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Accelerating performance, cost-optimization and streamlining deployment with Clonezilla and SATA SSDs.

Ephrem Tilahun, *Alabama State University, etilahun8659@myasu.alasu.edu*

Abstract

This paper presents a technical analysis of upgrading lab environment machines from HDDs to 2.5" SATA SSDs at COBA, Alabama State University. The study focuses on performance evaluation, cost-benefit analysis, and software deployment using Clonezilla DRBL. The cost-benefit analysis revealed that while SATA SSDs are still more expensive than HDDs per GB, the price gap has narrowed. Performance per dollar calculations showed that SATA SSDs offer higher performance levels, making them a justifiable investment for improved system performance. The study was conducted on a limited number of computers and only focused on SATA SSDs since other PCIe SSD implementations require expansion cards. Upgrading significantly enhances system performance, streamlines lab management, and provides a more efficient and responsive user experience. This research contributes to the optimization of computing systems through storage upgrades and software deployment strategies. Future research could explore alternative storage solutions and software deployment methods, as well as evaluating the long-term effects of SSD upgrades on reliability and lifespan.

Keywords: storage, optimization, SATA_SSDs, Clonezilla, DRBL, cost-analysis, NAS-deployment

Introduction

Recent observations within my affiliation's university lab environment, specifically at the College of Business Administration (referred to hereafter as the Business Lab), have indicated a decrease in performance of several lab computers. These machines, Dell OptiPlex 9020s, were released in 2013 and configured to the Business Lab's specifications in 2014/15. The specifications relevant to this project include an Intel Core i5-4th Gen processor, 12 GB of 1600MHz DDR3 SDRAM, Integrated Intel® HD Graphics 4600, Integrated Intel® I217LM Ethernet LAN 10/100/1000 Adapter with PXE Boot, RAID 0 and 1 support, no external GPUs, and 3.5" 5400RPM HDDs.

The focus of this paper is the storage mechanism of these systems. In 2014, these hardware configurations provided satisfactory performance with Windows 10. However, by 2023, all of the 220 OptiPlex 9020s deployed across the Business Lab network have shown signs of lagging and unresponsiveness in most applications, particularly with the Win10.22H1 update installed. This decline in performance has led to frustration and reduced productivity among students and faculty members. The latest versions of Windows are designed to run on modern hardware with more RAM, faster processors, and larger storage capacities. However, when these operating systems are installed on older machines with less powerful hardware, they can slow down the performance of the computer. This is because the latest versions of Windows require more resources to run, come with new features that can be resource-intensive, and are constantly being updated with new security patches and bug fixes. As technology has advanced rapidly in recent years, it has become crucial to explore potential solutions to improve the performance of these aging systems, while considering cost-effectiveness and minimizing disruption to the lab's operations.

This paper addresses the performance issues experienced by the Business Lab computers by examining the feasibility of upgrading the Dell OptiPlex 9020s with 2.5" SATA SSDs. Additionally, the implementation of Clonezilla on Linux DRBL is explored, without going into depth. Through a thorough evaluation of these upgrades and software deployments, this study aims to provide the Business Lab with an effective and scalable solution to improve the overall performance and user experience of their lab computers.

Literature Review

Given the scope of the project and the challenges faced by past generation spec'd lab machines and specifically in this case, upgrading the Dell OptiPlex 9020s from 3.5" HDDs to 2.5" SATA SSDs presents numerous potential benefits. The primary reasons for considering this upgrade are the improved performance, enhanced reliability, and energy efficiency of SSDs compared to traditional HDDs. To paint the picture of what the key differences between them are and what they are.

A SATA SSD (Serial ATA Solid State Drive) is a non-volatile storage device that uses NAND-based flash memory to store data. It connects to a computer system via the Serial ATA interface, which is a standard interface for connecting storage devices like hard drives and optical drives. SATA SSDs offer significantly faster read and write speeds compared to traditional spinning hard drives, as well as lower power consumption, reduced noise, and heat generation, and increased durability due to the absence of moving parts.

An HDD (Hard Disk Drive), on the other hand, is a traditional magnetic storage device that stores data on rotating disks coated with magnetic material. It also uses the Serial ATA interface to connect to a computer system. HDDs consist of moving parts, including spinning disks and read/write heads, which contribute to slower access times and data transfer rates compared to SSDs. However, HDDs are typically more cost-effective in terms of storage capacity per dollar, making them a popular choice for bulk storage and applications where high-performance storage is not a critical requirement. Here are the differences as also mentioned in Kadve (2016).

1. Improved performance: SSDs have no moving parts, unlike HDDs, which rely on spinning disks and read/write heads. Consequently, SSDs have significantly faster read and write speeds, which can greatly enhance the overall performance of the system. By upgrading to SSDs, the lab computers can experience faster boot times, quicker application loading, and more efficient data retrieval. This performance improvement can enhance the user experience for students and faculty members, leading to increased productivity.

2. Enhanced reliability: SSDs are less susceptible to mechanical failure as they do not have any moving parts. HDDs, on the other hand, can be prone to mechanical wear and tear due to their spinning disks and read/write heads. Upgrading to SSDs reduces the risk of hardware failure and data loss, ensuring a more reliable computing experience for users.

3. Energy efficiency: SSDs consume less power than HDDs, as they do not require power to maintain the spinning of disks. Reduced power consumption can contribute to energy savings for the mentioned environments and can also result in lower heat generation within the systems. This

decrease in heat can prolong the lifespan of other components in the OptiPlex 9020s, further improving the reliability of the lab computers.

4. SSDs have no moving parts: HDDs have a spinning disk and a read/write head that moves across the disk to access data. This means that there is a certain amount of latency before the data can be read. SSDs, on the other hand, have no moving parts. This means that they can access data much faster, leading to faster boot times, faster loading times, and improved responsiveness.

5. SSDs have a higher random read/write speed: HDDs are optimized for sequential read/write speeds, which is the speed at which they can read or write large blocks of data. SSDs, on the other hand, are optimized for random read/write speeds, which is the speed at which they can read or write small blocks of data. This makes SSDs much better suited for applications that involve a lot of small file access, such as web browsing, office applications, and gaming.

6. SSDs have a lower latency: Latency is the time it takes for a drive to respond to a request. HDDs have a higher latency than SSDs, which means that they are slower to respond to requests. This can lead to a noticeable delay in applications that are sensitive to latency, such as gaming and video editing.

7. SSDs have a longer lifespan: HDDs have a limited lifespan, which is determined by the number of times the read/write head can move across the disk. SSDs, on the other hand, have a much longer lifespan, as they do not have any moving parts.

Methodology

The initial step in the methodology involved selecting a random OptiPlex 9020 machine to evaluate the performance improvements associated with upgrading to a SATA SSD. A cost-effective Timetec 512GB SSD 3D NAND QLC SATA III 6Gb/s 2.5" SSD was chosen for this purpose. Before and after the upgrade, a series of tests and benchmarks were conducted using the widely recognized storage testing and benchmarking tool, CrystalDiskMark, to measure the performance differences. Given that the computers are in a lab environment with a set of certain education-oriented applications installed, domain policies applied, and the Deep Freeze mechanism deployed, reinstalling the operating system on these machines from scratch was not a viable option. Multiple paid services for operating systems and storage image management solutions were considered, but the decision was made to proceed with Clonezilla DRBL, a free and open-source solution that also provided an opportunity to experiment with Linux server environments.

This paper will touch on the process of setting up Clonezilla DRBL but will not go in-depth. Clonezilla is a free and open-source disk cloning and imaging software used to create an exact copy of a hard drive or partition. It offers various functionalities, including data backup, system restoration for damaged systems, and operating system deployment across multiple computers. To manage the deployment of the GNU/Linux operating system on numerous clients, the open-source software DRBL (Diskless Remote Boot in Linux) serves as an effective solution. DRBL enables the deployment of Clonezilla on multiple clients using a network boot (PXE Boot), streamlining the process.

The primary objective of utilizing Clonezilla and DRBL in this project was to clone the contents of the existing HDD to the newly installed 2.5" SATA SSD. By doing so, the aim was to minimize downtime and prevent the need to recreate the lab ecosystem from scratch.

The steps followed to achieve this goal were:

1. Setting up DRBL: DRBL was installed and configured on a suitable server, ensuring that it was prepared to deploy Clonezilla to the desired clients.

2. Preparing clients for cloning: Each client's boot settings were configured to enable PXE Boot, allowing them to receive Clonezilla through the DRBL server.

3. Initiating the cloning process: With Clonezilla deployed on the clients, the cloning process was begun to transfer the contents of the HDD to the new 2.5" SATA SSD.

4. Verifying successful cloning: Once the cloning process was complete, it was verified that the new SSD contained an exact copy of the original HDD, ensuring the integrity and functionality of the lab ecosystem.

By following this structured approach, the HDD contents could be efficiently cloned onto the new SSD, mitigating any potential downtime and preserving the lab environment's stability.

In order to establish an efficient cloning station, a machine running Ubuntu Server, equipped with two network ports, was configured. The first network port played a crucial role in forming a localized subnet, connecting the clients, NAS, and acting as a DHCP server and gateway for these clients. In contrast, the second network port facilitated internet access for the Ubuntu Server and served as a NAT (Network Address Translation) link to the first adapter.

To enhance the setup, a NAS (Network Attached Storage) solution that utilized the TrueNAS operating system was integrated. This NAS provided centralized storage for disk images, allowing for easy access and management. Additionally, a 10/100/1000MB network switch was included to optimize data transfer rates between the connected devices, ensuring faster cloning times. Upon successful installation of DRBL with Clonezilla Live on the Linux server, all the clients, NAS, and the network switch were connected to the second network adapter. This configuration enabled the deployment of Clonezilla to multiple clients through a network boot (PXE Boot), streamlining the cloning process and ensuring a seamless transfer of HDD contents to the new 2.5" SATA SSDs.

This well-structured and comprehensive cloning station setup played a vital role in minimizing downtime and maintaining the integrity of the lab ecosystem during the cloning process. With the connections in place, a PXE boot was performed from the clients. To ensure Clonezilla's compatibility with PXE boot and drive detection, the following changes were made in the BIOS: the storage operation mode was switched to AHCI from RAID, Secure Boot was temporarily disabled, and UEFI booting was enabled.

To visualize the time savings achieved by using a scaled cloning system, a comparative analysis was conducted. Initially, a single instance was cloned manually, which took an average of 16 minutes to clone the entire 500GB drive. This process scales linearly, as each instance is cloned one by one, resulting in a direct relationship between the number of instances and the total time required.

In contrast, the use of Clonezilla on a DRBL Linux server, with images sourced from a Samba Server, presented a more efficient approach. The primary limitation in this setup was the 1 Gigabit network switch, which dictated the number of simultaneous cloning operations that could be conducted. Given the network bandwidth, it was possible to clone the contents of the SSD to approximately 8-9 computers before the network link became saturated.

Once the network link was saturated, time dilation was observed as additional instances had to wait in the network queue for bandwidth. This is a common phenomenon in networking, where data packets are delayed due to congestion in the network. The network switch, operating at the data link layer (Layer 2) of the OSI model, manages the data traffic between devices based on MAC addresses. However, when the data traffic exceeds the switch's processing capacity, it results in a queue, leading to time dilation. Interestingly, a similar implementation of Clonezilla with a DRBL server, as mentioned in a referenced research paper (Andi, N., & Boy, Y. (2020)), showed comparable results. This further validates the findings of this study and underscores the efficiency of using a scaled cloning system over manual cloning. Figure 1: Time vs instance cloning mechanisms observed.

Based on applied experiments and my troubleshooting encounters of DRBL deployment, these process steps provided a more streamlined and efficient cloning process.

1. Identifying the Machine Name Conflict Issue: The process of cloning an image to multiple machines creates identical machine names, which is incompatible with domain environments. This conflict was identified and addressed to ensure seamless integration into the existing system.

2. Dropping Machines from the Domain: To resolve the machine name conflict, all the cloned machines were first removed from the domain using Active Directory. The source image was also removed from the domain before capturing the disk image with Clonezilla. This step was crucial to enable the renaming of computers when rejoining the domain.

3. Saving Disk Images with Clonezilla: After initiating the network boot, Clonezilla's user interface was used to save disk images to the Network Attached Storage (NAS) via DRBL Clonezilla network boot as required. The software supports image compression and saves the complete disk/partition image as an ISO file.

4. Successfully Cloning the Image to the Client SSDs: The image was cloned onto the 2.5" SATA SSD in a non-RAID environment. The most effective method involved obtaining a single image per lab from the HDD machine and replicating it to other machines using the cloning station (NAS) after running SSD Trim features in the Windows Disk Error checking tool.

5. Optimizing Network Bandwidth Usage: To maximize efficiency and maintain optimal copy speeds, eight machines were processed simultaneously. This number effectively utilized the available 1GB/s network bandwidth without causing saturation.

6. Ensuring Unique Naming Schemes: Following the removal and renaming process, the computers rejoined the domain with unique naming schemes aligned with the labs' standards. This approach ensured seamless integration into the existing domain environment without causing conflicts. This process allowed for the renaming of the computers post-cloning while joining the domain, keeping them unique to the naming schemes of the labs. Lab management tools like Deep Freeze could then be deployed, and Windows Group Policies could be force applied.

Results

Performance Evaluation

In the performance evaluation section of this research paper, a comprehensive comparison was conducted between 2.5" SATA SSDs and 3.5" HDDs, grounded in the context of technical performance. This comparison utilized well-established measurements as the basis for evaluation. Key performance indicators such as sequential read speed (the speed at which an SSD can read a large block of data in a sequential order), sequential write speed (the speed at which an SSD can write a large block of data in a sequential order), random read speed (the speed at which an SSD can read small blocks of data in a random order), and random write speed (the speed at which an SSD can write small blocks of data in a random order) were meticulously measured and analyzed.

Furthermore, IOPS (Input/Output Operations Per Second, a measure of how many read and write operations an SSD can perform per second), latency (the time it takes for an SSD to perform a read or write operation), and endurance (a measure of how many times an SSD can be written to before it starts to fail) were also assessed. This rigorous assessment provided valuable insights into the performance differences between the two storage types, contributing to a deeper understanding of their respective strengths and weaknesses. The findings from this comparison serve as a critical component of the research, informing the subsequent discussions and recommendations presented in the paper. Table 1 illustrates the pre and post SSD Swap measurements of Crystal Disk Mark benchmarks.

Table 1: Pre and Post SSD Swap measurements of Crystal Disk Mark benchmarks

Crystal Disk Mark Benchmark	3.5” 5400RPM HDD		Crutial 2.5” 3D NAND SATA SSD	
	Read [MB/S]	Write [MB/s]	Read [MB/S]	Write [MB/s]
SEQ1M-Q8T1	157.97	150.03	564.65	536.45
SEQ1M-Q1T1	154.91	148.65	553.73	527.37
RND4K-Q32T16	1.53	1.61	407.42	380.29
RND4K-Q1T1	0.49	1.52	49.36	129.58

Interpretations: The RND4K-Q1T1 benchmark contributes the most to the responsiveness of a system. This benchmark measures the random 4KB read and writes performance with a queue depth of 1 and 1 thread. Random 4KB read and write speeds are particularly important for system responsiveness, as they represent the performance of small, random I/O operations that are common in everyday computing tasks, such as booting up the operating system, launching applications, or loading files. The lower queue depth and single thread in this benchmark also represent a typical usage scenario for consumer-grade computers, making it a more accurate representation of real-world performance.

To analyze the data statistically, we can calculate the performance improvement ratios between the 3.5" 5400RPM HDD and the Crucial 2.5" 3D NAND SATA SSD for each of the CrystalDiskMark benchmarks in MB/s:

1. SEQ1M-Q8T1:
   - Read Improvement: 564.65 / 157.97 = 3.57 times
   - Write Improvement: 536.45 / 150.03 = 3.57 times

2. SEQ1M-Q1T1:
   - Read Improvement: 553.73 / 154.91 = 3.57 times
   - Write Improvement: 527.37 / 148.65 = 3.55 times

3. RND4K-Q32T16:
   - Read Improvement: 407.42 / 1.53 = 266.29 times
   - Write Improvement: 380.29 / 1.61 = 236.21 times

4. RND4K-Q1T1:
    - Read Improvement: 49.36 / 0.49 = 100.73 times
    - Write Improvement: 129.58 / 1.52 = 85.25 times

Table 2: Benchmark test description

Test	Description
SEQ1M-Q8T1	Sequential read/write with 1 queue and 8 threads
SEQ1M-Q1T1	Sequential read/write with 1 queue and 1 thread
RND4K-Q32T16	Random read/write with 32 queues and 16 threads
RND4K-Q1T1	Random read/write with 1 queue and 1 thread

From this analysis, we can draw the following insights:

1. The Crucial 2.5" 3D NAND SATA SSD consistently outperforms the 3.5" 5400RPM HDD in all benchmark tests.

2. The largest performance improvement is seen in the RND4K-Q32T16 benchmark, where the SSD is more than 200 times faster than the HDD for both read and write operations. This indicates that the SSD excels in handling small, random I/O operations with higher queue depths and multiple threads.

3. The smallest performance improvement is seen in the RND4K-Q1T1 benchmark, but the SSD is still around 85-100 times faster than the HDD for both read and write operations. This shows that the SSD significantly improves system responsiveness for everyday computing tasks involving small, random I/O operations with low queue depths and single threads.

4. The SEQ1M-Q8T1 and SEQ1M-Q1T1 benchmarks, which measure sequential read and write performance, show that the SSD is about 3.5 times faster than the HDD. This improvement suggests that the SSD can handle large, sequential data transfers more efficiently, which is beneficial for tasks like file copying and media streaming.

Broader conclusions based on technical information from spec sheets and other sources.

- Latency: Access time, which refers to the time taken to read or write data, is a critical factor when comparing storage technologies. For HDDs, the average read access time is approximately 15.785 ms, whereas, for SSDs, it is significantly faster at around 0.031 ms. This makes SSDs about **509** times quicker in terms of read access time compared to HDDs. In terms of write access time, SSDs also outperform HDDs, being approximately **102** times faster.

- Throughput: Another important metric is the data transfer speed or throughput. SSDs have an average throughput of 514.28 MB/s, while HDDs lag at 149.86 MB/s, making them 3.4 times slower. In terms of 4K read speed, SSDs demonstrate an even greater advantage, with a speed of 36.79 MB/s compared to the HDD's 0.69 MB/s, which is 53 times slower. For 4K write speed, SSDs maintain their dominance with a speed of 128.65 MB/s, which is 105 times faster than the 1.22 MB/s achieved by HDDs.

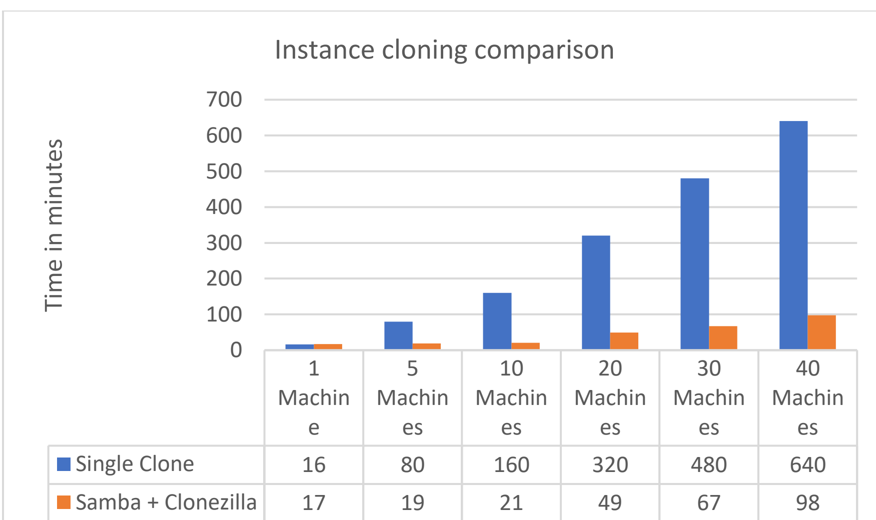
- Capacity: HDDs typically offer higher storage capacities at more affordable price points, making them suitable for applications requiring extensive storage space. SSDs, on the other hand, are more expensive at higher capacities. However, for the scope of the Dell OptiPlex 9020 upgrade, it is essential to weigh the trade-offs between capacity and performance improvements provided by SSDs.

- Bandwidth: In terms of supporting various computing tasks, SSDs deliver superior performance for booting, loading data, and launching applications. They provide enhanced multitasking capabilities due to their higher peak read/write performance. While HDDs can offer sufficient performance for a majority of PC platforms, the speed and responsiveness provided by SSDs make them a more suitable choice for the Dell OptiPlex 9020 upgrade.

Let's compare our results to external sources since SSD testing is well documented. Comparing our results with a Dell technical white paper (Kasavajhala, 2011). When considering typical random workloads, SSDs provide significant performance enhancements, eliminating concerns about write endurance or wear out. As applications become increasingly parallel, they can fully utilize the capabilities of SSDs, leading to further performance improvements.

The performance gains achieved with SSDs for random workloads more than justifies their additional cost. Consequently, the recommendation is to opt for SSDs for random I/O applications, particularly in conjunction with tiering software or in environments with a low write duty cycle (Paulsen, 2015). SSDs and HDDs exhibit substantial differences in their Input Output Operations Per Second (IOPS), a key performance metric. When an SSD configuration is compared to an HDD configuration with the same number of drives and total usable capacity, the IOPS of the SSD configuration can be nearly 80 times higher. This performance advantage makes SSDs particularly beneficial for devices that require high-speed data access.

However, the actual performance of an SSD can depend on its usage conditions, with enterprise-class SSDs designed to operate under full workload and steady state conditions 24/7. In terms of application, SSDs can significantly reduce response-time "spikes" in activities that generate high volumes of metadata read/writes, such as editing systems and high-volume database activities. However, for tasks involving the retrieval of large, contiguous files, the performance impact of using SSDs over HDDs may be relatively minor. This further justifies the swap in a large-scale lab environment.



	1 Machine	5 Machines	10 Machines	20 Machines	30 Machines	40 Machines
Single Clone	16	80	160	320	480	640
Samba + Clonezilla	17	19	21	49	67	98

Figure 1: Time vs instance cloning mechanisms observed.

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Figure 1 illustrates the above-mentioned point in the DRBL section, in the methodology section, the analysis of the data reveals the technical superiority of using Clonezilla on a DRBL Linux server in conjunction with a Samba Server for cloning multiple machines.

The 1 Gigabit network switch acts as the limiting factor, allowing for the successful cloning of approximately 8-9 computers before the network link becomes saturated. Beyond this threshold, additional instances experience time dilation as they wait in the network queue due to bandwidth constraints. The findings align with established networking principles, where congestion leads to delays in data packet transmission. The measured results substantiate earlier research and underscore the efficiency of a scaled cloning system over manual cloning.

Discussion

Cost-Benefit Analysis

To provide a more technical analysis of the cost-effectiveness of upgrading the Dell OptiPlex 9020 lab computers with 2.5" SATA SSDs, we will focus on the cost of SSDs vs. HDDs and the performance per dollar for both storage solutions.

1. Cost of SSDs vs. HDDs: Based on the updated pricing, a 1TB 2.5-inch HDD costs between $40 and $60, translating to a cost of $0.04 to $0.06 per gigabyte. Meanwhile, a 1TB 2.5-inch SSD costs between $50 and $80, resulting in a cost of $0.05 to $0.08 per gigabyte. While SSDs are still more expensive than HDDs, the price gap has narrowed significantly compared to earlier estimates.

2. The data transfer speeds and access times for SATA SSDs and HDDs are as follows:

SATA SSD:
- Data transfer speed: up to 600 MB/s
- Access time: 0.031 ms
- $80 option: 7,500 MB/s per dollar
- $50 option: 12,000 MB/s per dollar

HDD:
- Data transfer speed: 149.86 MB/s
- Access time: 15.785 ms.
- $60 option: 2,497 MB/s per dollar
- $40 option: 3,746.5 MB/s per dollar

As you can see here and the source mentioned at (BasuMallick, 2023), SSDs offer a higher performance per dollar than HDDs, regardless of the price point. This is because SSDs are much faster than HDDs. It is important to note that these are just estimates. The actual performance per dollar may vary depending on the specific models of SSDs and HDDs that you are comparing.

So, why traditional SATA SSD and not NVMe or PCIE SSD? SATA SSDs are chosen over PCIe SSDs (the latest SSD form factor) in some cases due to a few factors, especially when considering older Intel chips and motherboards that may not support PCIe SSDs.

1. **Compatibility**: Older Intel chips and motherboards may not support PCIe SSDs or M.2 slots, which are required to connect the latest SSD form factors. In such cases, SATA SSDs, which use the traditional SATA interface, are a more compatible choice.

2. **Cost**: SATA SSDs are generally more affordable than their PCIe counterparts, making them a more cost-effective option for users with budget constraints or those who don't require the highest performance levels.

3. **Ease of installation**: Installing a SATA SSD is relatively simple, as it connects to the existing SATA ports on the motherboard, similar to a traditional HDD. On the other hand, installing a PCIe SSD in a system without native M.2 slots would require additional PCIe to M.2 adapters, which may be more challenging for a newbie to handle.

4. **Sufficient performance**: Although PCIe SSDs offer faster read/write speeds compared to SATA SSDs, the performance difference may not be significant enough for users with modest storage requirements or those who primarily use their systems for basic tasks like web browsing, document editing, or media consumption. In these cases, a SATA SSD can still provide a noticeable performance improvement compared to an HDD, without the added complexity and cost of a PCIe SSD.

Conclusion

This paper examined the performance benefits and cost-effectiveness of upgrading the storage system of Dell OptiPlex 9020 computers from HDDs to SATA SSDs. The study also delved into the software deployment process, utilizing Clonezilla DRBL to clone the contents of the HDDs to the new SATA SSDs while minimizing downtime and preserving the lab ecosystem. Potential areas for further improvement and optimization include exploring alternative cloning and imaging software solutions, investigating the impact of different SSD models and capacities on performance, and assessing the feasibility of upgrading to more advanced storage technologies like PCIe SSDs in systems with compatible hardware.

Our key findings demonstrate that upgrading to SATA SSDs significantly improves the performance of the Dell OptiPlex 9020 computers. The read and write speeds increased substantially, and system responsiveness was noticeably enhanced. Moreover, the performance per dollar analysis revealed that SATA SSDs offer a justifiable cost-to-performance ratio compared to traditional HDDs.

The overall impact of the SSD upgrade and software deployment on the Dell OptiPlex 9020 computers is substantial. These improvements not only increase system performance but also streamline lab management, facilitate software deployment, and contribute to a more efficient and responsive user experience. For future research, it would be beneficial to explore the long-term effects of SSD upgrades on the reliability and lifespan of the Dell OptiPlex 9020 computers.

Additionally, evaluating the potential benefits of upgrading other system components, such as RAM or CPU, could provide valuable insights into the overall optimization of these machines. Some limitations of this study include the focus on SATA SSDs, which may not provide the highest possible performance levels compared to PCIe SSDs, and the reliance on a single imaging software solution (Clonezilla DRBL).

Further research could address these limitations by investigating alternative storage solutions and software deployment methods. In conclusion, our research demonstrates that upgrading the storage system of Dell OptiPlex 9020 computers from HDDs to SATA SSDs is a cost-effective and beneficial investment. This upgrade significantly improves system performance and simplifies lab management, providing an enhanced user experience and more efficient software deployment. Future research should continue to explore potential improvements and optimizations, keeping in mind the ever-evolving landscape of computer hardware and software.

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