White Paper

Samsung Solid-State Drive PM863

Optimized solid-state drives ideal for data center environments

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The enormous growth in data traffic is driving data centers to find ways to handle the volume

1. Executive summary

Today's data centers must serve requests from diverse applications and databases with numerous kinds of services, each requiring different performance needs. Therefore, IT managers want solid-state drives (SSDs) that are optimized to handle :

- **Mixed Workload Performance.** Deliver outstanding performance under mixed workloads typical of diverse data center applications that simultaneously access the same device
- **Read/Write Quality of Service (QoS).** Retain consistent IOPS performance under various heavy workloads

Designed to deliver optimal performance under data centers' varying workloads, the Samsung PM863 has been proven to display superior performance in a real data center environment. Based on a V-NAND TLC, the Samsung PM863 SSD outperforms 2D planar MLC SSDs in mixed workload performance and QoS.

The PM863 shows outstanding random read/write performance up to 99K/18K IOPS respectively with constant performance. In a comparison test under a 4 KB mixed workload, the PM863 shows more than a 90% IOPS read/write consistency, while the competitor products show fluctuations with an average ± 28% IOPS deviation.

The 960 GB PM863 SSD, with 0.8 Drive Writes Per Day (DWPD), is superior to the 0.35 DWPD 800 GB MLC SSD in a 4 KB random read/write QD32 mixed workload proportion of 75%/25%. It also shows a 45% higher mixed performance and superior read and write QoS at 99.99% by 36% and 72% repectively.

Moreover, the 960 GB PM863 SSD is superior to the 800 GB 3 DWPD in a 4 KB random read/write QD32 mixed workload proportation of 75%/25%. It is similar to the 800 GB 3 DWPD in mixed performance. However, it is superior to the 800 GB 3 DWPD in read and write QoS at 99.99% by 36% and 52% respectively. These results prove that the PM863 SSD is an economical and optimized solution for data center environments that outperforms the 2D planar MLC SSD, which shows relatively low performance and is expensive. Plus, the enhanced reliability features of the PM863 ensure uninterrupted operation regardless of power losses. Based on these findings, it is clear that the PM863 is the preferred choice for data center IT managers.

2. Industry trends

In recent years, there has been exponential growth in data center traffic, driven by businesses and consumers. Employees are more connected than ever before wherever their work takes them around the world. From emailing and texting to videoconferencing, workers have access to data from virtually anywhere. Likewise, consumer traffic on the Internet and the ubiquitous use of mobile devices has given rise to everything from online banking and purchasing to social networking and video on demand (VOD). To meet this demand, data centers must handle enormous volumes of data of various kinds 24/7, 365 days a year. Various types of data center SSDs have been released to address these demands. Typically, an SLC or MLC NAND flash is mounted on the SSD with manufacturer claims of high-performance and high-reliability, along with a high price tag. However, testing these SSDs has proven that they do not offer consistent and steady high-performance. Plus, they have some compatibility issues, revealing that they are not suitable for data center applications.

3. Introduction

Choose an SSD that provides consistent high performance and reliability

To improve this expensive and inefficient structure, Samsung Electronics has developed the V-NAND TLC-based PM863 SSD. It is generally believed that TLC NAND flash is slower and less stable than SLC and MLC NAND flash. However, the Samsung Vertical-NAND (V-NAND) TLC is quite different. Using superb solution technology, Samsung Electronics has proven that its TLC NAND flash easily performs as well as SLC/MLC NAND flash. The Samsung V-NAND TLC-based PM863 SSD demonstrates 20% higher mixed random read/write performance than the MLC-based data center SSD and 20 times better performance on latency (QoS). Considering that the MLC-based data center SSD has been evaluated as the most superior SSD in the market, these statistics are impressive. This white paper will prove through test data how the Samsung V-NAND TLC-based SSD is highly efficient compared with a competitor's MLC SSD in both mixed workload performance and read/write QoS. Tests were performed with various types of workloads in a real-life data center environment to compare the superior performance and Input/Output Per Second (IOPS) consistency of the Samsung PM863 SSD versus a competitor's MLC SSD. superior performance and Input/Output Per Second (IOPS) consistency of the Samsung PM863 SSD versus a competitor's MLC SSD.

4. About the Samsung PM863 SSD

The Samsung PM863 SSD has been optimized for data center use, boasting high-performance random read/write mixed workloads and always processing read/write Input/Output (IO) with a constant and equal response time. This benefit makes the PM863 an excellent choice for environments that must comply with a Service Level Agreement (SLA), such as cloud services. In addition, the PM863 is an economical and highly reliable solution to the TLC NAND flash because of its innovative V-NAND technology. The PM863 provides higher reliability than the 2D planar NAND flash as a result of its vertical structure, which virtually eliminates the interference between NAND flash cells. In addition, the improved error correction engine quickly detects errors that occur during SSD operation, recovers the user data and improves the reliability of the data stored in the NAND flash memory.

Powerful features protect valuable data and expensive servers

5. PM863 specifications

The maximum capacity of the PM863 has improved over four times that of the previous generation PM853T to almost 3,840 GB compared to 960 GB. Random read/write performance has also greatly improved. The 4 KB random read/write performance was 90 K IOPS/14 K IOPS maximum to the PM863 reaching up to 99 K IOPS/18 K IOPS.
In addition, the PM863 provides the following same powerful functions as the previous generation PM853T :

- **Power-loss Protection.** Protects from loss of data due to sudden power disconnections by using a tantalum capacitor build into the PM863 to safely and accurately copy and store user data written to the DRAM (the volatile memory in the SSD) to the NAND flash memory.
- **End-to-end Protection.** Safeguards user data in the PM863 along the entire data transfer path, from the host interface to the NAND flash memory, by duplicating the Cyclical Redundancy Check (CRC) and Error Check and Correct (ECC) at each section of the path to ensure accuracy and safety at all time.
- **Dynamic Thermal Throttling.** Monitors the temperature of the SSD automatically and, if the SSD rises above safe levels, it forcibly delay I/O processing until the temperature of the SSD drops to normal levels, ensuring the safe use of expensive servers.

	Samsung PM863
Form Factor	2.5"
Density	120 / 240 / 480 / 960 / 1,920 / 3,840 GB
Host Interface	Serial ATA Interface of 6 GB/s
Mean Time Between Failures (MTBF)	2,000,000 Hours
UBER	1 in 10^{17}
128 KB Sequential R/W (MB/s)	Up to 540 / 480 MB/s
4 KB Random R/W (IOPs)	Up to 99,000 / 18,000 IOPS
Advanced Error Correcting Code (ECC) Engine	Supported
Power-loss Protection	Supported
End-to-end Protection	Supported
Dynamic Thermal Throttling	Supported
Flash Cell Care Technology	Supported
Physical Dimensions	100.2 ± 0.25 x 69.85 ± 0.25 x 6.8 ± 0.2 mm (3.94 ± 0.01 x 2.75 ± 0.01 x 0.27 ± 0.01 in.)
Power Consumption	Active Read[1]/Write[2]: Up to 3.0 Watt/4.0 Watt
Temperature (Operating)	0° - 70°C (32° - 158°F)
Weight	Up to 65 g (2.29 oz)

Table 1. PM863 Specifications

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PM863 technology is compared to 2D planar MLC NAND flash memory products

6.Mixed workload performance and read/write QoS

1) Performance comparison targets and the performance measurement environment

The system configuration used to measure the performance of the 960 GB and 800 GB* PM863 included basic sequential, mixed random read/write performance and QoS and was compared with two products that use the 2D planar MLC NAND flash memory. Product one is a 0.35 DWPD 800 GB SSD (hereafter referred to as MLC SSD-A). Product two is a 3 DWPD 800 GB SSD (hereafter referred to as MLC SSD-B). Like the PM863, the MLC SSD-A is designed for read-intensive workloads and uses a 25 nm MLC NAND flash. The MLC SSD-B is designed for mixed read/write usage, such as an Online Transaction Processing (OLTP) environment and uses a 20 nm MLC NAND flash. The MLC SSD-B provides a larger over provisioning (OP) ratio than the MLC SSD-A and therefore, provides a higher random write performance than the MLC SSD-A.

It's important to note that all performance items mentioned in this white paper have been measured at the sustained state, except the sequential read/write performance. The sustained state in this document refers to the status that a 128 KB sequential write has been completed equal to the drive capacity and the 4 KB random write has completed twice as much as the drive capacity.

It's important to note that all performance items mentioned in this white paper have been measured at the sustained state, except the sequential read/write performance. The sustained state in this document refers to the status that a 128 KB sequential write has been completed equal to the drive capacity and then 4 KB random write has completed twice as much as the drive capacity.

The performance measurement environment is as follows :

Processor	Intel® Core™ i7-4790 @3.60 GHz
Memory	8 GB DDR3-1600
Motherboard	ASRock® Z97 Extreme6
SATA Mode	Advanced Host Controller Interface (AHCI)
Operating System	Ubuntu® 2.04 (Linux® Kernel 3.2.0)
Test Suite and Workloads	Tool: Fio® 2.1.2, Aerospike® Certification Tool (ACT)
SSD Precondition	Sustained state (or steady state)
Target SSD	PM863 960 GB SSD, PM863 800 GB SSD (intentionally reduced capacity by ATA command) Competitor 800 GB MLC SSD–A (0.35 DWPD), Competitor 800 GB MLC SSD–B (3 DWPD)

Table 2. Performance Measurement Environment

* There is officially no 800 GB PM863 in existence. Samsung reduced the size of the 960 GB PM863 for test purposes only to conduct fair comparisons with two other 800 GB competitive products on the market.

The V-NAND TLC-based PM863 shows greater performance over the MLC NAND-based SSDs

2) Sequential and random read/write performance

First, the basic performance of the 960 GB PM863 was compared with the performance of the MLC-based SSD. Compared with the MLC SSD-A, the sequential read performance of the 960 GB PM863 is 13% higher and the sequential write performance is 5% higher, as illustrated in Figure 1.

Figure 1. Basic Performance Comparison

Actually, the sustained random read/write performance is more important than the sequential performance. When comparing the three products for the 4 KB random read/write performance, the 960 GB PM863 shows 31% higher performance than the MLC SSD-A and for the 4 KB random read performance, the 960 GB PM863 shows 50% higher write performance. In the case of the 8 KB random read/write performance, the 960 GB PM863 shows 12% and 50% higher performance than the MLC SSD-A, respectively.

We also compared the 800 GB MLC SSD-B with the 800 GB PM863. Generally, the default capacity of the PM863 is 960 GB. However, in this test, we reduced the PM863 capacity to 800 GB for a performance comparison using the same conditions.

As shown in Figure 1, when comparing the 800 GB PM863 SSD with the 800 GB MLC SSD-B, the 800 GB PM863 SSD shows less sequential read/write performance by 1% and 2% than the MLC SSD-B. However, for the 4 KB random read/write performance, the 800 GB PM863 SSD shows 14% higher 4 KB random read performance and 31% higher 4 KB random write performance than the MLC SSD-B. This result is the same as the 8 KB random read/write conditions. The 800 GB PM863 SSD shows 9% higher 8 KB random read performance and 33% higher 8 KB random write performance than the MLC SSD-B.

When considering that most workloads in the data center are random patterns, you can see that the V-NAND TLC-based PM863 shows greater performance than the MLC NAND-based products, even when comparing only the basic performance.

More requests are performed in less time with the PM863 compared with the other products

3) Latency QoS

In addition to the sequential and random read/write performance, we need to compare the latency of the SSD. The term latency is similar to the I/O response time. The sequential or random read/write performance shows how may I/Os can be processed within a unit of time. The latency shows how quickly the host read/write I/O can be processed and completed. A short latency indicates that the SSD can operate quickly. As shown in Table 3, it takes about 116 us for the MLC SSD to process one 4 KB random read request. But it takes about 106 us for the PM863 SSD to process one request, showing about a 9% shorter latency than the competitor's product. For 4 KB random write latency, the MLC SSD-B takes about 37 us but the 800 GB PM863 takes about 24 us, showing a 35% faster response time than the MLC SSD-B.

The most remarkable part of the data is that the average latency is the response time for a 4 KB random read/write Queue Depth (QD)1. QD1 means that the host provides one read or write request to the SSD, and then provides the next request to the SSD after the first request has been completed. Therefore, we can indirectly know how much the internal path of the SSD, from the controller firmware to the NAND, is optimized for processing one request by comparing the latency with the QD1 condition. In other words, the faster the processing of one host request, for example a QD1 request, the more the SSD's internal data path is optimized and the better it can perform under intensive workloads QD2. Through the result shown in Table 3, we can see that the Samsung PM863 has lower latency compared to the MLC SSD-A and MLC SSD-B, proving that the data I/O processing path of the PM863 is more optimized than both MLC SSDs. Thus, the PM863 can process the host requests faster than the competitor products under intensive I/O environments.

	MLC SSD	
	MLC SSD-A (800 GB)	MLC SSD-B (800 GB)
4 KB Random Read @ QD1 (us)	116	116
4 KB Random Write @ QD1 (us)	74	37
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	PM863 (960 GB)	PM863 (800 GB)
4 KB Random Read @ QD1 (us)	106	106
4 KB Random Write @ QD1 (us)	52	24

Table 3. 4 KB Random Read/Write Latency Comparison

Figure 2 shows the latency QoS of a 100% 4 KB random read/write workload. As mentioned earlier in this white paper, Figure 2 shows that the latency QoS of the PM863 is significantly better than that of the MLC SSD. For example, with a 4 KB random read QD1, the latency QoS of the MLC SSD-A is 2.2 msec at QoS 99.9%. However, the latency QoS of the 960 GB PM863 is 0.1 msec, which is more than 20 times faster than the MLC SSD-A. The results are similar at 4 KB random read QD32. The latency QoS of the MLC SSD-A is 2.4 msec at QoS 99.9%, but the 960 GB PM863 is 0.5 msec, 4.8 times faster than the MLC SSD-A.

The left graph in Figure 2 measures the latency QoS at 99.9%, while the right graph in Figure 2 measures the latency QoS at 99.99%. For a 4 KB random write request, the PM863 shows that its performance is much higher than the MLC SSD-B. With a 4 KB random write QD32, the latency QoS of the 800 GB MLC SSD-B

is 9.9 msec. However, the 800 GB PM863 is just 3.2 msec, which is 3 times faster than the MLC SSD-B. These results conclude that the Samsung PM863 performs more requests in less time compared to the other products.

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In head-to-head tests, the PM863 demonstrated higher performance and lower latency QoS when compared with the MLC SSD

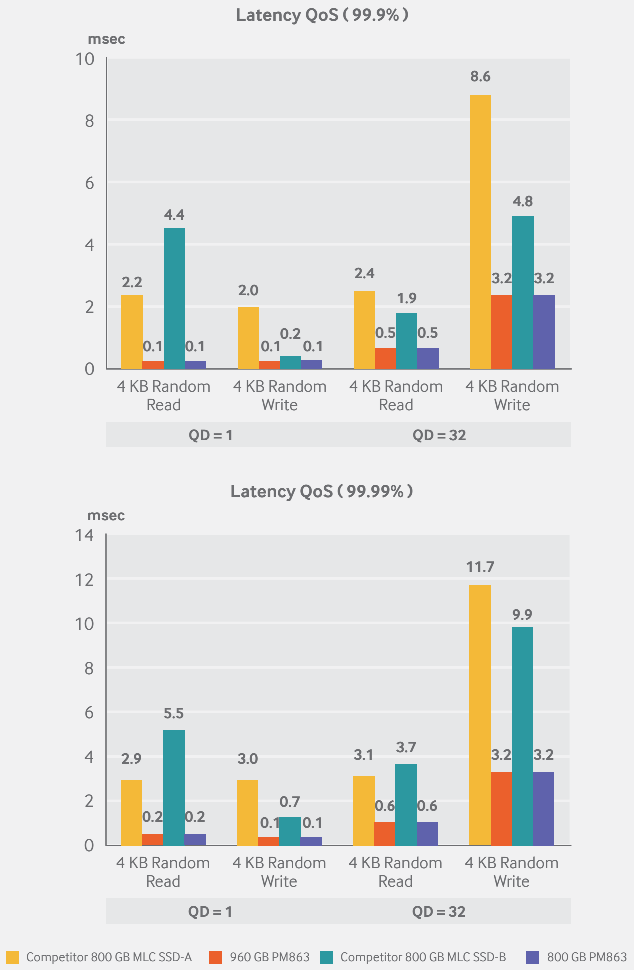

Figure 2. Latency QoS Comparison

In fact, Figure 2 above implies many more meanings. Since we know that the latency with 99.99% QoS denotes how many seconds are required to complete 9,999 commands among 10,000 requests, when 10,000 requests are provided to the SSD, the MLC SSD-B processes 9,999 write requests within 9.9 msec and the PM863 processes 9,999 write requests within 3.2 msec. Therefore, when many billions of random I/Os are provided to the SSD in a real data center, the PM863 can process more requests within a shorter time than the MLC SSD.

With a simple comparison of basic performance and QoS, we can see that the V-NAND TLC-based PM863 SSD is a more suitable product for data centers than the MLC SSDs as it provides higher performance and QoS quality. Moreover, in this white paper, we would like to emphasize that the PM863 SSD is far better than the MLC SSDs for various workloads provided in a real data center. Next, we will describe the performance of the PM863 measured from the user experience (UX) perspective by showing that the PM863 can provide superior performance and maintain constant performance with a mixed workload, and how its performance will change when intense I/O stress is put on the SSD for more than 24 hours.

In a typical 70:30 read/write scenario, the 960 GB PM863 is a more economical option

7. Criteria for choosing the best data center SSD

Enhance the user experience with the superior performance of the PM863

In a real data center, SSD applications can be infinite, ranging from video streaming service to cloud service, OLTP, messaging service and virtual desktop infrastructure (VDI). It may be very difficult to measure how much superior performance will be provided by SSDs for the various services. As the services are provided to users, the workload given to the SSD is not a simple sequential I/O, pure 100% random read or 100% random write workload, but a mixture of random read and write workload.

Therefore, we can determine whether the SSD can provide high performance with a small deviation in real data center services by observing the performance indices shown in the mixed workload environment. Here, we will compare the V-NAND TLC-based PM863 with the 2D planar MLC-based SSDs by using the mixed workload to discuss the performance that users will experience in a real environment and determine which product is more suitable for the data center.

1) Top-notch mixed performance using Samsung V-NAND technology

As mentioned before, the workload in a real data center has a mixed pattern. Therefore, in this test, we measured and compared the performance at the sustained state when the 4 KB random read/write I/Os are mixed in a certain proportion.

From Figure 3 above, we can make some interesting conjectures. First, from the right graph, we can see that the V-NAND TLC-based PM863 is far better than the 2D planar MLC SSD. When the 4 KB random read/write I/Os are mixed in the proportion of 70:30, the MLC SSD-A shows about 25 K IOPS random read performance. However, our 960 GB PM863 shows about 36 K IOPS, which is 45% higher performance than the MLC SSD-A. This trend is the same for the 4 KB random write performance. When mixed in the proportion of a 70:30 ratio, the performance of MLC SSD-A is only about 11 K IOPS; however, the performance of 960 GB PM863 is 16 K IOPS, which is 45% higher than the MLC SSD-A.

In the same way, we compared the MLC SSD-B with the 800 GB PM863. The results show that the 4 KB random read performance of the MLC SSD-B is just 36 K IOPS, but the performance of the 800 GB PM863 is almost 52 K IOPS, which is 44% higher than the MLC SSD-B. For the 4 KB random write performance, the MLC SSD-B shows only 16 K IOPS but the 800 GB PM863 shows 22 K IOPS, which is 38% higher than the MLC SSD-B.

Interestingly, from the left graph, we can see the 100% 4 KB random read/write performance. That graph shows that the 800 GB MLC SSD-B (in green) has a higher 4 KB random write performance than our 960 GB PM863 (in red). However, when the read/write requests are mixed in the proportion of a 70:30 ratio, the 4 KB random read/write mixed performance of the two products is identical, as shown in the right graph in Figure 3. This means that the 960 GB PM863 shows almost the same performance as the 800 GB MLC SSD-B for the mixed pattern in which the read requests are much more than the write requests, even if the 4 KB random write performance of the 960 GB PM863 is a little bit lower than the 800 GB MLC SSD-B because the 960 GB PM863 provides a higher 4 KB random read performance than the competitors' products. The MLC SSD-B targets 3 DWPD and is known as a suitable product for the environment, in which write requests account for 30% of the total requests. As you can see in the right graph in Figure 3, the 800 GB PM863 has 52+22=74 K IOPS in the read/write proportion of the 70:30 ratio. However, the 800 GB MLC SSD-B shows only 52 K IOPS under the same condition. Moreover, considering that the performance of the 8 KB request is very important in the database environment, the 800 GB PM863 has 30+13= 43 K IOPS in the read/write proportion of the 70:30 ratio, while the 800 GB MLC SSD-B has only 30 K IOPS. Therefore, in the read/write 70:30 ratio scenario, it can be more profitable to choose the 960 GB PM863 rather than the expensive MLC SSD-B for reducing total cost of ownership (TCO).

Figure 3. Mixed Performance Comparison

With nearly a 50% higher mixed performance, the 960 GB PM863 is a better data center choice

This time, we compared the mixed performance by adjusting the write proportion. With the default request size of 4 KB, we set the write proportion to 0% (in other words, read 100%), 25%, 50%, 75% and 100% and then compared the read/write performance for each case. The following tables show the comparison of the MLC SSD-A with the 960 GB PM863.

Read Performance (960 GB PM863 vs. 800 GB MLC SSD-A)						
Read%	**QD1**	**QD2**	**QD4**	**QD8**	**QD16**	**QD32**
25%	+18%	+18%	+30%	+40%	+45%	+46%
50%	+14%	+11%	+11%	+26%	+38%	+47%
75%	0%	+8%	+8%	+13%	+21%	+45%
100%	+6%	+5%	+5%	+11%	+29%	+29%

Write Performance (960 GB PM863 vs. 800 GB MLC SSD-A)						
Write%	**QD1**	**QD2**	**QD4**	**QD8**	**QD16**	**QD32**
25%	0%	+8%	+8%	+13%	+21%	+45%
50%	+14%	+11%	+11%	+26%	+38%	+46%
75%	+18%	+18%	+30%	+40%	+45%	+46%
100%	+39%	+43%	+46%	+47%	+47%	+47%

Table 4. 4 KB Mixed Random Read/Write Peformance of the MLC SSD-A and the 960 GB PM863

As shown in Table 4, the 960 GB PM863 shows higher performance than the 800 GB MLC SSD-A in all 4 KB mixed patterns. The 960 GB PM863 shows up to a 47% higher mixed performance, which proves that its design is more suitable for the data center environment.

In addition, we compared the mixed performance of the 800 GB PM863 with that of the 800 GB MLC SSD-B. As described before, the 800 GB MLC SSD-B targets mixed usage. The following tables show the performance comparison.

Read Performance (800 GB PM863 vs. 800 GB MLC SSD-B)						
Read%	**QD1**	**QD2**	**QD4**	**QD8**	**QD16**	**QD32**
25%	+24%	+27%	+32%	+49%	+43%	+41%
50%	+16%	+21%	+24%	+31%	+44%	+59%
75%	+1%	+10%	+16%	+21%	+26%	+37%
100%	+7%	-6%	-3%	+3%	+21%	+12%

Write Performance (800 GB PM863 vs. 800 GB MLC SSD-B)						
Write%	**QD1**	**QD2**	**QD4**	**QD8**	**QD16**	**QD32**
25%	+1%	+9%	+17%	+21%	+26%	+37%
50%	+16%	+21%	+25%	+31%	+44%	+59%
75%	+24%	+27%	+32%	+49%	+43%	+41%
100%	+51%	+33%	+34%	+34%	+33%	+34%

Table 5. 4 KB Mixed Random Read/Write Performance of the MLC SSD-B and the 800 GB PM863

Table 5 shows a higher performance for 800 GB PM863 than the 800 GB MLC SSD-B in most of the 4 KB mixed patterns. When defining the margin of measurement error as ±5%, we can see that the mixed performance of the 800 GB PM863 is higher than that of MLC SSD-B in most of the read/write combinations, up to 59%. As shown above, it can be more efficient to choose the V-NAND TLC-based 960 GB PM863 rather than the expensive MLC SSDs and tailor the 960 GB PM863 according to the performance requirements.

The 960 GB PM863 shows superior read latency QoS of up to 47% and write latency of up 95%

2) Superior QoS to fulfill SLA

One of the most important performance indices that the SSD should have is QoS. Basically, QoS indicates the consistency of the SSD's performance under heavy workloads at a guaranteed minimum performance level. Like the cloud service, when a lot of users concurrently access the server, the server is required to provide a certain level of throughput or process the user I/Os within a specified time. For paid cloud service, the SLA fee is contracted between the cloud service provider and a user, and the cloud service provider should guarantee the throughput and latency based on the contracted SLA. To meet market requirements, data center SSD manufacturers must show IOPS results that reflect consistent throughput and latency QoS to indicate how much time is required to process the read/write I/O.

This section will prove that the PM863 SSD is more optimized for the data center environment than the MLC-based SSDs by comparing the IOPS consistency and latency QoS of each.

Under the assumption that the workload of the data center is random read/write mixed workloads, we carried out the following test. By adjusting the write proportion, we tested the difference of latency QoS of the PM863 and the MLC-based SSDs for a 4 KB random read/write mixed workload.

As shown in Table 6, for the 4 KB random read/write mixed workload, the 960 GB PM863 SSD shows up to 47% superior performance over the MLC SSD-A in read latency QoS. For the write latency QoS, the 960 GB PM863 SSD shows up to 95% superior latency QoS at the low QD and up to 70% superior latency QoS at the high QD.

Read Latency QoS (99.99%) (960 GB PM863 vs. 800 GB MLC SSD-A)						
Read%	**QD1**	**QD2**	**QD4**	**QD8**	**QD16**	**QD32**
25%	+23%	+27%	+35%	+46%	+47%	+38%
50%	+11%	+18%	+25%	+31%	+38%	+37%
75%	-7%	+4%	+13%	+22%	+26%	+36%
100%	+94%	+93%	+91%	+88%	+84%	+77%

Write Latency QoS (99.99%) (960 GB PM863 vs. 800 GB MLC SSD-A)						
Write%	**QD1**	**QD2**	**QD4**	**QD8**	**QD16**	**QD32**
25%	+94%	+91%	+88%	+90%	+90%	+72%
50%	+94%	+91%	+93%	+93%	+83%	+75%
75%	+94%	+95%	+80%	+88%	+82%	+72%
100%	+96%	+95%	+94%	+90%	+83%	+72%

Table 6. 4 KB Mixed Random Read/Write Latency QoS of the MLC SSD-A and the 960 GB PM863

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In the read/write workload scenario, the 800 GB PM863 basically shows superior latency QoS

We compared the 800 GB PM863 SSD with the MLC SSD-B, which basically assumes the read/write mixed workload scenario. In most cases, as shown in Table 7, the 800 GB PM863 shows superior latency QoS compared with the MLC SSD-B. Generally, considering that the 3 DWPD products define the read/write proportion as 70%/30% or 75%/25%, the Samsung 800 GB PM863 shows an almost similar read latency QoS at QD1 with a read/write proportion of 75%/25%. However, as the QD gets larger, the difference of latency QoS gets larger: the read latency QoS is shortened by up to 39%, and the write latency QoS is shortened by up to 88% with a read/write proportion of 75%/25%.

Read Latency QoS (99.99%) (800 GB PM863 vs. 800 GB MLC SSD-B)						
Read%	QD1	QD2	QD4	QD8	QD16	QD32
25%	+34%	+38%	+41%	+50%	+54%	+55%
50%	+28%	+33%	+36%	+38%	+47%	+51%
75%	+4%	+13%	+32%	+34%	+36%	+39%
100%	+97%	-16%	+95%	+93%	+91%	+26%

Write Latency QoS (99.99%) (800 GB PM863 vs. 800 GB MLC SSD-B)						
Write%	QD1	QD2	QD4	QD8	QD16	QD32
25%	+80%	+88%	+86%	+86%	+86%	+58%
50%	+92%	+89%	+89%	+71%	+65%	+67%
75%	+92%	+91%	+49%	+71%	+75%	+65%
100%	+79%	+92%	+90%	+85%	+78%	+67%

Table 7. 4 KB Mixed Random Read/Write Latency QoS of the MLC SSD-B and the 800 GB PM863

Therefore, if a user focuses on only the latency QoS, the user does not need to reduce the capacity of the PM863 to 800 GB. As shown in Table 8, in most cases, the 960 GB PM863 SSD shows superior latency QoS when compared with the MLC SSD-B. When a user is planning a service which considers the latency QoS as more important than the sustained random write performance, it is better to use the PM863 capacity as 960 GB, without reducing to 800 GB, and use more user space with improved latency QoS.

Read Latency QoS (99.99%) (960 GB PM863 vs. 800 GB MLC SSD-B)						
Read%	QD1	QD2	QD4	QD8	QD16	QD32
25%	+31%	+34%	+39%	+48%	+49%	+47%
50%	+18%	+29%	+32%	+35%	+43%	+45%
75%	-4%	+5%	+26%	+30%	+33%	+36%
100%	+97%	-16%	+95%	+93%	+91%	+28%

Write Latency QoS (99.99%) (960 GB PM863 vs. 800 GB MLC SSD-B)						
Write%	QD1	QD2	QD4	QD8	QD16	QD32
25%	+82%	+88%	+87%	+86%	+87%	+52%
50%	+92%	+90%	+89%	+75%	+56%	+62%
75%	+93%	+91%	+32%	+67%	+73%	+63%
100%	+79%	+92%	+91%	+85%	+78%	+67%

Table 8. 4 KB Mixed Random Read/Write Latency QoS of the MLC SSD-B and the 960 GB PM863

Through the data above, we can see that the V-NAND TLC-based PM863 SSD is more suitable for the data center environment in most cases than the MLC SSD. However, even if the latency is superior at the 99.99% QoS, an abnormally large maximum latency may be a critical weak point for the data center environment. Therefore, we compared the maximum latency with the 4 KB random read/write mixed workload.

Optimal maximum latency is achieved with an advanced error correction engine and fair resource allocation

3) Superb management for maximum latency

As shown in Table 9 below, we can see that the maximum latency of the PM863 is shorter than that of the MLC SSD. For example, when comparing the maximum read latency of the 960 GB PM863 and the MLC SSD-A, the maximum read latency of the 960 GB PM863 is more efficient, about 50% on average, than that of MLC SSD-A. And when comparing the maximum read latency of the 800 GB PM863 and the MLC SSD-B, the maximum read latency of the 800 GB PM863 is more efficient, about 60% on average, than that of MLC SSD-B. Remember, the maximum latency is the worst latency in the worst situation. Generally, the user data written in the NAND flash can be distorted because of its physical characteristics. To prevent this, the SSD developers introduce special flash cell algorithms and the error correction engine. In addition, the PM863 blocks any bounce of maximum latency by fairly allocating resources while processing user I/Os. The fact that the maximum latency of the PM863 is superior to other SSDs indirectly proves that it provides higher performance than others in the worst situation. Plus, the Samsung advanced error correction engine and cell care algorithms, optimized for the V-NAND TLC NAND flash, are more advanced than the error correction technologies applied to the 2D planar MLC SSDs.

Maximum Read Latency (960 GB PM863 vs. 800 GB MLC SSD-A)						
Read%	QD1	QD2	QD4	QD8	QD16	QD32
25%	+29%	+47%	+54%	+59%	+86%	+48%
50%	+48%	+42%	+45%	+56%	+58%	+49%
75%	+43%	+43%	+43%	+46%	+42%	+37%
100%	+82%	+73%	+86%	+91%	+90%	+86%

Maximum Write Latency (960 GB PM863 vs. 800 GB MLC SSD-A)						
Write%	QD1	QD2	QD4	QD8	QD16	QD32
25%	+93%	-72%	+93%	+96%	+87%	+82%
50%	+65%	+24%	+97%	+93%	+83%	+81%
75%	+96%	+78%	+96%	+93%	+92%	+68%
100%	+97%	+69%	+95%	+91%	+80%	+80%

Maximum Read Latency (800 GB PM863 vs. 800 GB MLC SSD-B)						
Read%	QD1	QD2	QD4	QD8	QD16	QD32
25%	+53%	+56%	+68%	+69%	+71%	+63%
50%	+50%	+47%	+54%	+61%	+70%	+57%
75%	+26%	+46%	+59%	+58%	+54%	+51%
100%	+88%	+87%	+94%	+75%	+88%	+72%

Maximum Write Latency (800 GB PM863 vs. 800 GB MLC SSD-B)						
Write%	QD1	QD2	QD4	QD8	QD16	QD32
25%	+94%	+91%	+95%	+49%	+75%	+80%
50%	+93%	+89%	+97%	+78%	+89%	+80%
75%	+50%	+94%	+97%	+83%	+88%	+77%
100%	+99%	+98%	+97%	+88%	+88%	+79%

Table 9. Comparison of the Maximum Latency of the PM863 and the MLC SSDs

The PM863 shows excellent IOPS consistency in the 100% random read/write condition

4) Solid mixed performance for stable IOPS consistency

In addition to the latency QoS, the IOPS consistency is an important performance index in the data center environment. If the latency QoS indicates how long it takes to process a specific read/write I/O, the IOPS consistency indicates how consistently the SSD performance can be kept. Some SSDs shows high peak performance, but have a large deviation in performance after the SSDs are entered in the sustained state, so they are not suitable for the data center environment. High IOPS consistency indicates that the SSD can provide consistent and constant performance to users. For easy comparison, the IOPS consistency for a 100% 4 KB random read workload and 100% 4 KB random write workload are compared. We measured how long the SSD performance can be kept under the pure 100% random read and 100% random write conditions, not the mixed workload.

As shown in Figure 4 on the next page, under the 100% random read/write condition, the 960 GB PM863, the 800 GB PM863, and the MLC SSD show excellent IOPS consistency. For example, when comparing the 960 GB PM863 with the MLC SSD-A, the average 4 KB random read performance of the 960 GB PM863 is 98 K IOPS and the standard deviation is 10. In other words, the 960 GB PM863 processes the 4 KB random read request at the speed of 98 K IOPS, and the deviation of 4 KB random read IOPS between high IOPS and low IOPS is just 10 IOPS. Under the same condition, the average 4 KB random read performance of the MLC SSD-A is 76 K IOPS and the standard deviation is 632. For the 4 KB random write workload, the performance of the 960 GB PM863 is on average 18 K IOPS and the standard deviation is 282, providing the higher performance in a constant way. Finally, the 960 GB PM863 can provide higher random read performance with lower deviation than the MLC SSD-A.

We measured the IOPS consistency of the MLC SSD-B, too. As shown in the right graph of Figure 4, the 4 KB random read performance of the MLC SSD-B is 87 K IOPS and its standard deviation is 54, and the 800 GB PM863 average is 98 K IOPS. Therefore, the 800 GB PM863 can provide higher random read performance than the competitor's product. For the 4 KB random write, the performance of the 800 GB PM863 averages 39 K IOPS, which is 34% higher than the MLC SSD-B, and it can process random write constantly.

Random read/write mixed pattern performance of the PM863 exceeds that of the competitors

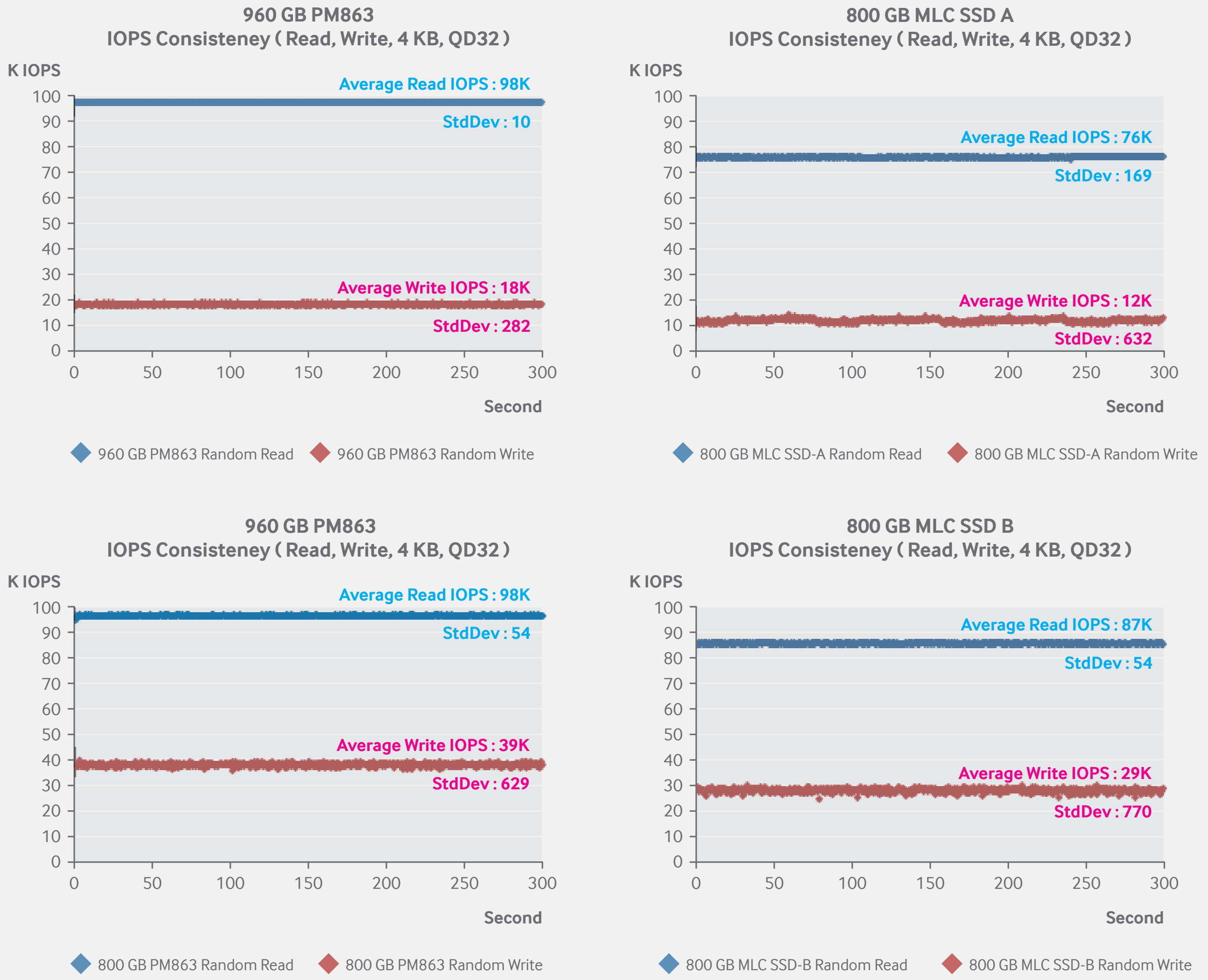


Figure 4. IOPS Consistency of 100% 4 KB Random Read and 100% 4 KB Random Write

However, the more important workload at the data center is the 4 KB random read/write mixed pattern. Therefore, we compared the IOPS consistency for the read/write mixed pattern, the most popular data center workload. Under a 70% read / 30% write condition, the average IOPS and the standard deviation of the 4 KB random read/write mixed I/O is shown in Figure 5 on the next page. As illustrated in Figure 5, the average 4 KB random read performance of the 960 GB PM863 is superior to the MLC SSD-A by 10 K IOPS, and the average 4 KB random write performance of the 960 GB PM863 is superior to the MLC SSD-A by 5 K IOPS. Likewise, the 960 GB PM863 provides higher performance and constantly maintains performance. Figure 5 also shows that the standard deviation of read IOPS of the 960 GB PM863 is 450. However, the standard deviation of read IOPS of the MLC SSD-A is 1,594. This means that the performance of about 1.5 K IOPS may be measured higher or lower. For the write IOPS, the standard deviation of the PM863 is lower than that of the MLC SSD-A, concluding that the V-NAND TLC-based 960 GB PM863 is more stable than the MLC SSD-A, and delivers higher performance.

When optimized for mixed use, the PM863 outperforms the MLC-based SSDs in consistency

This trend is observed when comparing the 800 GB PM863 SSD with the MLC SSD-B, also. For 4 KB random read IOPS, the 800 GB PM863 SSD shows an average 52 K IOPS and a standard deviation of 196. However, the MLC SSD-B shows an average 36 K IOPS and a standard deviation of 1,303, showing lower performance and less standard deviation than the 800 GB PM863. Finally, this result indicates that the 800 GB PM863 SSD provides consistently higher performance than the MLC-based competitors' products when optimized for mixed usage. This is the same for the 4 KB random write performance. The 800 GB PM863 shows an average 22 K IOPS and a standard deviation of 196, but the MLC SSD-B shows an average 16 K IOPS and a standard deviation of 561, which is a lower performance level and greater standard deviation than Samsung PM863 800 GB SSD.

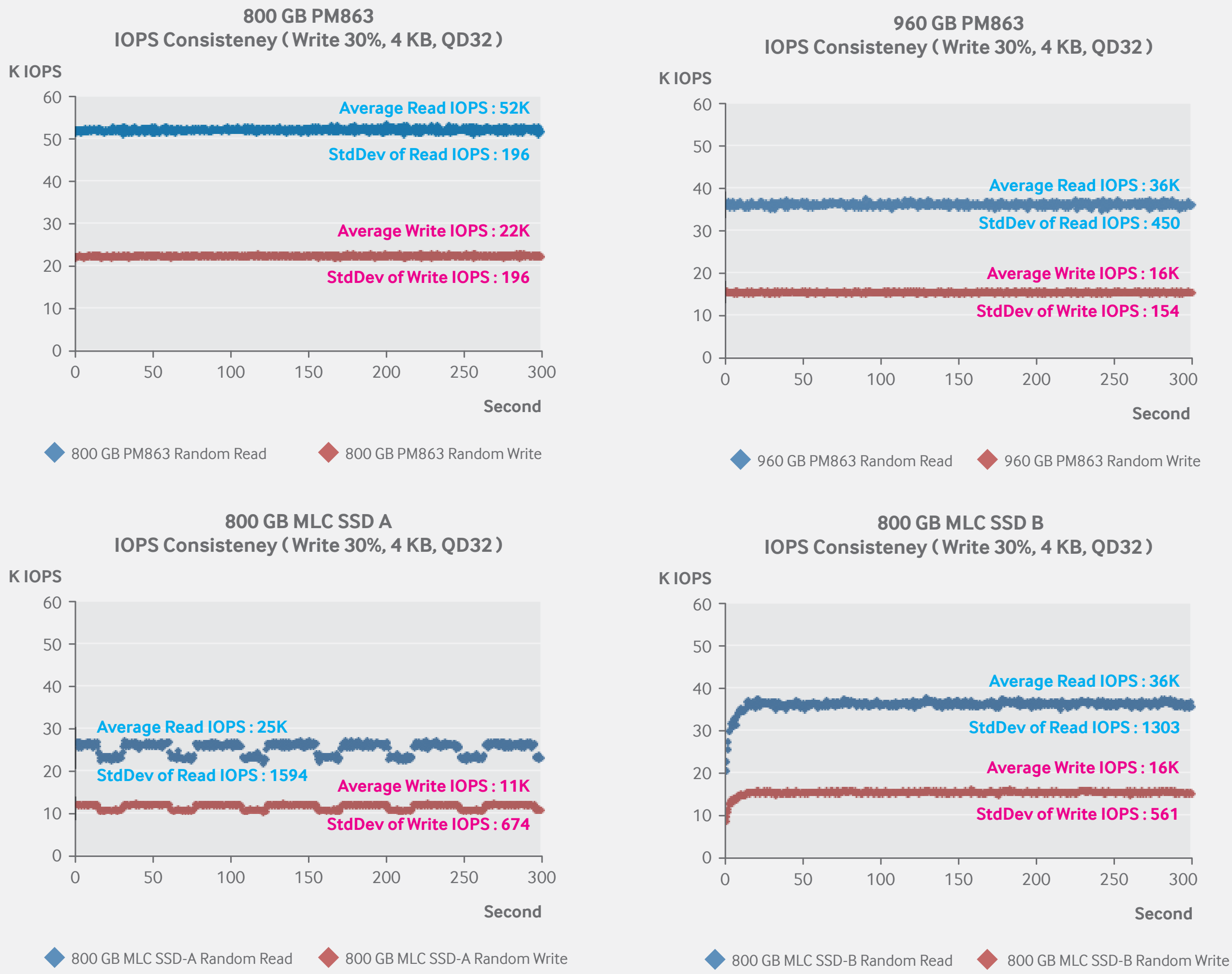


Figure 5. IOPS QoS with Mixed Workloads

The PM863 is designed to serve a constantly greater improved mixed workload performance

When comparing Figure 4 with Figure 5, an interesting fact can be observed. Figure 4 represents the IOPS consistency for the pure 100% random read/write. In Figure 4, the standard deviation of the 4 KB random read of the 960 GB PM863 is 10 and 54 for the 800 GB PM863. But the value increases to 450 and 196 respectively at the mixed workload in Figure 5. In the mixed pattern, the IOPS of the 960 GB PM863 is increased by 440 IOPS and the IOPS of the 800 GB PM863 is increased by 142 IOPS. In comparison, the standard deviation of the MLC SSD-A in the mixed pattern is increased from 169 to 1,594, as much as about 1.4 K IOPS, and that of the MLC SSD-B is increased from 54 to 1303, as much as about 1.2 K IOPS. From this result, we can see that the PM863 SSD is designed to serve a constantly greater improved performance for the mixed workload than the competitors' products.

Based on this result, we measured the IOPS consistency of the Samsung PM863 SSD and the MLC SSD when the write proportion is changed at the mixed workload. Generally, the IOPS consistency is calculated using the following formula:

IOPS Consistency = ([IOPS in the 99.9th percentile] ÷ [Average IOPS]) × 100*

By analyzing the above formula, we can see that the IOPS consistency value gets larger when the IOPS in the 99.9th percentile is near the average IOPS. In other words, even when there is a deviation in the IOPS, high IOPS consistency indicates that the deviation is small and the performance is constant. Table 10, on the next page, shows the IOPS consistency of the 960 GB PM863 SSD and the MLC SSD-A. In a real data center environment, we assume the 4 KB random read/write mixed workload and calculate the read/write IOPS consistency according to the write proportion. As shown in Table 10, the 960 GB PM863 shows more than a 90% IOPS consistency for both read and write. However, under the write proportion of 25%, the MLC SSD-A shows a read IOPS consistency of 73.9% and write IOPS consistency of 72.5%, indicating that the MLC SSD-A is not suitable for a data center environment where consistent and constant performance is essential. Finally, Samsung PM863 can provide the performance of an average IOPS ± 10% to users consistently. However, the MLC SSD-A can provide the performance of an average IOPS ± 28%. This means that the 960 GB PM863 is the right choice for a data center environment.

* IOPS consistency in the 99.9th percentile is crucial for cloud data center environments, such as Amazon Web Services™ (AWS).

See: https://aws.amazon.com/ebs/faqs/

IOPS consistency comparisons of the 960 GB PM863 and the MLC SSD-A

Read IOPS Consistency (4 KB Random R/W Mixed Workload)			
	Write Ratio	MLC SSD-A (800 GB)	PM863 (960 GB)
QD1	0%	97.0%	99.4%
	25%	73.9%	96.3%
	50%	88.4%	93.9%
	75%	79.5%	91.5%
QD2	0%	96.3%	99.3%
	25%	87.7%	95.9%
	50%	87.6%	93.1%
	75%	80.8%	92.2%
QD4	0%	96.3%	99.5%
	25%	87.6%	95.5%
	50%	84.1%	90.9%
	75%	92.8%	94.9%
QD8	0%	97.4%	99.7%
	25%	88.5%	94.9%
	50%	85.4%	94.4%
	75%	81.9%	93.1%
QD16	0%	98.2%	98.7%
	25%	84.5%	95.9%
	50%	84.3%	94.2%
	75%	86.2%	92.7%
QD32	0%	98.8%	100.0%
	25%	96.8%	94.7%
	50%	88.3%	93.5%
	75%	86.0%	92.6%

Write IOPS Consistency (4 KB Random R/W Mixed Workload)			
	Write Ratio	MLC SSD-A (800 GB)	PM863 (960 GB)
QD1	25%	72.5%	91.7%
	50%	86.6%	93.7%
	75%	77.8%	94.1%
	100%	83.4%	94.6%
QD2	25%	83.4%	94.5%
	50%	86.8%	94.3%
	75%	82.4%	93.0%
	100%	85.4%	94.8%
QD4	25%	85.2%	95.1%
	50%	84.7%	94.7%
	75%	90.2%	95.0%
	100%	87.9%	94.7%
QD8	25%	88.9%	94.7%
	50%	86.4%	95.2%
	75%	82.1%	94.5%
	100%	87.5%	95.5%
QD16	25%	84.7%	95.8%
	50%	85.1%	94.3%
	75%	87.6%	96.0%
	100%	87.1%	95.3%
QD32	25%	95.9%	95.6%
	50%	89.3%	95.8%
	75%	88.0%	96.3%
	100%	87.5%	95.9%

Table 10. Comparison of IOPS Consistency of the 960 GB PM863 and the MLC SSD-A

IOPS consistency comparisons of the 800 GB PM863 and the MLC SSD-B

This phenomenon is also the same for the MLC SSD-B. In Table 11 below, the MLC SSD-B shows an 83.3% - 99.4% IOPS consistency with the 4 KB random read/write mixed workload. However, the Samsung 800 GB PM863 SSD shows a 90.5% -99.1% IOPS consistency, proving that the V-NAND-based TLC SSD is significantly superior to the MLC SSD. In conclusion, the Samsung 800 GB PM863 SSD can provide the performance of an average IOPS ± 10% with a 4 KB read/write I/O mixed workload, regardless of the write proportion, and the MLC SSD-B shows an IOPS fluctuation up to about ± 16% and may not meet the SLA.

Read IOPS Consistency (4 KB Random R/W Mixed Workload)			
	Write Ratio	MLC SSD-B (800 GB)	PM863 (800 GB)
QD1	0%	89.9%	98.0%
	25%	84.5%	96.7%
	50%	88.4%	93.0%
	75%	89.3%	92.9%
QD2	0%	99.2%	98.9%
	25%	93.5%	94.6%
	50%	90.0%	92.3%
	75%	90.3%	93.3%
QD4	0%	86.8%	99.1%
	25%	92.9%	93.3%
	50%	93.2%	93.2%
	75%	91.9%	93.9%
QD8	0%	88.1%	99.0%
	25%	92.5%	95.2%
	50%	93.3%	94.6%
	75%	92.4%	93.9%
QD16	0%	93.4%	98.2%
	25%	94.4%	95.3%
	50%	93.5%	95.6%
	75%	85.5%	91.6%
QD32	0%	99.4%	98.7%
	25%	95.5%	96.5%
	50%	90.0%	93.4%
	75%	87.3%	91.9%

Write IOPS Consistency (4 KB Random R/W Mixed Workload)			
	Write Ratio	MLC SSD-B (800 GB)	PM863 (800 GB)
QD1	25%	83.3%	98.0%
	50%	88.1%	90.5%
	75%	90.4%	92.6%
	100%	91.0%	95.1%
QD2	25%	90.4%	92.0%
	50%	92.3%	93.5%
	75%	90.9%	93.1%
	100%	89.6%	94.7%
QD4	25%	91.6%	91.5%
	50%	93.8%	94.1%
	75%	93.2%	93.6%
	100%	90.7%	94.8%
QD8	25%	92.5%	94.4%
	50%	94.8%	94.3%
	75%	91.2%	93.9%
	100%	90.8%	96.3%
QD16	25%	94.3%	95.3%
	50%	93.8%	95.6%
	75%	85.4%	93.2%
	100%	88.8%	94.9%
QD32	25%	95.1%	96.0%
	50%	90.3%	94.1%
	75%	87.0%	94.0%
	100%	89.3%	94.7%

Table 11. Comparison of IOPS Consistency of the 800 GB PM863 and the MLC SSD-B

The 960 GB PM863 demonstrates a higher user capacity in SNS scenarios

8. User scenarios (UX Performance)

Discover the notable results of the PM863 when tested in user scenarios

So far, we have reviewed that the V-NAND-based PM863 SSD can provide superior performance, QoS and performance consistency with a mixed workload. Now, we will check the PM863 performance in detailed data center services by using a user scenario.

1) Social Network Services (SNS)

The Aerospike Certification Tool (ACT) is an application that applies a huge volume of I/O stress on the SSD and benchmarks how the SSD provides stable latency without any fault. The purpose of the ACT is to determine whether a specific SSD is suitable for real-time big data. For example, the ACT simulates whether the SSD can process big data created by social network services (SNS), such as Twitter® and Facebook® 24/7, 365 days a year without any performance degradation.

The ACT tests the SSD for 24 hours. Based on the 24-hour benchmarking result, the ACT Certificate can be given to the SSD only when the transactions over 1 msec are within 5% of the total transactions, transactions over 8 msec are within 1% of the total transactions, and transactions over 64 msec are within 0.1% of the total transactions.

First, the test results of the MLC SSD-A and the 960 GB PM863, outlined in Table 12 on the next page, show the proportions of transactions over 1 msec, 2 msec, 8 msec and 64 msec for 24 hours. For example, after 4 hours had elapsed since the starting time of the test (Time Slice 4), the 960 GB PM863 showed the proportion of transactions over 1 msec, 2 msec, 8 msec and 64 msec to be 1.73%, 0.04%, 0% and 0%, respectively. On the other hand, the results of the MLC SSD-A were 4.81%, 0.19%, 0.0% and 0.0%. As shown in Table 10, the performance was stabilized after 10 hours from the test start and the latency has a certain constant ratio. When the 24-hour test was completed, the proportions of transactions over 1 msec and 2 msec were 2.39% and 0.05% on average. However, those of the MLC SSD-A were 2.84% and 0.08%, showing lower performance than the 960 GB PM863. Of course, both the MLC SSD-A and the 960 GB PM863 satisfied the ACT Certificate requirements. However, if the MLC SSD-A provides a user capacity smaller than that of the 960 GB PM863, and the performance is not so excellent, there is no need for users to purchase the MLC SSD-A.

ACT comparisons between the 960 GB PM863 and the 800 GB MLC SSD-A

	PM863 (960 GB)				MLC SSD–A (800 GB)			
Time Slice	% > 1 ms	% > 2 ms	% > 8 ms	% > 64 ms	% > 1 ms	% > 2 ms	% > 8 ms	% > 64 ms
1	0.44	0.01	0.0	0.0	0.47	0.0	0.0	0.0
2	0.44	0.00	0.0	0.0	0.45	0.0	0.0	0.0
3	0.44	0.01	0.0	0.0	2.50	0.10	0.0	0.0
4	1.73	0.04	0.0	0.0	4.81	0.19	0.0	0.0
5	4.00	0.10	0.0	0.0	2.98	0.08	0.0	0.0
6	3.47	0.09	0.0	0.0	2.48	0.06	0.0	0.0
7	2.91	0.06	0.0	0.0	3.06	0.08	0.0	0.0
8	2.56	0.05	0.0	0.0	3.13	0.09	0.0	0.0
9	2.31	0.04	0.0	0.0	2.96	0.08	0.0	0.0
10	2.31	0.04	0.0	0.0	2.93	0.08	0.0	0.0
11	2.73	0.05	0.0	0.0	3.02	0.08	0.0	0.0
12	2.67	0.05	0.0	0.0	3.04	0.08	0.0	0.0
13	2.60	0.05	0.0	0.0	3.01	0.08	0.0	0.0
14	2.58	0.05	0.0	0.0	3.02	0.08	0.0	0.0
15	2.55	0.05	0.0	0.0	3.04	0.08	0.0	0.0
16	2.56	0.05	0.0	0.0	3.03	0.08	0.0	0.0
17	2.60	0.05	0.0	0.0	3.04	0.08	0.0	0.0
18	2.63	0.05	0.0	0.0	3.04	0.08	0.0	0.0
19	2.62	0.05	0.0	0.0	3.04	0.08	0.0	0.0
20	2.62	0.05	0.0	0.0	3.05	0.08	0.0	0.0
21	2.62	0.05	0.0	0.0	3.04	0.08	0.0	0.0
22	2.63	0.05	0.0	0.0	3.04	0.08	0.0	0.0
23	2.64	0.05	0.0	0.0	3.05	0.08	0.0	0.0
24	2.64	0.05	0.0	0.0	3.05	0.08	0.0	0.0
Avg	2.39	0.05	0.0	0.0	2.84	0.08	0.0	0.0
Max	4.00	0.10	0.0	0.0	4.81	0.19	0.0	0.0

Table 12. Comparison of ACT Results of the 960 GB PM863 and the 800 GB MCL SSD-A

The ACT results prove the PM863 provides superior performance under I/O stress for extended periods

Next, we tested the 800 GB PM863 and the 800 GB MLC SSD-B in the same way. Table 13 shows how they each performed based on the ACT 24-hour evaluation results. Both the 800 GB PM863 and the MLC SSD-B satisfy the ACT Certificate requirements, but the difference of quality between the two is significant.

During the 24-hour ACT evaluation, the proportion of transactions over 1 msec for the 800 GB PM863 was just 0.93%. However, the proportion of transactions over 1 msec for the MLC SSD-B was 1.65%. We can definitely see that the 800 GB PM863 is more useful in processing big data than the MLC SSD-B.

	PM863 (800 GB)				MLC SSD-B (800 GB)			
Time Slice	**% > 1 ms**	**% > 2 ms**	**% > 8 ms**	**% > 64 ms**	**% > 1 ms**	**% > 2 ms**	**% > 8 ms**	**% > 64 ms**
1	0.44	0.01	0.0	0.0	0.62	0.01	0.0	0.0
2	0.44	0.01	0.0	0.0	0.61	0.01	0.0	0.0
3	0.44	0.0	0.0	0.0	0.62	0.01	0.0	0.0
4	0.44	0.0	0.0	0.0	0.61	0.01	0.0	0.0
5	0.44	0.0	0.0	0.0	1.64	0.07	0.0	0.0
6	0.45	0.01	0.0	0.0	2.65	0.12	0.0	0.0
7	0.45	0.0	0.0	0.0	2.28	0.09	0.0	0.0
8	0.44	0.0	0.0	0.0	2.01	0.07	0.0	0.0
9	1.04	0.02	0.0	0.0	1.83	0.06	0.0	0.0
10	1.61	0.02	0.0	0.0	1.66	0.05	0.0	0.0
11	1.50	0.02	0.0	0.0	1.56	0.05	0.0	0.0
12	1.39	0.02	0.0	0.0	1.71	0.06	0.0	0.0
13	1.30	0.02	0.0	0.0	1.94	0.07	0.0	0.0
14	1.22	0.02	0.0	0.0	1.88	0.07	0.0	0.0
15	1.17	0.02	0.0	0.0	1.83	0.06	0.0	0.0
16	1.10	0.01	0.0	0.0	1.80	0.06	0.0	0.0
17	1.05	0.01	0.0	0.0	1.77	0.06	0.0	0.0
18	1.01	0.01	0.0	0.0	1.77	0.06	0.0	0.0
19	0.97	0.01	0.0	0.0	1.78	0.06	0.0	0.0
20	0.97	0.01	0.0	0.0	1.80	0.06	0.0	0.0
21	1.00	0.01	0.0	0.0	1.80	0.06	0.0	0.0
22	1.06	0.01	0.0	0.0	1.79	0.06	0.0	0.0
23	1.13	0.02	0.0	0.0	1.79	0.06	0.0	0.0
24	1.15	0.02	0.0	0.0	1.78	0.06	0.0	0.0
Avg	0.93	0.01	0.0	0.0	1.65	0.06	0.0	0.0
Max	1.61	0.02	0.0	0.0	2.63	0.12	0.0	0.0

Table 13. Comparison of ACT Results of the 800 GB PM863 and the MLC SSD-B

In a message service scenario, the PM863 shows superior message synchronization

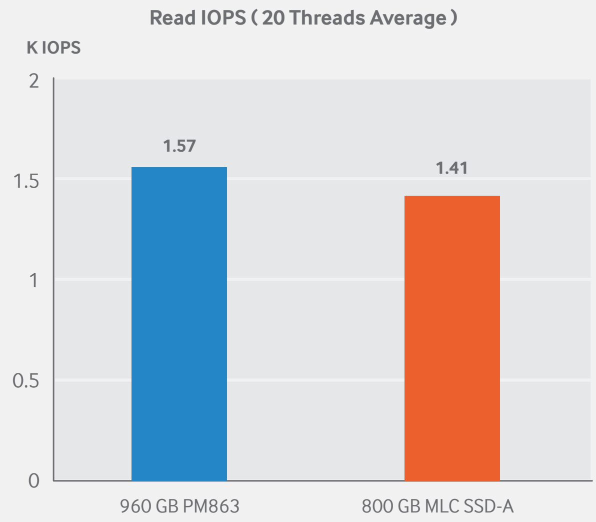
The ACT benchmark results prove that the V-NAND TLC-based PM863 SSD provides superior performance over the 2D planar MLC SSD under I/O stress for an extended period of time, and that the V-NAND TLC-based PM863 SSD is more suitable for processing big data in real time.

2) Messenger service

As the use of smartphones has grown over time, mobile messenger services, such as Kakao Talk® and LINE, have recently become widespread. As a result, to successfully provide these messenger services, expansion of servers and the development of an SSD that meets the needs of these services becomes urgent. In most cases with mobile messengers, we can see that so many users create group chat rooms and several users exchange texts, photos and videos in the group chat room, rather than using 1:1 chat rooms. In short, one user sends text messages or photos and the other users read the messages and view the photos. This means that, when one write request occurs (when one text message or photo is uploaded), the content is uploaded (written) on the messenger server and then sent to dozens of users in the group chat room, creating dozens of read requests.

Based on this service model, we mixed one 512 KB random write thread (representing the user uploading photos or video clips) and 20 random read threads of 4 KB each (representing the users that read the text message and view the photos or video clips) for the test. We assumed that messages were sent and received within a certain time gap when the messenger service users start chatting, and set the restriction on the write throughput to provide only 32 random writes of 512 KB each per second.

Figure 6 shows the read performance and latency QoS that the SSD can provide for the messenger service. First, the left graph of Figure 6 shows the performance is given to each read thread among 20 read threads. For the 960 GB PM863, each read thread receives 1.57 K IOPS and a total of 31.4 K IOPS performance can be given to the 20 read threads. On the other hand, for the 800 GB MLC SSD-A, each read thread receives 1.41 K IOPS and a total of 28.2 K IOPS performance given to the 20 read threads. This means that the performance of the MLC SSD-A is lower than that of the V-NAND TLC-based PM863 in the messenger service scenario. The right graph of Figure 6 shows the read latency QoS.



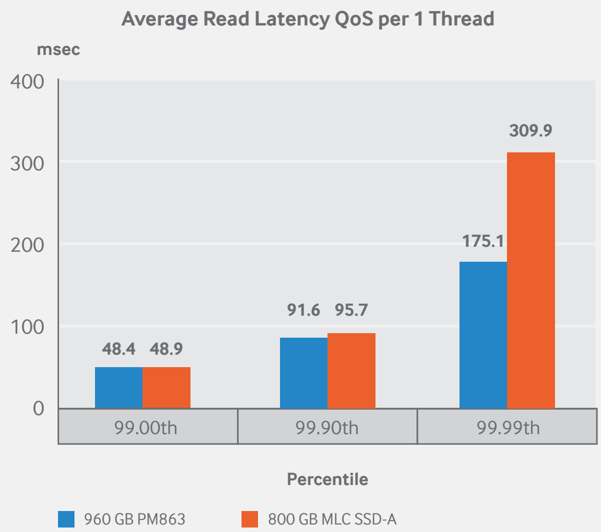


Figure 6. Performance for Messenger Service (960 GB PM863 vs. 800 GB MLC SSD-A)

Based on a web server workload, the PM863 provides an absolutely higher performance level

The graph was created by calculating the QoS data of each read thread and then averaging the latencies of the percentile. For example, QoS 99.99% indicates the average read latencies of read threads, which corresponds to QoS 99.99%. As shown in the right graph of Figure 6, the average latency of QoS 99.99% of the 960 GB PM863 is 175.1 msec, but for the 800GB MLC SSD-A it is 309.9 msec. This value is the read latency that one read thread feels. In short, a large read latency QoS indicates that it may be difficult to share the same data with other users at exactly the same time. For the 960 GB PM863, the text message or photo uploaded by a user can be shared with 20 users (20 read threads) within 175.1 msec at QoS 99.99%. But for the MLC SSD-A, the text message or photo uploaded by a user can be shared with 20 users (20 read threads) within 309.9 msec, indicating that message synchronization may be difficult.

3) Application to the web, file, exchange and database servers

Now, we will test how superior the V-NAND TLC-based PM863 SSD is in the web, file, exchange and database server environments compared with the MLC-based SSDs.

Application to web server

Because the PM863 design is optimized for the read-intensive environment, we compared the performance to web server applications, the representative read intensive scenario. A general web server workload consists of 512 bytes - 512 KB random read requests. There may be a deviation among the use cases, but the proportion of the 4 KB random read and the 512 byte random read is known as the highest. For the detailed web server workload, see Table 14 below.

	Workload Composition
Web Server	512 KB 22%, 1 KB 15%, 2 KB 8%, 4 KB 23%, 8 KB 15%, 16 KB 2%, 32 KB 6%, 64 KB 7%, 128 KB 1%, 512 KB 1% - random read (read 100%)

Table 14. Web Server Workload Composition

The results were evaluated based on the web server workload of Table 14 as in Figure 7 on the next page. As indicated in the graph, the PM863 SSD shows superior performance for all queue depths over the MLC SSD. When comparing the 960 GB PM863 with the 800 GB MLC SSD-A, the PM863 shows superior performance in the low QD (QD1 - QD8), about 10% ~ 16%, and then in the high QD (QD16 - QD128) up to 32%. Therefore, we can see that the PM863 provides an absolutely higher performance than the competitor's product.

The comparison of the 800 GB PM863 and the 800 GB MLC SSD-B shows a similar pattern. For QD2, both the PM863 and MLC SSD–B show the identical performance. However, in the low QD (QD1 - QD8), the 800 GB PM863 shows superior performance by about 7% ~ 16%, and then shows a significant performance difference in the high QD (QD16 - QD128) by up to 24%.

Finally, we can see that the V-NAND TLC-based PM863, whether it is the 800 GB or 960 GB PM863, is the best choice for performance and capacity in a read-intensive environment such as a web server.

Web server performance comparisons between the PM863 and the MLC-based SSDs

Figure 7. Performance Comparison in Web Server

In a read-intensive file server scenario, the PM863 shows up to 30% higher performance

Application to file server

Another representative read-intensive use case is the file server. A file server refers to a server on the network designed to share documents, sound files, photos and movies. Generally, as the main purpose of a file server is fast sharing, the proportion of read requests is higher than the proportion of write requests. So, we composited the file server workload as shown in Table 15. Most of the requests were 4 KB requests and the read/write proportion was 80% : 20%. The results of the PM863 for the file server are shown in the graph in Figure 8 on the next page.

	Workload Composition
File Server	512 KB 10%, 1 KB 5%, 2 KB 5%, 4 KB 60%, 8 KB 2%, 16 KB 4%, 32 KB 4%, 64 KB 10% - random read/write mixed pattern (read 80%, write 20%)

Table 15. File Server Workload Composition

As shown in Figure 8, the V-NAND TLC-based PM863 shows up to 47% higher performance than the MLC-based SSD. When comparing the performance of the 960 GB PM863 with that of the 800 GB MLC SSD-A, the 960 GB PM863 shows superior performance in the low QD (QD1 - QD8), about 14% - 20%, and then in the high QD (QD16 - QD128) by up to 47%. The 800 GB PM863 also shows superior performance over the MLC SSD-B. The 800 GB PM863 shows more than 20% higher performance, regardless of the QD. When checking the file server workload, 20% of write requests are mixed. However, the interesting fact is that the file server performance, with a write request mixed workload, shows higher performance than the MLC SSD, rather than with the web server performance with a 100% read request workload. That means, that the PM863 shows superior performance in a mixed workload environment rather than in a 100% read workload environment. When an SSD is developed for read-intensive service, it cannot provide high performance in the real data center environment if it is not optimized for the read/write mixed workload.

File server performance comparisons between the PM863 and the MLC-based SSDs

Figure 8. Performance Comparison in File Server

The PM863 shows improved performance over the MLC SSDs in an exchange server environment

Application to exchange server

The next possible read-intensive service is the exchange server. As we know, the exchange server is useful for sending and receiving e-mails and allows easy sharing of schedules and contacts. The workload of the exchange server consists of a 32 KB random read/write mixed workload as shown in Table 16. The PM863 performance in the exchange server environment is shown in Figure 9.

	Workload Composition
Exchange Server	32 KB - random read/write mixed pattern (read 68%, write 32%)

Table 16. Exchange Server Workload Composition

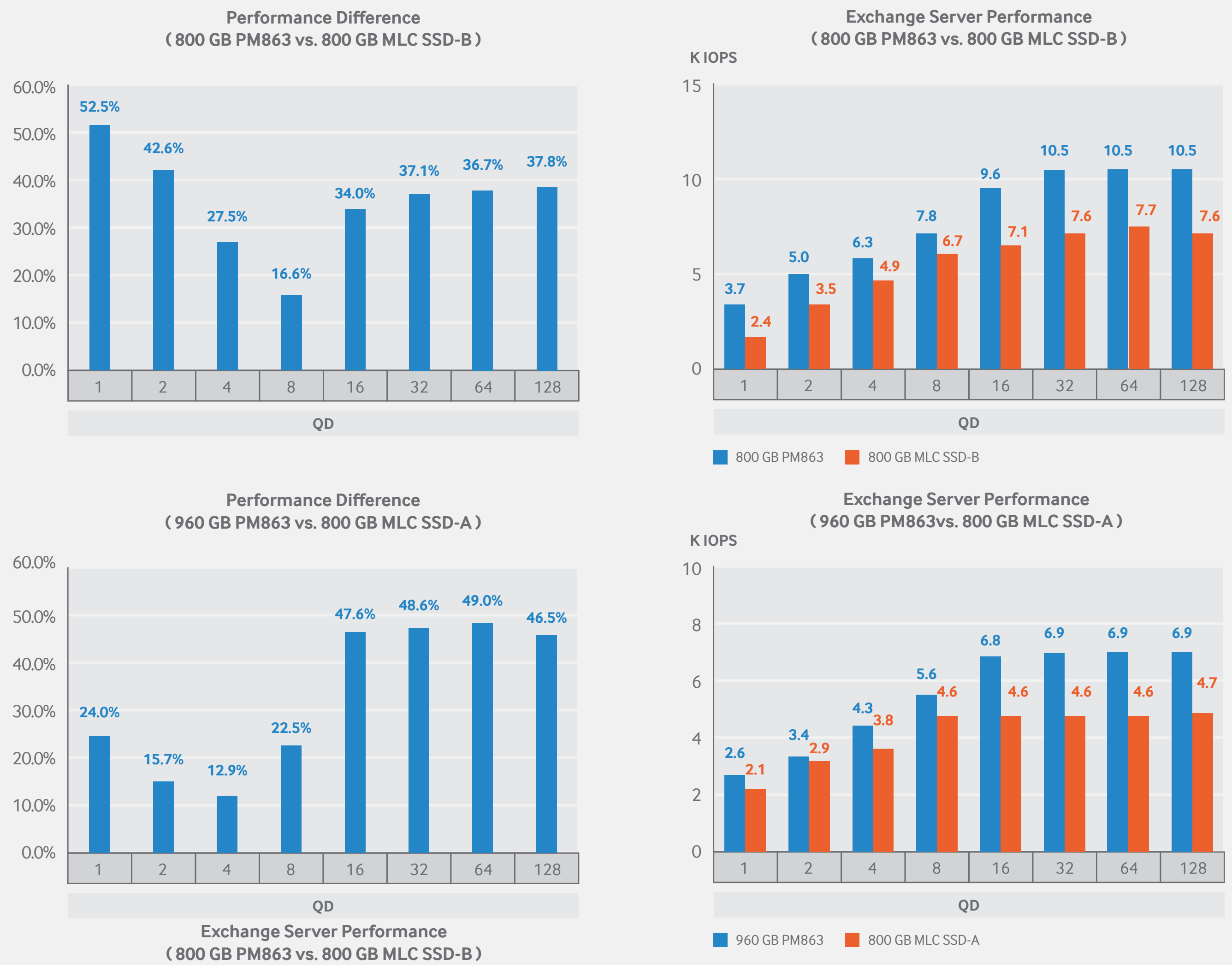


Figure 9. Performance Comparison in Exchange Server

In a database server scenario, the PM863 proves its differential performance competitiveness

As shown in Figure 9, the 960 GB PM863 shows a minimum of 12% and a maximum of 49% improved performance compared to the 800 GB MLC SSD-A. The 800 GB PM863 also shows a minimum of 16% and a maximum of 52% improved performance compared to the 800 GB MLC SSD-B.

Application to database server

A database server is also classified as a read-intensive service scenario except for the delete transaction. Therefore, the read performance of an SSD is an essential factor to improve the database server performance. For example, in regard to the update transaction, which is common in the database, it simply reads, modifies and rewrites the existing data. Therefore, when analyzing the composition of the total workload, the proportion of read requests is higher than that of the write requests. Table 17 shows the composition of the workload in a database server.

	Workload Composition
Database Server	8 KB – random read/write mixed pattern (read 67%, write 33%)

Table 17. Database Server Workload Composition

Figure 10 shows the performance difference in the database server between the PM863 and the MLC SSD. When comparing the 960 GB PM863 with the 800 GB MLC SSD-A, the 960 GB PM863 SSD shows 60% higher performance in QD32. In the low QD, the performance difference between the 960 GB PM863 and the 800 GB MLC SSD-A is very slight. However, when the workload is intensive and the QD increases, the 960 GB PM863 shows an improved performance of 20% in minimum and over 60% in maximum, proving that the PM863 is the best choice for a database environment.

When comparing the 800 GB PM863 with the 800 GB MLC SSD-B, the result shows that the 800 GB PM863 is the best choice. The 800 GB PM863 SSD shows a minimum of 16% higher performance in the low QD (QD1 - QD8) than the 800 GB MLC SSD-B. Plus, the 800 GB PM863 SSD shows about a 42% higher performance in QD32 or the higher QD, proving its differential performance competitiveness.

Results confirm that the PM863 is optimized to be well suited for demanding data center environments

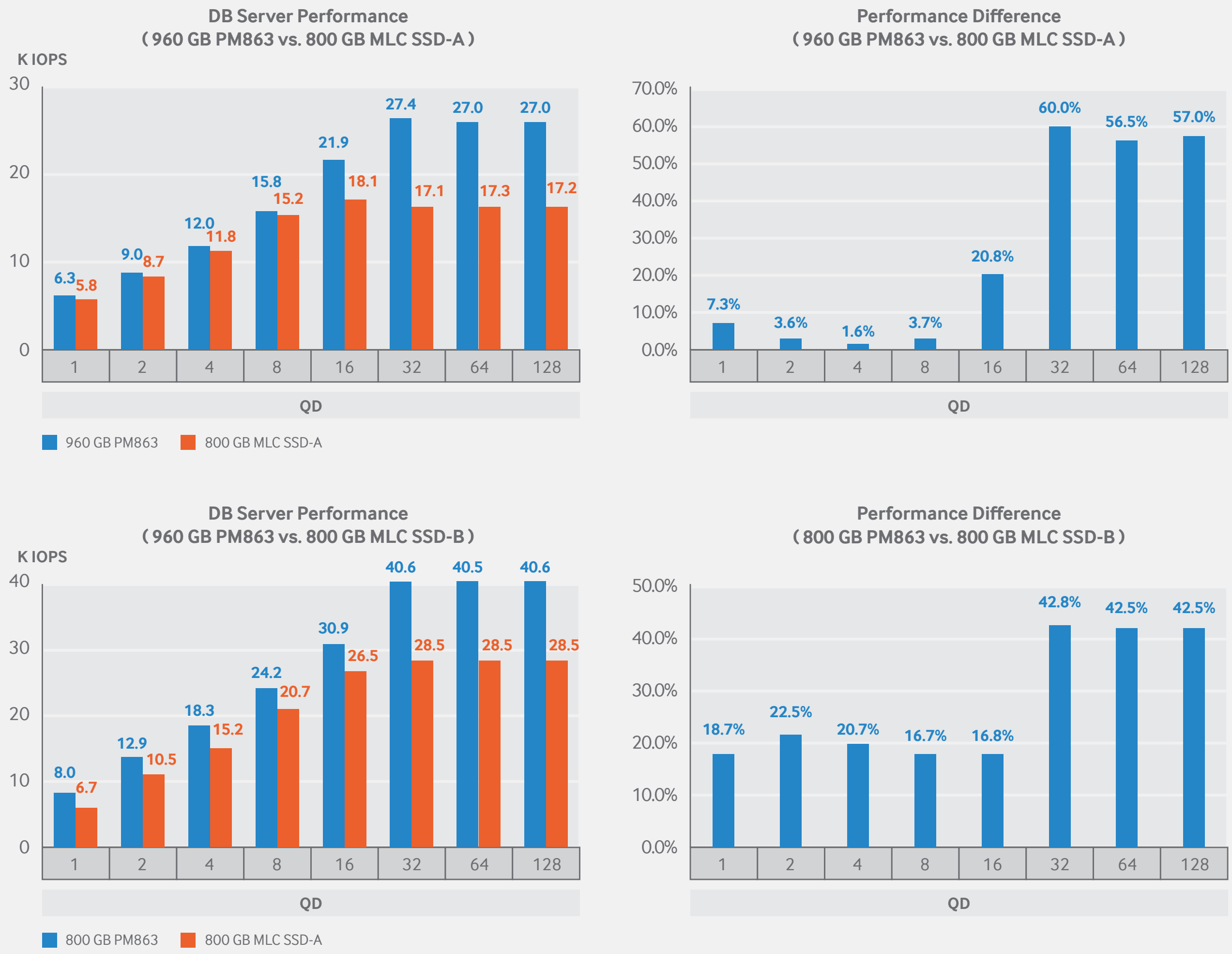


Figure 10. Performance Comparison in Database Server

9. Conclusion

In this white paper, we proved that the PM863 SSD is optimized for the read-intensive data center environment. The PM 863 is an economical V-NAND TLC-based SSD that consistently provides high performance. Superior read/write mixed performance, improved QoS, excellent IOPS consistency and great performance in SNS, messenger services and various server environments further prove that the PM863 is the superior SSD for the data center environment.

Nowadays, data centers are facing business challenges in providing cloud service and various types of high-volume data traffic. These demands require that the storage provide economic and stable performance, along with enhanced reliability. We are confident that the PM863 is the smart choice to satisfy economic feasibility, stability and reliability by minimizing power consumption, providing consistent performance and storing user data safely, even in the event of a power loss.

Appendix

10. Appendix - Index 'A': Analysis of workload by application in the data center

1. Workload Analysis

	Type	Main Request Size	Sequential Read	Random Read	Sequential Write	Random Write
Web Server Script (Synthetic)	A	4 KB, 8 KB, 64 KB	24%	71%	1%	4%
	B	0.5 KB, 4 KB	0%	100%	0%	0%
	C	4 KB, 8 KB, 16 KB+	24%	71%	1%	4%
	D	16 KB+	0%	50%	0%	50%
Web Server	A	4 KB, 8 KB	0%	29%	20%	51%
	B	4 KB, 8 KB	0%	61%	1%	38%
	C	16 KB	22%	50%	24%	4%
	D	4 KB	0%	2%	14%	84%
Exchange Server (Synthetic)	A	4 KB	0%	67%	0%	33%
	B	4 KB	0%	67%	0%	33%
Search Engine (Synthetic)	A	4 KB, 8 KB, 16 KB	0%	100%	0%	0%
Video on Demand (Synthetic)	A	512 KB	100%	0%	0%	0%
	B	512 KB	0%	100%	0%	0%
	C	16 KB+	0%	100%	0%	0%
Mail Server	A	0.5 KB, 32 KB	0%	58%	5%	37%
	B	0.5 KB	0%	0%	56%	44%
Database OLTP	A	8 KB	0%	70%	0%	30%
	B	4 KB, 8 KB	0%	67%	0%	33%
DBMS (Synthetic)	A	8 KB	0%	67%	0%	33%
	B	8 KB	0%	67%	0%	33%
Decision Support System	A	8 KB, 512 KB	5%	94%	1%	0%
Cache	A	4 KB	0%	25%	0%	75%
	B	4 KB	0%	65%	0%	35%
File Server (Synthetic)	A	8 KB	23%	67%	3%	7%
	B	4 KB	0%	80%	0%	20%

Table 18. Work Analysis

Legal and additional information

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For more information

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