDs with industry-standard workloads and benchmarks.
- A 41 percent performance improvement on average with Intel IT-developed workloads.
- About 59 to 70 minutes longer battery life compared with an HDD, providing extended mobile use and reducing recharge cycles and battery replacements.
- The ability to move more quickly between locations due to faster start up, standby, and resume, and the ability to safely transport a notebook while it is on.

Significant benefits for IT include an anticipated reduction in support costs, the performance required to support emerging technologies, and better service to our users. Reduced support costs are due to the inherent advantages of SSD technology, including:

- Better reliability resulting in reduced user down time, fewer support calls, and fewer drive replacements.
- Faster installation of operating systems and applications, and faster end user data restoration.
- Increased battery life resulting in fewer replacements.
- Faster data wipe techniques, including Department of Defense (DoD)-compliant wipes.

Based on promising test results and enthusiastic response from PoC participants, we plan to transition our PoC deployment of SSDs into a standard IT-supported service, distributing additional SSDs throughout our workforce to extend the benefits of the technology. As SSDs gain popularity with users and IT departments alike, we expect that price reductions and larger drive capacities will accelerate mainstream SSD adoption.

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Background

Mobile technology has become prevalent over the past few years, with companies of all sizes benefiting from the greater computing accessibility and increased productivity notebooks provide. Intel's global workforce is highly mobile: About 83 percent of employees use notebook PCs, which deliver a powerful client that can run a rich set of productivity and other business applications, even when they are working from home or traveling without reliable network access.

While mobile solutions show tangible results to organizations worldwide, we receive several common requests from our users and other IT organizations. These include:

- Faster system performance
- Longer battery life
- Improved reliability

Intel IT is continually looking for ways to address these customer needs. To enhance mobile computing, we are investigating solid-state drive (SSD) technology and are excited about the potential of SSDs to improve the user experience over more traditional hard disk drives (HDDs).

Table 1. Hard Disk Drives versus Solid-State Drives

Hard Disk Drives	Solid-State Drives
More fragile due to rotating platters and mechanical arms	More rugged because there are no moving parts
Reduced battery life due to high energy consumption	Longer battery life and cooler machines due to reduced energy consumption
Decreased performance as file fragmentation increases	Consistent performance because fragmentation is not an issue
Greater risk of data loss and hard disk failure when transported	More resistant to the bumps and drops expected from mobile users
Slower responsiveness and performance due to drive spin-up time and mechanical arm movement	Faster responsiveness and performance due to no drive spin-up time, no mechanical arm movement, and minimal latency

Intel® SATA Solid-State Drive Technology

Drawing from decades of memory engineering experience, Intel® solid-state drives are designed to deliver outstanding performance and reliability, featuring the latest-generation native SATA interface with an advanced architecture employing 10 parallel NAND flash channels equipped with single-level cell NAND flash memory for even greater overall performance and reliability. With powerful Native Command Queuing to enable up to 32 concurrent operations, Intel SSDs deliver higher I/O operations per second (IOPS) and throughput performance than other SSDs on the market today—and drastically outperform traditional hard disk drives. Intel SSDs also feature low write amplification and a unique wear-leveling design for higher reliability, meaning Intel SSDs not only perform better—they last longer.

Technology Overview

Currently, SSDs are more expensive than HDDs, but the potential benefits of the technology for users and IT could ultimately reduce TCO. Table 1 contrasts the drives.

HDD Technology

An HDD is a non-volatile storage device that stores digitally encoded data on rapidly rotating platters with magnetic surfaces. Each platter has a head that physically moves over the platter as it spins to read or write data. The first step in reading or writing data from an HDD is to make the drive spin up to a constant speed—for example 7,200 revolutions per minute (RPM).

HDDs experience reliability issues because of their basic hardware construction. The rotating motion of the platters and the movement of the mechanical arms cause wear and tear to the drive, which can lead to hard disk failure. Additionally, HDDs cannot withstand extreme shock and vibration when in use, so they are prone to problems when users carry their notebooks from one place to another. This can result in file corruption, system crashes, and potential data loss.

SSD Technology

An SSD is a data storage device that uses solid-state memory to store persistent data. Unlike flash-based memory cards, an SSD emulates an HDD, thus easily replacing it in most applications.

Solid-state storage technology typically provides faster system performance than HDDs. As there are no mechanical delays, they usually provide faster access rates and less latency. Also, SSDs can provide improved overall system responsiveness while consuming much less power than a traditional HDD. This translates into a better mobile computing experience for the user.

SSDs are more reliable than conventional HDDs due to the absence of spinning platters and mechanical arms. In demanding environments, SSDs provide the ruggedness required for mobile applications. Unlike an HDD, an SSD can withstand extreme shock and vibration while active with data integrity and significantly reduced danger of data loss.

Each manufacturer has different specifications for designing and building SSDs, just as with HDDs. In addition to obvious factors like read/write performance, power consumption, interface, and mean time between failures (MTBF), SSDs also vary based on:

- **Memory cell technology.** In general, multi-level cell (MLC) technology for mainstream use and single-level cell (SLC) technology for enterprise use. SLC technology generally has faster write speeds than MLC technology and is priced correspondingly.

- **Controller competence.** The core capability of an SSD lies in the sophistication and competency of the controller. The controller manages every aspect of an SSD's function, including performance, power management, error-correcting code (ECC) handling, and data reliability.
- **Write amplification.** A ratio of the NAND writes performed compared to the writes requested from the host computer. The write amplification, combined with the quantity of data written, has a major impact on expected drive longevity.
- **Wear-leveling algorithms.** NAND cells wear out with use. An efficient wear-leveling algorithm places data across all areas of the drive, providing for equal wear and maximum life.

Developing a Proof of Concept Study

We recently initiated a proof of concept (PoC) that involves formal testing and deploying notebooks with SSDs to employees. We wanted to:

- Understand and quantify how SSD technology provides a better mobile experience for our users and for IT.
- Create an overall total cost of ownership (TCO) model.
- Understand the conditions and timing for further SSD deployments to our workforce.

Proof of Concept

Our goal was to determine whether SSDs address common requests for improved system performance, battery life, and reliability to provide a better mobile experience for users. Our PoC included an array of industry-standard benchmark and Intel IT performance tests as well as deployment of over 40 SSDs to selected employee participants.

Industry-standard Benchmark Tests

We ran formal tests for performance and battery life using industry-standard benchmark suites on mainstream IT notebooks. Notebook configurations were based on the 2006 Intel® Stable Image Platform (Intel® SIPP), with Intel® Centrino® with vPro™ technology, Intel® Core™2 Duo mobile processor T7300, and Mobile Intel GM965 Express chipset.

Test systems ran Microsoft Windows Vista Enterprise* and had 2 GB of SDRAM, 14-inch LCD screens, and new six-cell batteries that were conditioned prior to testing; device initiated power management (DIPM) was enabled. For testing purposes, we used 7200-RPM and 5400-RPM platter HDDs and Intel® X25-M Mainstream SATA Solid-State Drive pre-release units; Table 2 compares the drives.

We ran performance tests, which included 3-D, e-Learning, video creation, and office productivity application workloads, in both native and virtual client environments. The process for performance and battery life tests involved running each test on the HDDs, then placing the SSD into the same notebook and running the tests again. We repeated this cycle three times and averaged the scores.

Intel IT Performance Tests

We used the same process and hardware for Intel IT performance tests as in the industry-standard benchmark tests, but with our IT build on Microsoft Windows XP*. These internally developed tests use Intel IT workloads running operations similar to those our users encounter in their daily work—including loading, unloading, and data manipulation within office productivity applications, and changing the operating state of the notebook.

Table 2. Drive Specifications

	Intel® X25-M Mainstream SATA Solid-State Drive (80 GB)	2.5" 7200-RPM SATA 3.0 Gb/s 16-MB Cache Drive	2.5" 5400-RPM SATA 1.5 Gb/s 8-MB Cache Drive
Bandwidth	▪ Up to 250 MB/s read speed ▪ Up to 70 MB/s write speed	▪ Up to 80 MB/s read and write	▪ Up to 44 MB/s read and write
Power	▪ Active: 0.150 W typical (PC workload)[1] ▪ Idle typical device initiated power management (DIPM): 0.06 W	▪ Active: read/write ▪ Average: 2.1 W ▪ Idle/standby average: 0.75/0.21W	▪ Active: read/write ▪ Average: 1.9/1.8 W ▪ Idle/standby average: 0.6/0.2 W
Average latency	85 microseconds (µs)	4,170 µs	5,600 µs
Life expectancy	1.2 million hours mean time between failures (MTBF)	0.5 million hours MTBF	Not specified

[1] See product information at www.intel.com for power benchmark testing results.

Participant Response

Soon after deploying Intel X25-M Mainstream SATA Solid-State Drives to PoC participants, we started receiving feedback as they commenced their daily work routines. Here are a few of the comments:

"After just a couple hours—incredible! Like a major CPU/platform upgrade in terms of performance/responsiveness...my first impression was outstanding and it has been a long time since one upgrade gave me that kind of responsiveness."

"Automated backup is much faster and does not slow down my system. In the past I would decline the prompt to start this if I was busy; with the SSD I choose to back up no matter what I'm doing."

"My summary—it rocks. Already, the fact that I can immediately walk from [one] meeting into my next without the shutdown is a huge time [and] productivity saver..."

"I flipped from hating my computer due to its lack of responsiveness into loving it again. The battery life has improved significantly, despite the fact that I have an old battery; [I] will buy a new battery to see whether I can survive a day...without plugging the notebook into the wall."

We also tested how long it takes to install a custom Intel IT build on SSDs as compared to HDDs. To build a client PC, Intel IT purchases a notebook from a vendor, deletes all vendor-supplied software, replaces it with our own qualified IT build, and distributes the machine to the user. Any time saved on installation reduces IT support costs.

SSD Deployment to Users

We deployed over 40 SSDs in twelve notebook models from three manufacturers to selected users; each notebook included an Intel Mainstream SATA Solid-State Drive in either a 2.5-inch (X25-M) or 1.8-inch (X18-M) SSD form factor. Our process involved imaging the original mechanical drive to an SSD. For a subset of users, we also ran an Intel IT-developed disk-intensive workload and measured start-up, shutdown, standby, and resume times with both the original-issue HDD and the new SSD.

Once we installed the SSDs, we disabled the drive shock utility, disabled defragmentation software if necessary, and installed a drive-monitoring agent. The controller-level statistics collected with the drive monitoring agent will help us validate estimates for normal drive usage, drive reliability, and life expectancy, as well as monitor for errors.

Results

Our PoC resulted in a group of enthusiastic users. The SSDs delivered significant benefits to them, including better system performance and improved battery life. They felt more productive because they could move around with their notebooks in use without fear of damaging their drives or data. We also anticipate improved reliability; we will be able to more thoroughly analyze this after a longer period of data collection. Proven benefits to IT included the ability to provide faster support activities and support for emerging technologies.

User Benefits

Overall, our PoC tests show that SSDs not only deliver a better user experience—faster system responsiveness, overall performance, and longer battery life as compared to HDDs—but that the technology is all "behind the scenes." This means that users don't need any training to use this new technology.

SSD technology also promises a consistent level of performance without the need to defragment the drive. The industry-standard workloads and Intel IT workloads were completed on drives that were freshly installed and defragmented, where we expect them to perform optimally. Over time, as the files and disk become fragmented, HDD performance declines without running a defragmentation process. We expect SSD performance to stay consistent without performing defragmentation.

Better system performance

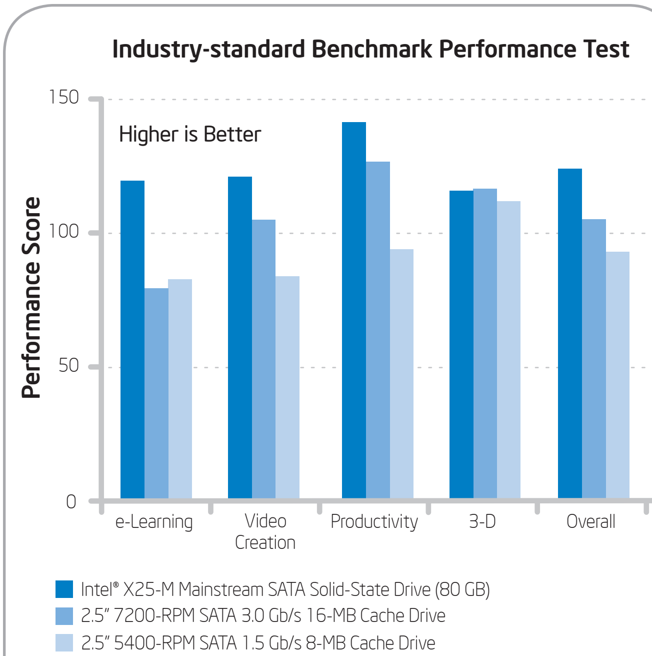
- **Industry-standard workloads.** Results of industry-standard 3-D, e-Learning, video creation, and office productivity application workloads are shown in Figure 1; the higher the score, the better the performance. The SSD achieved an average 18 percent higher overall score than the 7200-RPM HDD, and an average 33 percent higher overall score than the 5400-RPM HDD. Tests on a system that did not support the SATA 3.0 Gb/s interface resulted in a much smaller improvement. Thus, we learned that matching a high-performance SSD to a notebook model that can take full advantage of the drive's capabilities is critical if users are to realize the full potential of the technology.
- **Intel IT workloads.** Another set of tests demonstrated that SSDs were noticeably faster when performing common tasks such as loading and using office applications, awakening from standby mode, and starting up the system. These tests show real-world improvements, on average 41 percent, for the tasks our employees encounter multiple times a day in the course of their work. Results are shown in Figure 2.
- **Pilot deployment.** Performance test results on a sample of systems in our pilot deployment were consistent with results in the lab. Also, feedback from pilot users indicated that overhead tasks such as network backup and virus scanning were faster and less intrusive.

Improved battery life

In another industry-standard benchmark test, we found that the notebooks with SSDs consumed less power. The SSD provided an average of 59 to 70 minutes of additional battery life compared to HDDs. Results are shown in Table 3. This increased battery life translates into extended mobile use, fewer recharge cycles, and reduced battery replacement. And because notebooks with SSDs use less energy, they also run cooler and more quietly.

Anticipated improved reliability

Monitoring is an ongoing process, but to date we haven't experienced any failures or data loss in the SSDs we deployed to PoC participants. Hardware manufacturer specifications for a typical HDD indicate a lifespan of between four to five years as opposed to a lifespan of seven to ten years—or more—for an SSD. Intel's PC environment is predominantly mobile, and we experience a significant number of support incidents related to HDD failures and corrupted data or



Performance Improvement with Solid-State Drives

	Overall Performance Score	Percent Improvement
Intel® X25-M Mainstream SATA Solid-State Drive (80 GB)	124	
2.5" 7200-RPM SATA 3.0 Gb/s 16-MB Cache Drive	105	18%
2.5" 5400-RPM SATA 1.5 Gb/s 8-MB Cache Drive	93	33%

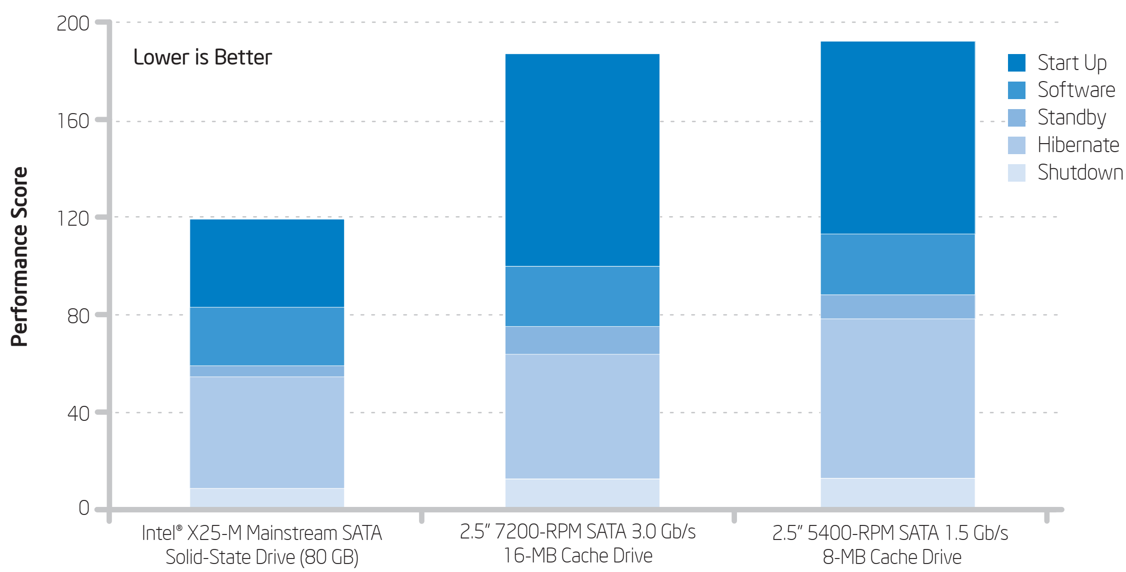
Figure 1. Notebooks with solid-state drives scored higher overall in performance benchmark tests using industry-standard workloads as compared to hard disk drives. Intel internal measurements, November 2008.

system files. A reduction in these incidents will reduce user downtime and potentially lost data.

Because SSD drives are more rugged and longer lasting than traditional HDDs, we expect changes to certain usage models. Users could:

- Keep their systems running while moving from one place to another without worrying about file corruption or hard disk crashes, thereby reducing downtime between meetings.
- Significantly reduce system performance interruption or downtime by eliminating the need to perform defragmentation and other background tasks.

It's important to note, however, that if an SSD is damaged, recovering and rebuilding data based on HDD platter scan services is not possible; diligently enforcing regular system backups of data on SSDs is important.



Performance Improvement with Solid-State Drives

		Intel® X25-M Mainstream SATA Solid-State Drive (80 GB)	2.5" 7200-RPM SATA 3.0 Gb/s 16-MB Cache Drive	Percent Improvement	2.5" 5400-RPM SATA 1.5 Gb/s 8-MB Cache Drive	Percent Improvement
Start Up	Time from Shutdown to Load OS	25.03	55.16	55%	55.46	55%
	Time to Load Web Browser after Logging On	3.65	12.29	70%	5.72	36%
	Time to Load e-Mail after Logging On	7.45	19.70	62%	17.88	58%
Software	Spreadsheet Load Time	0.59	1.11	47%	1.24	52%
	Presentation Load Time	0.48	0.73	34%	0.84	43%
	Word Processor Load Time	0.50	0.85	41%	0.91	45%
	Spreadsheet Number Crunch	22.50	22.00	-2%	22.00	-2%
Standby	Time to Standby	1.77	5.87	70%	5.70	69%
	Time from Standby to Logon	2.87	5.60	49%	4.23	32%
Hibernate	Time to Hibernate	10.47	16.37	36%	22.33	53%
	Time from Hibernate to Logon	35.40	34.87	-2%	43.13	18%
Shutdown	Time to Shutdown	8.92	12.83	30%	13.19	32%

Figure 2. Notebooks with solid-state drives performed Intel IT workloads significantly faster than hard disk drives. Intel internal measurements, November 2008.

IT Benefits

While SSDs are currently more expensive than HDDs, we believe that there are financial benefits to IT and user productivity benefits to the enterprise that will not just offset the cost difference, but will show a positive ROI. These benefits can really only be proven and quantified in time, but we will continue to track how faster and more reliable drives impact our business. As prices of the drives fall, the only significant barrier to mainstream adoption—the up-front cost—will disappear.

Improved TCO

Factors we intend to track and analyze for their impact on a TCO model include:

- Anticipated reliability improvements, resulting in lower support cost and reduced user downtime.
- Faster support "touches," including custom OS build installations, application installations, and data restore times.
- Cost avoidance of full-featured disk defragmentation software.
- Faster secure data wipes.
- Increased battery life, which reduces the number of recharge cycles and delays replacement.

Lower support costs

With no moving parts, SSDs provide greater reliability, increasing data integrity and reducing downtime. More robust SSDs mean fewer support calls and out-of-warranty drive replacements, which translate into direct IT savings.

Faster support "touches"

We install custom builds of the OS, as well as management, security, and productivity software, on every system we deploy to users. We found that the Intel IT-specific image build process tests finished in 20 to 35 percent less time with SSDs—about 30 minutes faster than those run on traditional HDDs. This demonstrates a bottom-line improvement with a positive impact to IT. The performance benefits of the drive can also speed the delivery of other support services like data migration or restoration.

Elimination of disk defragmentation software

HDDs are divided into tracks and sectors. As more disk space is used, more clusters contain sectors that are fragmented (occupying different physical platters, tracks, and sectors). With increasing fragmentation, it takes more time for the head to move to a particular track and for the platter to rotate to a position where it can be written or read; therefore, performance generally decreases over time.

Table 3. Battery Improvement with Solid-State Drives

	Overall Performance Score	Percent Improvement	Minutes Improvement
Intel® X25-M Mainstream SATA Solid-State Drive (80 GB)	248		
2.5" 7200-RPM SATA 3.0 Gb/s 16-MB Cache Drive	189	31%	59
2.5" 5400-RPM SATA 1.5 Gb/s 8-MB Cache Drive	178	39%	70

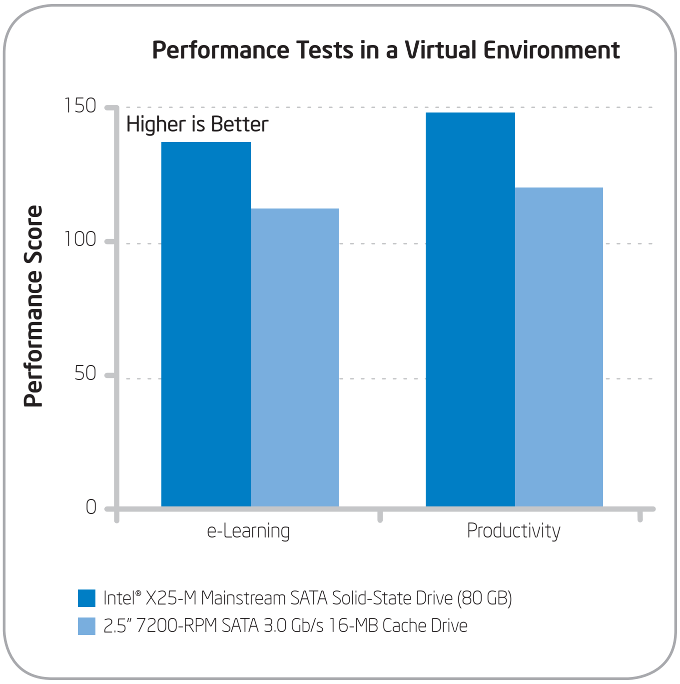


Figure 3. An Intel® X25-M Mainstream SATA Solid-State Drive (80 GB) performed up to 23 percent better than a hard disk drive in a virtual environment. Intel internal measurements, July/August 2008.

SSDs have no tracks or sectors. The underlying memory locations of the SSD are organized into clusters with which the OS can work just as it does the clusters on an HDD. Since there are no physical sectors underlying the clusters on an SDD, files do not become fragmented on the sector level; therefore, SSDs provide consistent high performance without the need to defragment the drive. We plan to monitor the consistent performance of the SSDs with further long-term studies.

Since SSDs don't require periodic disk defragmentation or optimization of the hard drive, this reduces time and costs for both the user and IT. IT can avoid buying licenses for full-featured versions of defragmentation software, and the user doesn't need to experience the performance impact of running the defragmentation process. We are working with our engineering team to prevent deployment of defragmentation software on PCs equipped with SSDs.

True DoD-compliant data wipes in less time

We ran wipe tests on an HDD and an SSD. In seven-pass wipes of the drives, the 80-GB, 7200-RPM HDD took 9 hours and 13 minutes, and the 80-GB SSD took 4 hours and 27 minutes, a time savings of more than 50 percent.

Intel security policy dictates that when a PC reaches the end of its lifecycle, we remove the hard drive and grind it before selling the PC shell. Due to the faster wipe times with an SSD, we may consider wiping the drive, rather than destroying it, thus increasing resale value. We can also wipe the drive when re-issuing notebooks within our company, receiving the same time savings. These wipes comply with stringent DoD standards.

The ATA command "Security Erase Unit" works differently with SSDs than with HDDs. This command is supported with SSDs and takes about one minute to run. We're currently assessing this feature in our environment to see if it results in a wipe that meets our information security requirements. If so, the time savings from using this command could further reduce our support costs.

Fewer battery replacements

Because a notebook equipped with an SSD generally provides a longer battery life, the battery will go through fewer recharge cycles compared to a notebook equipped with a HDD. This should result in fewer replacement batteries over the life of the asset.

Other Benefits

The performance, low power consumption, and physical characteristics of SSDs offer additional valuable benefits in support of emerging technologies.

Support for full disk encryption

Intel IT is currently investigating the use of full disk encryption on our mobile systems. The obvious security benefit of using this technology needs to be balanced with the performance impact on the system. We tested HDDs and SDDs in both encrypted and unencrypted states using our Intel IT workloads. While system performance was generally slightly slower after encryption was applied, with the combination of full disk encryption and SSDs, users will benefit from increased security and increased performance over a similar system with a standard HDD and no encryption.

Support for client virtualization

Intel IT is currently investigating client virtualization because it has the potential to transform client computing, reducing TCO and increasing IT control while giving users more flexibility. The performance benefit of SSDs supports client virtualization. We tested industry-standard workloads appropriate for a virtual environment—productivity software and e-Learning—and found that the notebook with the SSD performed 23 percent better overall than the notebook with the HDD, as shown in Figure 3, when using a virtualized client configuration.

Ability to develop new form factors

Since SSDs don't have rotating platters, they are not limited to being round and flat; they can be made much smaller and in a variety of shapes. From a product development perspective, this means smaller, lighter, and cooler notebooks with less fan noise. We are already seeing such notebooks in the market, and we expect that SSDs will continue to enable new form factors. Since the drives are smaller, lighter, and consume less power, we are also exploring the use of multiple SSDs in mobile workstations requiring extreme performance while maintaining mobile benefits.

Conclusion

Based on promising test results and enthusiastic response from PoC participants, we plan to transition our PoC deployment of SSDs into a standard IT-supported service. We are also planning to distribute additional SSDs to specific segments of our workforce in the near future to extend the benefits of the technology.

Our test results found that SSDs:

- Provide better system performance.
- Improve battery life— systems ran about 59 to 70 minutes longer between charges.
- Provide potentially better reliability.
- Decrease support costs.
- Reduce time to install operating systems and applications.
- Provide faster DoD-compliant data wipes, increasing reuse, resale value, and data security.
- Eliminate the need for disk defragmentation software.
- Support emerging technologies like drive encryption.
- Provide for new form factors.

Although there's a higher up-front cost for notebooks with SSDs, we can expect price reductions and higher capacities, which will demonstrate a lower TCO for IT and substantial productivity benefits to our users.

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Authors

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Acronyms

ATA	Advanced Technology Attachment
DIPM	device initiated power management
DoD	Department of Defense
HDD	hard disk drive
MLC	multi-level cell
MTBF	mean time between failures
PoC	proof of concept
ROI	return on investment
RPM	revolutions per minute
SATA	Serial Advanced Technology Attachment
SLC	single-level cell
SSD	solid-state drive
TCO	total cost of ownership

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