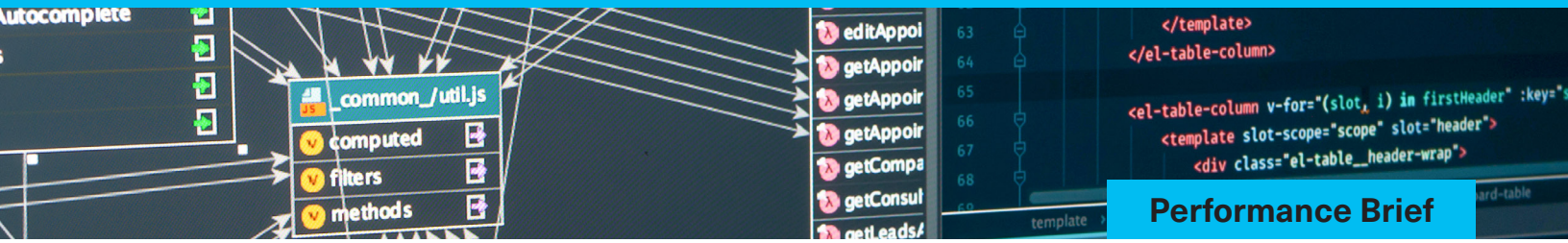
KIOXIA



Performance Brief

Delivering Major MySQL® TPM, Throughput, Latency, TPM/Watt and CPU Utilization Improvements with KIOXIA RM7 Series Value SAS SSDs Versus 2.5-inch Enterprise SAS HDDs

Introduction

Relational databases like MySQL excel at reading/writing individual rows or columns of data very quickly because they organize, query, manipulate and store data using the Structured Query Language (SQL). Reading/writing data quickly depends heavily on the underlying storage. For relational databases, slow storage I/O can bottleneck performance resulting in slower response times that negatively impact user experiences. To achieve higher performance and efficiency per server, relational databases require fast storage performance.

Traditional hard drive storage media is becoming ineffective when supporting the queries that are requested of it by the database. Although they can use fast storage interfaces, such as SAS, they are limited by slow rotational speeds which depend on mechanical read and write heads that can cause very high latency and low throughput. For relational databases, faster storage media that utilize NAND flash memory becomes necessary to take full advantage of the interface speeds that transfer these queries.

As will be shown through this performance brief, value SAS SSDs – a unique class of SAS SSD developed by Kioxia Corporation – is a superior alternative to 2.5-inch[1] enterprise SAS HDDs. They deliver faster performance, greater capacity and enhanced data protection features – all with the added benefit of easy integration with minimal disruption to IT operations.

Utilizing the same 12 Gbit/s SAS-3 interface as enterprise SAS HDDs, applications can have access to higher throughput and lower latency storage that enables the server to utilize its hardware resources more efficiently when servicing relational database workloads. The application performance improvements provided by swapping from enterprise SAS HDDs to KIOXIA RM7 Series Value SAS SSDs also present the opportunity for data center consolidation. This consolidation, coupled with a significant performance boost, is worth the cost of upgrading from older systems running SAS HDDs to newer systems running KIOXIA RM7 Series Value SAS SSDs.

This performance brief presents a comparison between enterprise SAS SSD performance and latency versus 2.5-inch enterprise SAS HDDs using MySQL database workloads. It compares KIOXIA RM7-R Series Value SAS SSDs with enterprise SAS HDDs from a leading provider (Vendor A). An HPE ProLiant DL380 Gen11 server was used for the test and associated test metrics, as well as HammerDB[2] test software, which enabled the TPROC-C[3] online transaction processing (OLTP) workloads to run against the MySQL database.

The test metrics recorded for both drive configurations included MySQL database throughput, transactions per minute (TPM) per watt, CPU utilization, read/write throughput, and read/write/workload latency. The results were recorded for each of three test runs of 5 minutes for both drive configurations to determine an average result, at which time the SSD improvements over HDDs was determined.

The test results show that the KIOXIA RM7-R Series Value SAS SSDs delivered major TPM, TPM per watt, CPU utilization, read/write throughput and read/write/workload latency improvements over enterprise SAS HDDs tested on the same 12 Gbit/s bus.

The results include a brief description of each workload test, a graphical depiction of the test results and analysis. Appendix A covers the hardware and software test configuration. Appendix B covers the configuration setup and test procedures.

Test Results Snapshot

KIOXIA RM7-R Series Value SAS SSDs delivered the following improvements over 2.5-inch enterprise SAS HDDs from Vendor A when tested:

Average MySQL Database Throughput
36x improvement

Average TPM per Watt
24x improvement

Average CPU Utilization
1.5x improvement

Average Read Throughput
36x improvement

Average Write Throughput
17x improvement

Average Read Latency
122x improvement

Average Write Latency
10x improvement

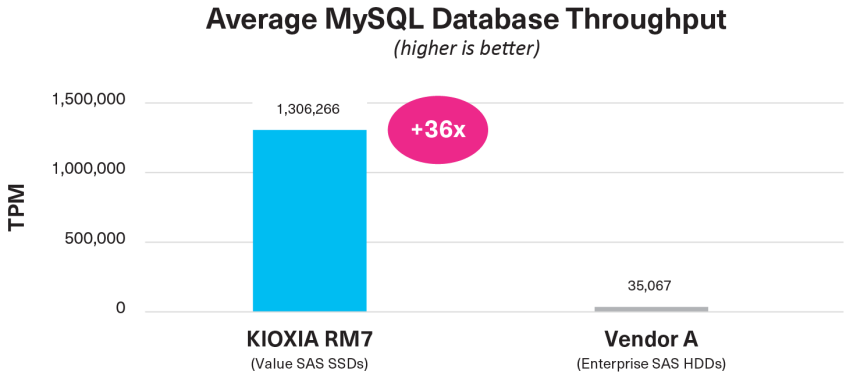
Average Workload Latency
From 10x to 49x improvement
(depending on the DB transaction)

Note: The test results were calculated to determine the SSD improvements over HDDs as presented in this Snapshot.

Test Results[4]

Test: Average MySQL® Database Throughput

This test determined the effect that underlying storage has on database performance which can have a significant impact on end user experiences. It measured the number of transactions executed in the TPROC-C workload per minute. The HammerDB software, executing the TPROC-C transaction profile, randomly performed new order, payment, order status, delivery and stock level transactions and simulated an OLTP environment with many users conducting simple and short transactions that require sub-second response times. There were three test runs of 5 minutes each conducted on both drive configurations to obtain an average number of TPM that the server was able to execute. The results are in TPM. The higher result is better.

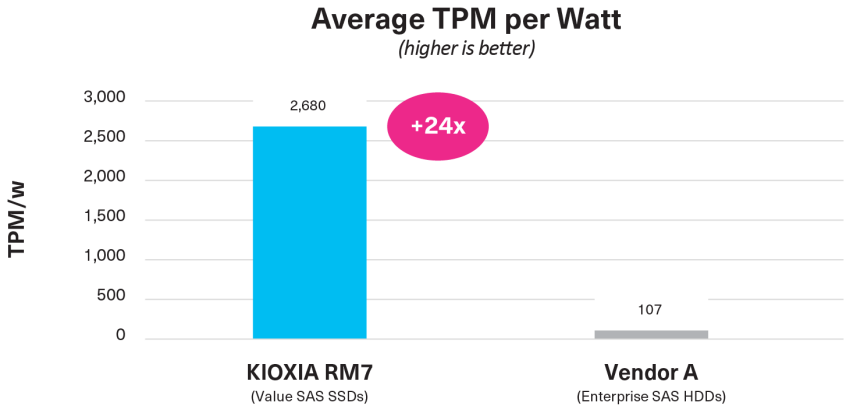


Calculated Results: Average TPM per Watt

Average TPM per watt measures how many database transactions per minute that a system can achieve per watt consumed. A higher average TPM per watt indicates a more energy-efficient system capable of performing more transactions per watt consumed when compared to a system running a similar workload. During the test runs, the KIOXIA RM7 Series Value SAS SSD configuration consumed slightly over 487 watts on average while the Vendor A enterprise SAS HDD configuration consumed an average of 329 watts. The KIOXIA RM7 Series Value SAS SSD configuration was able to complete 36x more transactions in the same test timeframe resulting in significantly more transactions per watt of power consumed by the system. The average TPM per watt calculations are determined as follows:

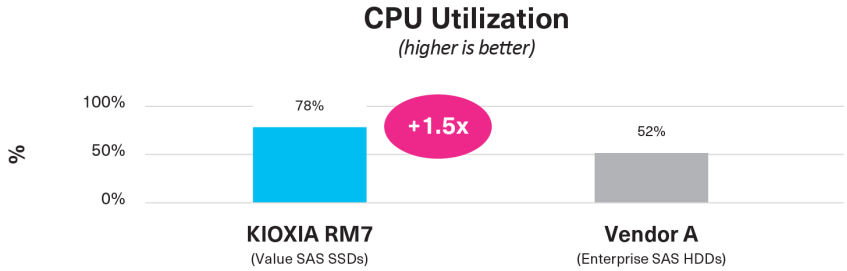
KIOXIA RM7 Series Value SAS SSDs:
1,306,266 TPM / ~487 watts = ~2,680 TPM/watt

Vendor A Enterprise SAS HDDs:
35,067 TPM / ~329 watts = ~107 TPM/watt



Additional System Test: Average CPU Utilization

Average CPU utilization is a metric that determines how much system CPU is used when the test and associated metrics are run. Higher CPU utilization indicates that the system is not being bottlenecked by storage and waiting for a response. As a result, more transactions can be serviced making better use of the CPU resource. The results show the average CPU utilization from three test runs of 5 minutes each for both drive configurations. The results are in percentage of use.



Observations:

The results for database throughput, TPM per watt and CPU utilization show the possibilities for server consolidation. To reach the database throughput metrics that the KIOXIA RM7 Series Value SAS SSDs demonstrated, multiple servers with enterprise SAS HDDs would be needed, which in turn would increase power consumption. Using value SAS SSDs in a MySQL® server provides the equivalent TPM of 36 MySQL servers running enterprise SAS HDDs. Based on these test results of comparable capacities, 16 SAS HDDs could theoretically be replaced by five KIOXIA RM7 Series Value SAS SSDs and still achieve better performance based on the tested metrics.

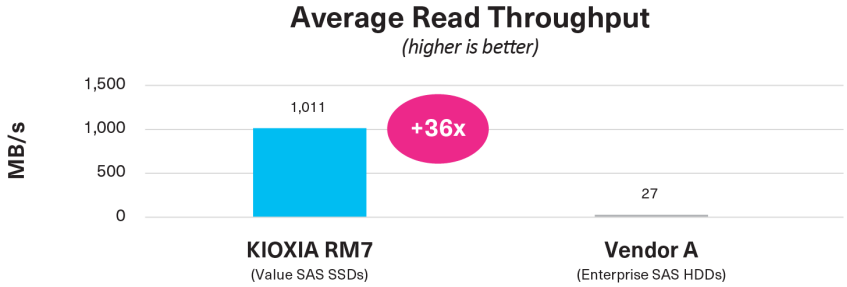
This server consolidation provides another benefit that reduces overall power requirements. The average TPM per watt results demonstrate that KIOXIA RM7 Series Value SAS SSDs provide a 24x improvement over enterprise SAS HDDs, achieving significantly better performance and much more energy efficiency. The CPU was also better utilized versus waiting for requests to finish with the enterprise SAS HDD configuration. This server consolidation can also reduce the overall cost of running the data center as less servers in operation yields more energy efficiency. If the servers are deployed with KIOXIA RM7 Series Value SAS SSDs, an overall decrease in the amount of energy used to run the data center can also be achieved, which in turn reduces the overall cost.

Additional Test Metrics:

During the MySQL database throughput test runs, additional performance metrics were collected to determine the impact that the TPROC-C workload had on the HPE ProLiant DL380 Gen11 server, including read/write throughput and read/write/workload latency as follows:

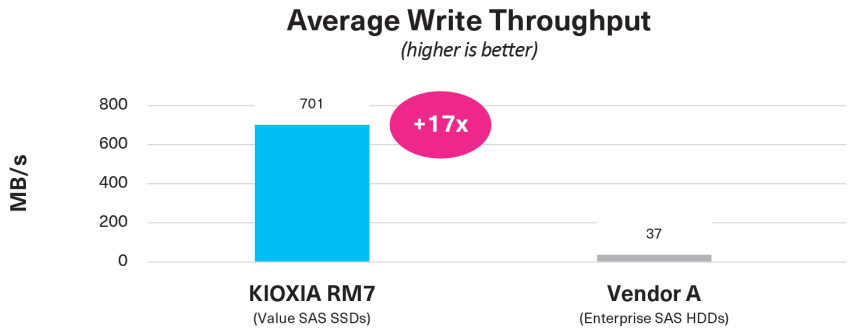
Metric 1: Average Read Throughput

This metric shows the average read throughput that both drive configurations were capable of as the HPE ProLiant DL380 Gen11 server responded to incoming database queries. If the number of incoming queries is much higher than the achievable database throughput, the server can become bottlenecked by the drives which are unable to keep up, creating longer wait times per query that negatively impact application performance and end user experiences. The results show the average read throughput from three test runs of 5 minutes each for both drive configurations. The results are in megabytes per second (MB/s). The higher result is better.



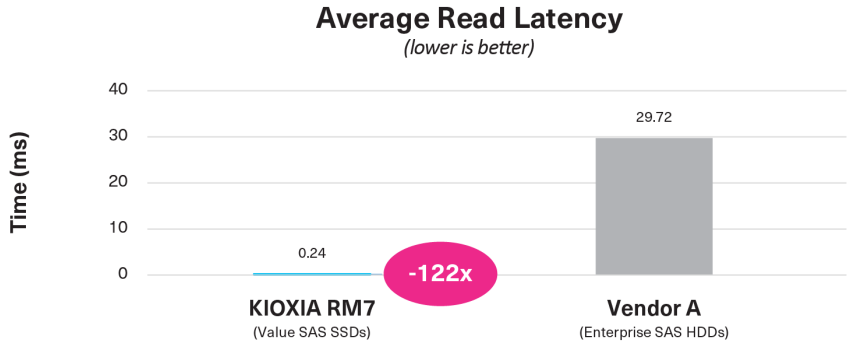
Metric 2: Average Write Throughput

This metric shows the average write throughput of both drive configurations and includes the average data throughput delivered by the HPE ProLiant DL380 Gen11 server. The write throughput issued to storage by the incoming database queries can be a limiting factor for this metric as the system must wait for the write operation to be completed before issuing additional read or write queries. The process is known as IO-wait and can negatively impact application performance and end user experiences. The results show the average write throughput from three test runs of 5 minutes each for both drive configurations. The results are in MB/s. The higher result is better.



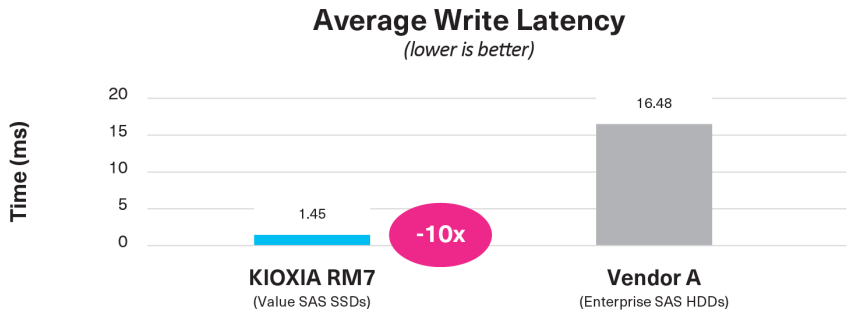
Metric 3: Average Read Latency

The average read latency is a metric of the time it takes to perform a drive read operation. It includes the time it takes for the workload generator to not only issue the read operation, but also the time it takes to complete the operation and receive a successfully completed acknowledgement. Most front-end servers utilize multiple back-end database calls that can be dependent on each other to load a single page. High read latency can cause delays when receiving requested data, and, if one database is dependent on the output of another, the latency can stack up which can impact end user experiences. The following results show the average read latency from three test runs of 5 minutes each for both drive configurations. The results are in milliseconds (ms). The lower result is better.



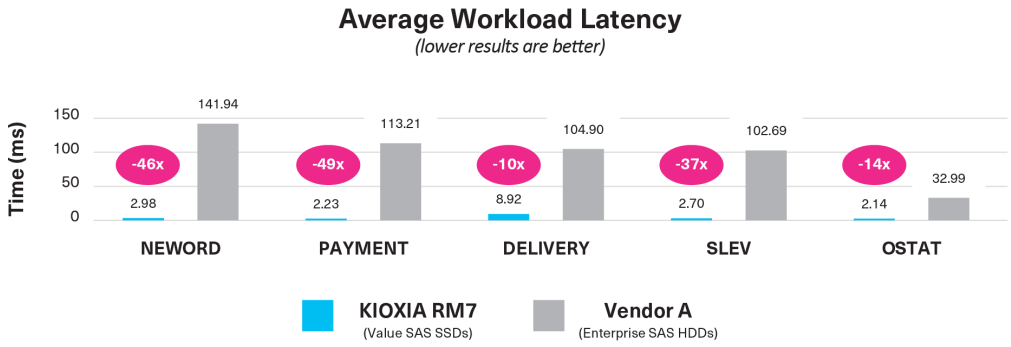
Metric 4: Average Write Latency

The average write latency is a metric of the time it takes to perform a drive write operation. It includes the time it takes for the workload generator to not only issue the write operation, but also the time it takes to complete the operation and receive a successfully completed acknowledgement. In database systems, high write latency can slow down transaction processing which can impact end user experiences. The following results show the average write latency from three test runs of 5 minutes each for both drive configurations. The results are in milliseconds (ms). The lower result is better.



Metric 5: Average Workload Latency

The average workload latency is a metric of the time it takes for HammerDB test software to execute the TPROC-C transaction profile, randomly receiving new orders (NEWORD) from customers, updating customer payments (PAYMENT) and balances, delivering orders (DELIVERY) asynchronously, retrieving customers most recent order status (OSTAT) and updating inventory status levels (SLEV) of returned stock. In database systems, high workload latency can slow down transaction processing and negatively impact end user experiences. The following results show the average workload latency of the transaction profile from three test runs of 5 minutes each for both drive configurations. The results are in milliseconds (ms). In each case, the lower result is better.



Analysis

The KIOXIA RM7-R Series Value SAS SSD RAID set deployed in the HPE ProLiant DL380 Gen11 server significantly outperformed the enterprise SAS HDD RAID set in the test and associated metrics conducted as depicted by the chart below:

Drive Configuration	Database Throughput *(in TPM)*	TPM per Watt *(in TPM/W)*	CPU Utilization *(in %)*	Read Throughput *(in MB/s)*	Write Throughput *(in MB/s)*	Read Latency *(in ms)*	Write Latency *(in ms)*	Workload Latency *(in ms)*
KIOXIA RM7-R Value SAS SSDs	1,306,266	2,680	78	1,011	701	0.24	1.45	See below
Vendor A Enterprise SAS HDDs	35,067	107	52	27	37	29.72	16.48	See below
SSD vs. HDD Improvement	+36x	+24x	+1.5x	+36x	+17x	-122x	-10x	See below

	Workload Latency *(in ms)*				
Drive Configuration	NEWORD *(45% random)*	PAYMENT *(45% random)*	DELIVERY *(4% random)*	SLEV *(4% random)*	OSTAT *(4% random)*
KIOXIA RM7-R Value SAS SSDs	2.98	2.23	8.92	2.70	2.14
Vendor A Enterprise SAS HDDs	141.94	113.21	104.90	102.69	32.99
SSD vs. HDD Improvement	-46x	-49x	-10x	-37x	-14x

The test results show that the KIOXIA RM7-R Series Value SAS SSDs completely outperformed the enterprise SAS HDDs across the board delivering the following improvements:

- *36x higher TPM*
- *24x higher TPM per watt*
- *1.5x higher CPU utilization*
- *36x higher read throughput*
- *17x higher write throughput*
- *122x lower read latency*
- *10x lower write latency*
- *10x to 49x lower workload latency depending on the database transaction*

The results also show the possibilities of server consolidation. To reach the application performance levels that the KIOXIA RM7 Series Value SAS SSDs demonstrated, multiple servers with enterprise SAS HDDs would be needed, which in turn increase power consumption.

It is also clear that the enterprise SAS HDDs were a bottleneck that dragged system performance down nearly to a halt and underutilized valuable CPU and memory resources. The averages of the database throughput and TPM per watt metrics demonstrate that KIOXIA RM7 Series Value SAS SSDs can deliver 36x more database transactions and 24x more performance per watt when compared to enterprise SAS HDDs. When running MySQL® applications on servers, KIOXIA RM7 Series Value SAS SSDs allow for data center consolidation, requiring less systems to reach the same performance levels.

KIOXIA RM7 Series Value SAS SSDs can be easily swapped with enterprise SAS HDDs and are a positive transformation for rack space and power requirements. Adding value SAS SSDs to systems that are slowed down by hard drives can reduce the number of systems required, which in turn reduces rack space and power requirements in the data center. Coupled with lower drive and database workload latencies, these value SAS SSDs demonstrated faster response times that equate to better end user experiences.

Summary

This performance brief presented a drive comparison using MySQL database workloads with KIOXIA RM7-R Series Value SAS SSDs and enterprise SAS HDDs from a leading provider (Vendor A). An HPE ProLiant DL380 Gen11 server running HammerDB software was used for the tests. The testing showed that KIOXIA RM7-R Series Value SAS SSDs were able to deliver significant performance improvements in TPM, read/write throughput, read/write/workload latency and CPU usage. For applications that require higher storage performance versus what HDDs can provide, value SAS SSDs are a better fit.

The TPM per watt results also demonstrated that the KIOXIA RM7-R Series Value SAS SSDs are more energy-efficient and capable of performing more work with less power when compared to the enterprise SAS HDD configuration. Power consumption has become an increasing concern for many companies, so providing better performance per watt can help reduce operational costs while allowing the database to handle more requests. Enterprise SAS HDDs are directly replaceable with value SAS SSDs, making the latter an excellent drop-in replacement for existing SAS storage deployments and for new or existing SAS servers.

Replacing enterprise SAS systems from legacy HDD technology to flash-based SSDs will allow for data center consolidation as demonstrated by the test results. To reach the application performance levels of a system running KIOXIA RM7 Series Value SAS SSDs, multiple servers with enterprise SAS HDDs would be needed. As a part of this consolidation, swapping from older generation systems to newer flash-based ones can also provide much better performance and more efficient CPU utilization.

KIOXIA RM7 Series Value SAS SSD Product Info

The latest generation KIOXIA RM7 Series Value SAS SSDs support the 12 Gbit/s SAS-3 interface and are available in two 2.5-inch form factor configurations: RM7-R Series for read-intensive applications (1 DWPD[5] / capacities up to 7.68 terabytes[6] [TB]) and RM7-V Series for higher endurance mixed-use applications (3 DWPD / capacities up to 3.84 TB). Security options[7] are available for both configurations.

Additional KIOXIA RM7 Series Value SAS SSD information is available here.

KIOXIA RM7 Series SSD[8]

Appendix A

Hardware/Software Test Configuration

Server Information		
Server Model	HPE ProLiant DL380 Gen11	
No. of Servers	1	
Host Interface	SAS-3	
Host Interface Speed	12 Gbit/s	

CPU Information	
CPU Model	Intel® Xeon® Gold 5416S
No. of Sockets	2
No. of Cores	32
Frequency *(in gigahertz)*	2.0 GHz

Memory Information	
Memory Type	DDR5
Memory Speed	DDR5-4400
Total Memory Size *(in gigabytes[2])*	256 GB

Storage Information		
Storage Drive Model	KIOXIA RM7-R Series	Vendor A
Form Factor	2.5-inch	2.5-inch
Interface	SAS-3	SAS-3
Interface Speed	12 Gbit/s	12 Gbit/s
No. of Drives	4	4
Drive Capacity	3.84 TB	1.2 TB
Drive Writes per Day	1	1
Active Power	up to 9 watts	up to 4.88 watts

Operating System Information	
Operating System (OS)	Linux® Ubuntu®
OS Version	24.04.2
Database Software Model	MySQL®
Database Version	8.0.41-0ubuntu0.24.04.1 (for Linux on x86_64)

Test Software Information	
Test Software Model	HammerDB
Benchmark	TPROC-C
Version	4.12

Appendix B

Configuration Setup/Test Procedures

Configuration Setup

The HPE ProLiant DL380 Gen11 server was installed with the Ubuntu® v24.04.2 operating system.

A software RAID 10[9] set was created.

An XFS® file system was added to the RAID 10 set.

A directory called /mnt/mysql_data was created, and the RAID 10 set was mounted.

Four 3.84 TB KIOXIA RM7-R Series Value SAS SSDs and four 1.2 TB Vendor A enterprise SAS HDDs were placed in a hardware RAID 10 set in the BIOS, using the default RAID controller settings.

MySQL® software was installed on the newly created volume.

The datadir for MySQL was changed to the RAID 10 set.

HammerDB test software was installed on the same volume that MySQL resided enabling the TPROC-C OLTP workloads to run against the MySQL database.

Ran a customized version of the script provided by HammerDB test software for MySQL database applications that ran a timed workload and started the MySQL Database Transactions test.

Test Procedures

The results were recorded when the TPROC-C workload was run against each drive configuration covering:

- *Average MySQL database throughput (in TPM)*
- *Average CPU usage (in %)*
- *Average read throughput (in MB/s)*
- *Average write throughput (in MB/s)*
- *Average read latency (in ms)*
- *Average write latency (in ms)*
- *Average workload latency (in ms) on 5 database transactions:*

    - Receive new orders (NEWORD) from customers (randomly occurred 45% of the time)
    - Update customer payments (PAYMENT) and balances (randomly occurred 43% of the time)
    - Deliver orders (DELIVERY) asynchronously (randomly occurred 4% of the time)
    - Retrieve customers most recent order status (OSTAT) (randomly occurred 4% of the time)
    - Update inventory status levels (SLEV) of returned stock (randomly occurred 4% of the time)

For all tests above, three total runs were performed of 5 minutes each and the average of the three runs were calculated and compared with each drive configuration. Additional notes:

- *The average power usage and maximum power usage were monitored and recorded during all tests.*
- *The average power usage and results from the MySQL database throughput test were used to calculate the average TPM per watt for each drive configuration.*

The calculation to determine improvements:

$$\frac{\textit{High test result} - \textit{Low test result}}{\textit{Low test result}}$$

NOTES:

[1] 2.5-inch indicates the form factor of the SSD and not its physical size.

[2] HammerDB is benchmarking and load testing software that is used to test popular databases. It simulates the stored workloads of multiple virtual users against specific databases to identify transactional scenarios and derive meaningful information about the data environment, such as performance comparisons.

[3] TPROC-C is the OLTP workload implemented in HammerDB derived from the TPC-C™ specification with modification to make running HammerDB straightforward and cost-effective on any of the supported database environments. The HammerDB TPROC-C workload is an open-source workload derived from the TPC-C Benchmark Standard and as such is not comparable to published TPC-C results, as the results comply with a subset rather than the full TPC-C Benchmark Standard. TPROC-C means Transaction Processing Benchmark derived from the TPC "C" specification.

[4] Read and write speed may vary depending on the host device, read and write conditions and file size.

[5] DWPD: Drive Write(s) Per Day. One full drive write per day means the drive can be written and re-written to full capacity once a day, every day, for the specified lifetime. Actual results may vary due to system configuration, usage, and other factors.

[6] Definition of capacity: KIOXIA Corporation defines a megabyte (MB) as 1,000,000 bytes, a gigabyte (GB) as 1,000,000,000 bytes, a terabyte (TB) as 1,000,000,000,000 bytes and a petabyte (PB) as 1,000,000,000,000,000 bytes. A computer operating system, however, reports storage capacity using powers of 2 for the definition of 1Gbit = 2^{30} bits = 1,073,741,824 bits, 1GB = 2^{30} bytes = 1,073,741,824 bytes, 1TB = 2^{40} bytes = 1,099,511,627,776 bytes and 1PB = 2^{40} bytes = 1,125,899,906,842,624 bytes and therefore shows less storage capacity. Available storage capacity (including examples of various media files) will vary based on file size, formatting, settings, software and operating system, and/or pre-installed software applications, or media content. Actual formatted capacity may vary.

[7] Optional security feature compliant drives are not available in all countries due to export and local regulations.

[8] The product image shown is a representation of the design model and not an accurate product depiction.

[9] RAID 10 is a redundant array of independent disks configuration that combines disk mirroring and disk striping to protect data.

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