KIOXIA

Application Brief

Accelerating MySQL® Performance with SupremeRAID™ Ultra GPU-based NVMe™ RAID and KIOXIA PCIe® 5.0 CD8P Series Data Center NVMe SSDs

Introduction

Businesses must safeguard mission critical data while maximizing performance and protecting that data. Redundant array of independent disks (RAID) is a technology that uses multiple physical drives together in various configurations to achieve specific goals, such as redundancy/fault tolerance, increased speed or a combination of both. RAID introduces various levels that define how data will be made redundant. The choice of RAID level depends on the specific requirements for performance, capacity and data protection of the application data that IT departments manage. RAID arrays are commonly used in enterprise environments to ensure data availability and reliability.

RAID solutions can be deployed in hardware, software or a mix of both. Traditional hardware RAID cards that used SSDs with older storage protocols (such as SATA and SAS) were able to fully utilize the performance of all drives connected to it. However, with the introduction of PCIe SSDs that use the NVMe storage protocol, these drives individually achieve very high input/output operations per second (IOPS) and throughput, as well as drastically lower latencies. Traditional hardware RAID cards now have problems completely utilizing full PCIe SSD performance due to under-performing controllers and PCIe lane limitations. These effects can cause bottlenecks in scaling high performance and large drive capacities to individual RAID cards.

Software-based RAID can offer a cost-effective way to achieve data redundancy and performance improvements using standard server and storage hardware. However, it also comes with its own set of challenges: (1) Performance is reliant on the host CPU that instead, could be used for applications; (2) Scalability requires migrating data that can be error prone and potentially lead to data loss; (3) Functional dependence on the OS; and (4) Limited performance in high-demand environments with heavy I/O loads.

For high-performance and mission-critical applications, hybrid solutions may be a better choice than current hardware or software-based RAID implementations. One example is SupremeRAID Ultra from Graid Technology Inc. This software-defined RAID solution utilizes a GPU to maximize NVMe SSD performance without overloading the CPU. Unlike traditional RAID solutions, with SupremeRAID Ultra, data travels directly from the CPU to storage, removing performance bottlenecks while increasing scalability, improving flexibility, and reducing total cost of ownership.

This application brief presents a performance comparison using 12 KIOXIA CD8P-R Series PCIe 5.0 Data Center NVMe SSDs, 3.84 terabyte[1] (TB) capacity each, deployed in a Supermicro® 2U Hyper A+ AS-2125HS-TNR server. Using the SupremeRAID Ultra solution, RAID 5 and RAID 6 tests were performed in a MySQL database environment and compared to similar Linux® MDRAID software RAID 5 and RAID 6 configurations.

The performance comparison covers database throughput transactions per minute (TPM), TPM per watt, transaction latencies (i.e., new order, payment, delivery, stock level and order status), drive throughput and drive IOPS. Three test runs were conducted to determine an average result.

The test results show that the fast PCIe 5.0 KIOXIA CD8P-R Series NVMe SSDs can deliver higher performance with the SupremeRAID Ultra solution as it performs RAID 5 and RAID 6 functions, offloading the host CPU and increasing application performance when compared to MDRAID software RAID.

The test results presented include a brief description of each comparison and a graphical depiction. The result comparisons are captured in the Test Analysis section. Appendix A covers the hardware and software test configuration. Appendix B covers the configuration setup and test procedures.

Test Results Snapshot

KIOXIA CD8P-R Series SSDs and Graid Technology SupremeRAID Ultra deliver exceptional MySQL performance versus software-based RAID as shown below:

-

Average Database Throughput TPM
5.8x (RAID 5) / 7.3x (RAID 6)

Average TPM per Watt
4.6x (RAID 5) / 5.8x (RAID 6)

Average New Order Transaction Latency
6x (RAID 5) / 7.7x (RAID 6)

Average Payment Transaction Latency
4.1x (RAID 5) / 5.1x (RAID 6)

Average Delivery Transaction Latency
6.1x (RAID 5) / 7.2x (RAID 6)

Average Stock Level Transaction Latency
2x (RAID 5) / 2.2x (RAID 6)

Average Order Status Transaction Latency
4.5x (RAID 5) / 5.5x (RAID 6)

Average Drive Throughput
Read: 7.4x (RAID 5) / 8.3x (RAID 6)
Write: 7.3x (RAID 5) / 8.9x (RAID 6)

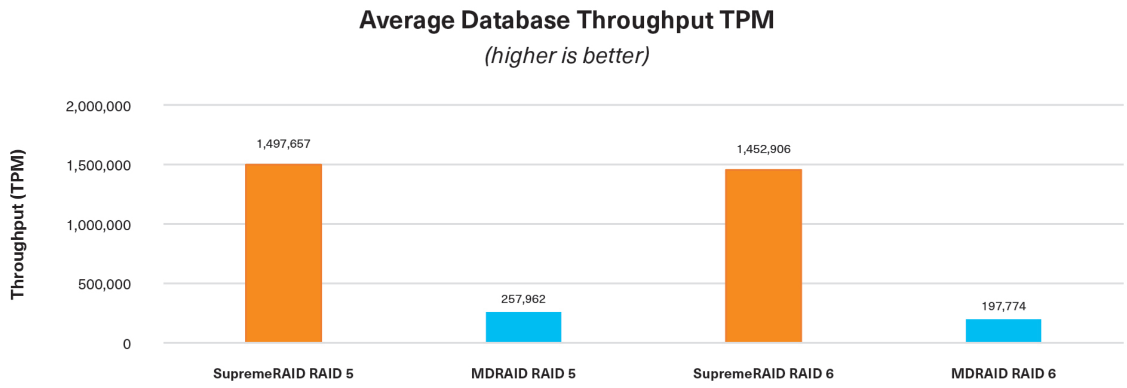
Average Drive IOPS
Read: 7.4x (RAID 5) / 8.3x (RAID 6)
Write: 7.1x (RAID 5) / 8.6x (RAID 6)

Test Results[2]

Test - Average Database Throughput TPM

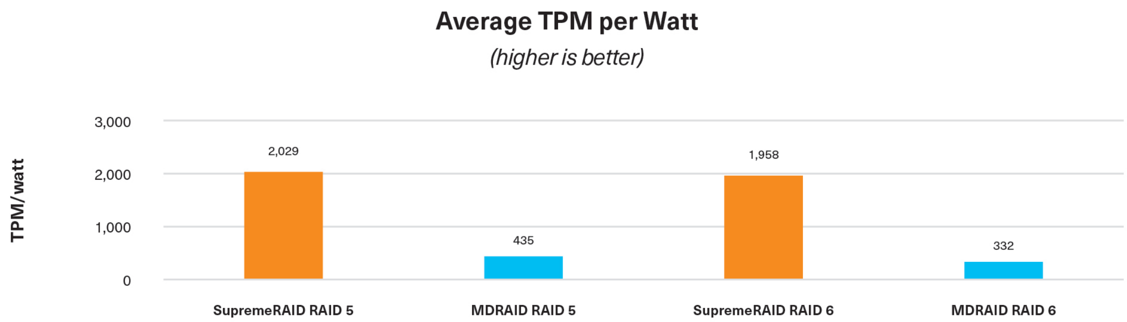
This test shows the underlying KIOXIA CD8P-R Series SSDs impact on MySQL® database performance. It measures the number of transactions executed by HammerDB[3] software and the TPROC-C[4] transaction profile that randomly performed new order, payment, delivery, stock level and order status transactions. The test simulates an online transaction processing (OLTP) environment with many users conducting simple and short transactions that require sub-second response times.

There were three RAID 5 test runs and three RAID 6 test runs of 5 minutes each conducted on both the SupremeRAID™ Ultra configuration and the software-based MDRAID configuration to obtain an average TPM number that the Supermicro® server was able to execute. The results are in TPM, and the higher results are better.



Calculation - Average TPM per Watt

Performance per watt refers to the energy efficiency of a computing system that measures the performance it delivers for each watt of power it consumes. It's a measurement of how much computation a system can achieve while using a specific amount of energy. The graph below reports the average TPM per watt that was noted between the two solutions where TPM (or database throughput) is the performance or computational metric. A higher TPM per watt indicates a more energy-efficient system, capable of performing more work per watt consumed. The results are in TPM/watt, and the higher results are better.



During the database throughput TPM test runs, additional performance metrics were collected to determine the impact that the TPROC-C MySQL workload had on the SupremeRAID Ultra and MDRAID solutions, including transaction latencies, drive throughput and drive IOPS.

Metric 1: Transaction Latencies

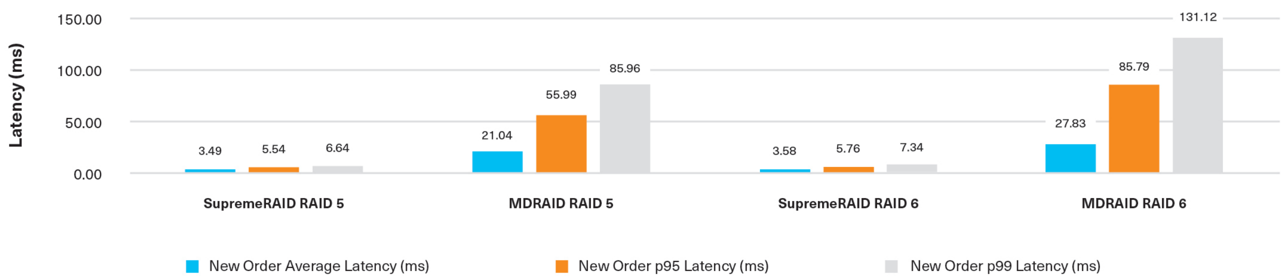
This metric shows the delay between a MySQL® database request being sent and the successful processing and delivery of its response. For this comparison, the transaction latencies measured included new order, payment, delivery, stock level and order status. There were three RAID 5 test runs and three RAID 6 test runs of 5 minutes each conducted on both the SupremeRAID™ Ultra configuration and the software-based MDRAID configuration to obtain average, 95th percentile (p95) and 99th percentile (p99) transaction latency results. The results are in milliseconds (ms), and the lower results are better.

a. New Order

The new order transaction latency metric consists of entering a complete order through a single database transaction. It represents a mid-weight, read/write transaction with high execution frequency and stringent response time requirements to satisfy online users. This transaction places a variable load on the system to reflect typical online relational database activity found in production environments.

Average New Order Transaction Latency

(lower is better)

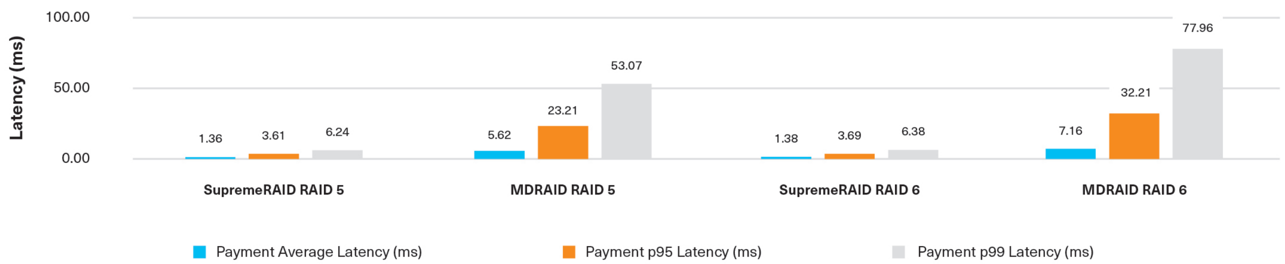


b. Payment

The payment transaction latency metric updates a customer's balance and reflects the payment on district and warehouse sales statistics. It represents a lightweight, read/write transaction with high frequency of execution and stringent response time requirements to satisfy online users.

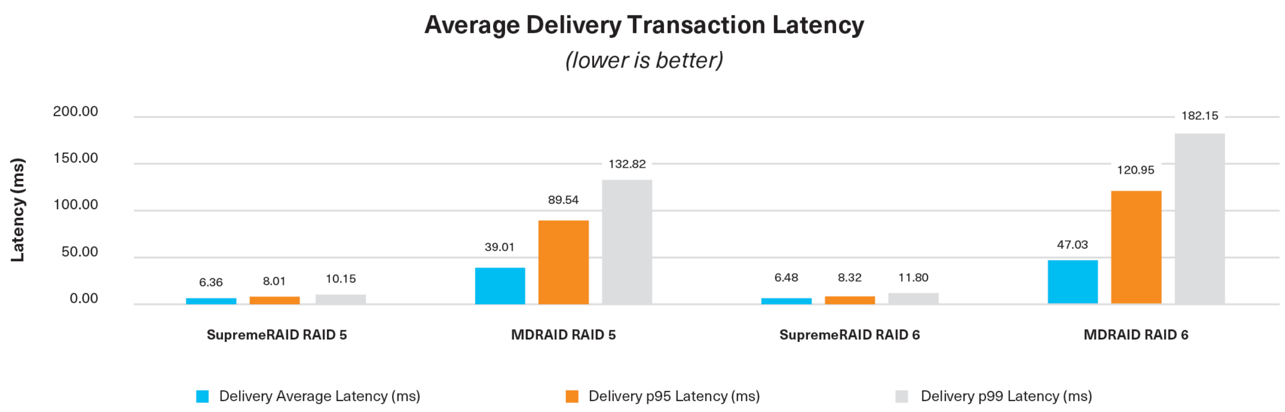
Average Payment Transaction Latency

(lower is better)



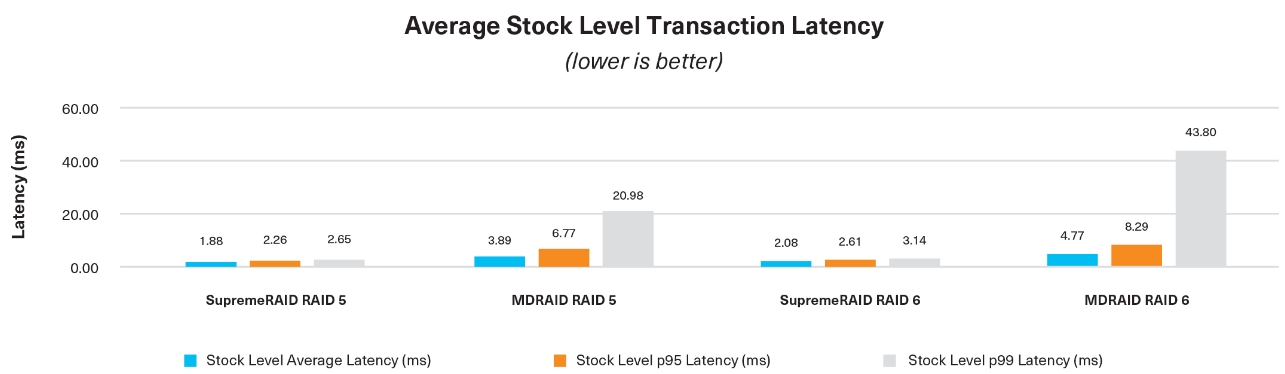
c. Delivery

The delivery transaction latency metric consists of processing a batch of 10 new (not yet delivered) orders. Each order is processed (delivered) in full within the scope of a read/write database transaction. The number of orders delivered as a group (or batched) within the same database transaction is implementation specific. This metric has low frequency of execution and must be completed within a relaxed response time requirement.



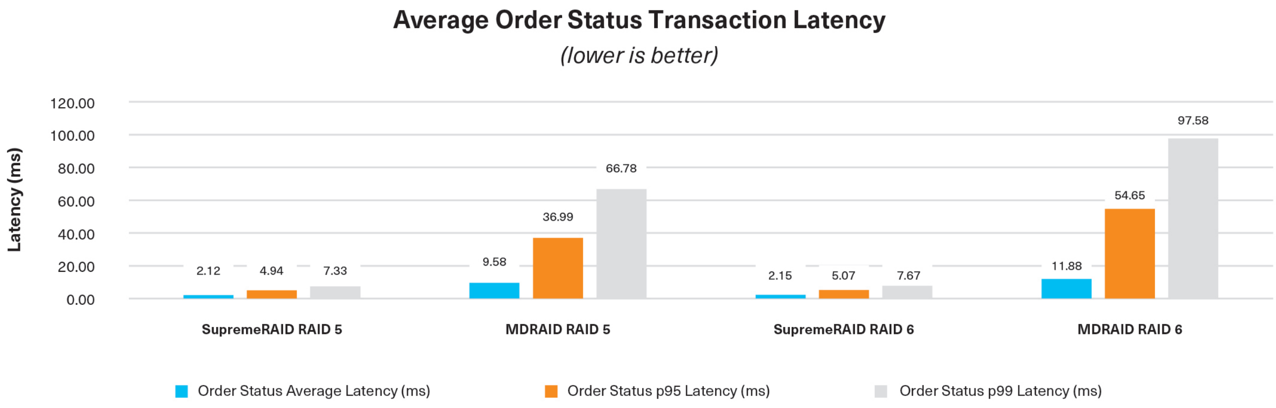
d. Stock Level

The stock level transaction latency metric determines the number of recently sold items that have a stock level below a specified threshold. It represents a heavy, read-only database transaction with low frequency of execution and a relaxed response time requirement.



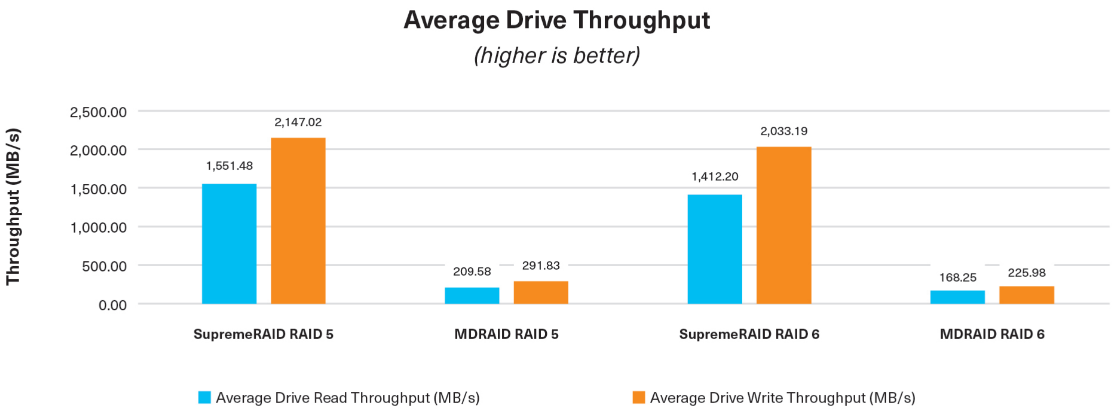
e. Order Status

The order status transaction latency metric queries the status of a customer's last order. It represents a mid-weight, read-only database transaction with low frequency of execution and relaxed response time requirement to satisfy online users.



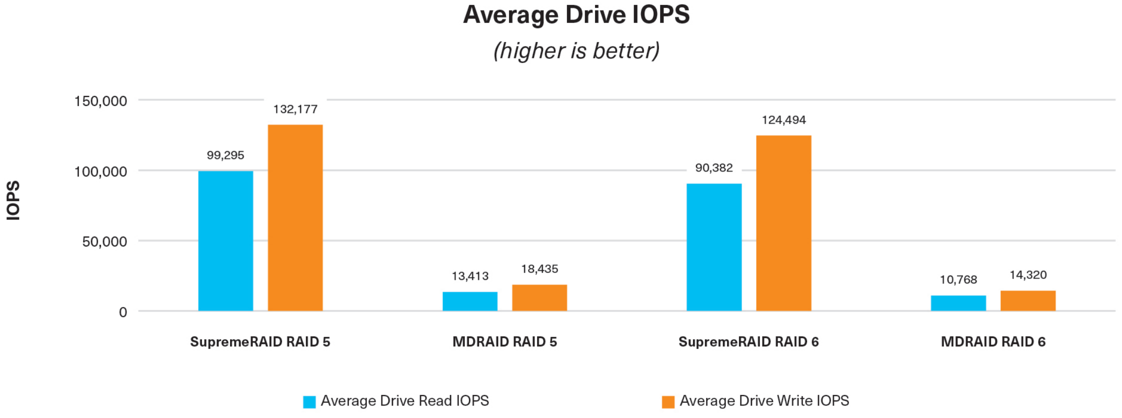
Metric 2: Average Drive Throughput (Read and Write)

This metric shows the average read and write throughputs that both SSD RAID configurations were able to achieve on the Supermicro® server as it responded to incoming database queries. If the number of incoming queries is much higher than the achievable database throughput, the server can overload, creating longer wait times per query, which can negatively affect application performance and user experiences. The results show the average read and write throughputs from three test runs of 5 minutes each for both SSD RAID configurations. The results are in megabytes per second (MB/s), and the higher results are better.



Metric 3: Average Drive IOPS (Read and Write)

This metric shows the average read and write IOPS that both SSD RAID configurations were capable of on the Supermicro server as it responded to incoming database queries. It measures the number of read and write data requests that the KIOXIA CD8P-R Series SSDs in both RAID configurations can handle in one second. This metric indicates the speed and efficiency of each SSD configuration's random data access, which is crucial for databases. A higher IOPS number means faster data handling. The results show the average read and write IOPS from three test runs of 5 minutes each for both SSD RAID configurations. The results are in IOPS, and the higher results are better.



Summation of Results

A summation of the test results below indicates that the KIOXIA CD8P-R Series SSDs / SupremeRAID™ Ultra configuration accelerated MySQL® database performance in all the tested performance areas as follows:

RAID 5 Test Results		KIOXIA CD8P-R Series SupremeRAID Ultra	KIOXIA CD8P-R Series MDRAID	KIOXIA CD8P-R Series SupremeRAID Ultra Differences
Database Throughput TPM	*(higher is better)*	1,497,657 TPM	257,962 TPM	5.8x
TPM per Watt	*(higher is better)*	2,029 TPM/watt	435 TPM/watt	4.6x
Transaction Latency	*(lower is better)*			
a. New Order - Average		3.49 ms	21.04 ms	6x
New Order - 95th Percentile		5.54 ms	55.99 ms	10.1x
New Order - 99th Percentile		6.64 ms	85.96 ms	12.9x
b. Payment - Average		1.36 ms	5.62 ms	4.1x
Payment - 95th Percentile		3.61 ms	23.21 ms	6.4x
Payment - 99th Percentile		6.24 ms	53.07 ms	8.5x
c. Delivery - Average		6.36 ms	39.01 ms	6.1x
Delivery - 95th Percentilex		8.01 ms	89.54 ms	11.1x
Delivery - 99th Percentile		10.15 ms	132.82 ms	13x
d. Stock Level - Average		1.88 ms	3.89 ms	2x
Stock Level - 95th Percentile		2.26 ms	6.77 ms	2.9x
Stock Level - 99th Percentile		2.65 ms	20.98 ms	7.9x
e. Order Status - Average		2.12 ms	9.58 ms	4.5x
Order Status - 95th Percentile		4.94 ms	36.99 ms	7.4x
Order Status - 99th Percentile		7.33 ms	66.78 ms	9.1x
Drive Read Throughput	*(higher is better)*	1,551.48 MB/s	209.58 MB/s	7.4x
Drive Write Throughput	*(higher is better)*	2,147.02 MB/s	291.83 MB/s	7.3x
Drive Read IOPS	*(higher is better)*	99,295 IOPS	13,413 IOPS	7.4x
Drive Write IOPS	*(higher is better)*	132,177 IOPS	18,435 IOPS	7.1x

RAID 6 Test Results		KIOXIA CD8P-R Series SupremeRAID Ultra	KIOXIA CD8P-R Series MDRAID	KIOXIA CD8P-R Series SupremeRAID Ultra Differences
Database Throughput TPM	*(higher is better)*	1,452,906 TPM	197,774 TPM	7.3x
TPM per Watt	*(higher is better)*	1,958 TPM/watt	332 TPM/watt	5.8x
Transaction Latency	*(lower is better)*			
a. New Order - Average		3.58 ms	27.83 ms	7.7x
New Order - 95th Percentile		5.76 ms	85.79 ms	14.8x
New Order - 99th Percentile		7.34 ms	131.12 ms	17.8x
b. Payment - Average		1.38 ms	7.16 ms	5.1x
Payment - 95th Percentile		3.69 ms	32.21 ms	8.7x
Payment - 99th Percentile		6.38 ms	77.96 ms	12.2x
c. Delivery - Average		6.48 ms	47.03 ms	7.2x
Delivery - 95th Percentilex		8.32 ms	120.95 ms	14.5x
Delivery - 99th Percentile		11.80 ms	182.15 ms	15.4x
d. Stock Level - Average		2.08 ms	4.77 ms	2.2x
Stock Level - 95th Percentile		2.61 ms	8.29 ms	3.1x
Stock Level - 99th Percentile		3.14 ms	43.80 ms	13.9x
e. Order Status - Average		2.15 ms	11.88 ms	5.5x
Order Status - 95th Percentile		5.07 ms	54.65 ms	10.7x
Order Status - 99th Percentile		7.67 ms	97.58 ms	12.7x
Drive Read Throughput	*(higher is better)*	1,412.20 MB/s	168.25 MB/s	8.3x
Drive Write Throughput	*(higher is better)*	2,033.19 MB/s	225.98 MB/s	8.9x
Drive Read IOPS	*(higher is better)*	90,382 IOPS	10,768 IOPS	8.3x
Drive Write IOPS	*(higher is better)*	124,494 IOPS	14,320 IOPS	8.6x

Summary

The SupremeRAID™ Ultra solution was able to better utilize the fast KIOXIA PCIe® 5.0 CD8P-R Series SSD performance when compared to the MDRAID software RAID solution delivering significantly more TPM and TPM per watt as well as lower transactional latencies. These performance increases allow for the database application to perform snappier and support more users, all while having your critical data supported by RAID provided redundancy and resiliency.

Products Tested

KIOXIA CD8P-R Series Data Center NVMe™ SSDs

Read-intensive KIOXIA CD8P-R Series Data Center NVMe SSDs include optimizations to support a broad range of scale-out and cloud applications. They use the PCIe 5.0 x4 interface at 32 gigatransfers per second delivering significant performance that includes up to 12,000 MB/s for sequential reads, up to 5,500 MB/s for sequential writes, up to 2,000,000 IOPS for random reads and up to 200,000 IOPS for random writes[5].

The KIOXIA CD8P-R Series is available in 2.5-inch and E3.S form factors. They deliver 1 Drive Write Per Day[6] (DWPD) endurance with storage capacities up to 30.72 TB, making them well-suited for hyperscale data centers and virtualized environments and for big data, IoT and online transaction processing applications, to name a few. Additional KIOXIA CD8P Series SSD specifications and information available here.

KIOXIA CD8P Series SSDs[7]

Used with permission from Graid Technology Inc.[7]

Graid Technology SupremeRAID Ultra

SupremeRAID Ultra (formerly SR-1010) is a next-generation, GPU-powered NVMe RAID solution engineered to deliver maximum performance for the most demanding enterprise workloads. It leverages NVIDIA RTX™ Ada GPUs to eliminate traditional RAID bottlenecks by offloading all RAID computation to the GPU, unlocking extreme workload performance, agility, and scalability. More information available here.

Appendix A

Hardware/Software Test Configuration

Server Information	
Server Model	Supermicro® 2U Hyper A+ AS-2125HS-TNR
No. of Servers	1
BIOS Version	3.7a
CPU Information	
CPU Model	AMD EPYC™ 9534
CPU Sockets	2
CPU Cores	64
CPU Frequency (base clock)	2.45 gigahertz (GHz)
Memory Information	
Memory Type	DDR5
Memory Speed	4,800 megatransfers per second (MT/s)
Memory Size	32 gigabytes (GB)
No. of DIMMs	24
Total Memory	768 GB
OS Information	
OS	Ubuntu®
OS Version	24.04.3 LTS
Kernel	6.8.0-88-generic
SupremeRAID™ Ultra Driver Version	2.0
MDRAID Driver (MDADM) Version	4.3
Database Software	MySQL®
Database Software Version	8.0.44
Filesystem	XFS®
Filesystem Version	v5
Hybrid RAID Information	
Model	SupremeRAID Ultra (formerly (SR-1010)
GPU	NVIDIA RTX™
Interface	PCIe® 4.0 x8
Dimensions	2.7" H x 6.6" L, Dual Slot
SSD Information	
Model	KIOXIA CD8P-R Series
Interface	PCIe 5.0 x4
No. of Devices	12
Form Factor	2.5-inch
Capacity	3.84 TB
Drive Write(s) Per Day	1 (5 years)
Active Power	19 W typ.
Load Generator Information	
Load Generator	HammerDB
Load Generator Version	4.12

Appendix B

Configuration Setup/Test Procedures

Configuration Setup

A Supermicro® AS-2125HS-TNR server was set up with an Ubuntu® 24.04.3 LTS operating system.

Twelve (12) 3.84 TB KIOXIA CD8P-R Series SSDs were installed onto the server.

A Graid Technology SupremeRAID™ Ultra card was installed into the server.

The Graid Technology SupremeRAID Ultra 2.0 driver was installed in the Ubuntu OS.

Each of the 12 KIOXIA CD8P-R Series SSDs were created as SupremeRAID Ultra physical drives and then added to a singular drive group in a RAID 5 configuration. A virtual drive covering the entire capacity of the drive group was created.

The virtual drive was set up with an XFS® filesystem and mounted with noatime and nodiratime flags.

MySQL® version 8.0.44 database software was installed on the system and this virtual drive would be used to store the MySQL data and log files.

The HammerDB load generator was installed and used to create a TPROC-C database to MySQL.

Test Procedures

HammerDB was then used to generate load against the database using TPROC-C defined transaction profiles.

The following metrics were gathered from three test runs of 5 minutes each to determine an average:

a. Database Throughput Transactions per Minute (TPM)
b. TPM per Watt
c. Transaction Latencies
    i. New Order
    ii. Payment
    iii. Delivery
    iv. Stock Level
    v. Order Status
d. Drive Throughput (Read and Write)
e. Drive IOPS (Read and Write)

These tests were then repeated against a Linux® MDRAID solution where a RAID 6 set was created against the KIOXIA CD8P-R Series SSDs and used to store the MySQL data and log files.

The data was then compared between the two RAID configurations.

The tests above were then repeated with a RAID 6 configuration for both the SupremeRAID Ultra configuration and the MDRAID configuration.

The data was then compared between these two RAID configurations.

NOTES:

[1] 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.

[2] Actual read and write speed may vary depending on various factors such as host devices, software (drivers, OS, etc.) and read and write conditions.

[3] 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.

[4] 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.

[5] KIOXIA CD8P-R Series SSD performance specifications are provided by Kioxia Corporation and accurate as of this publication date but subject to change.

[6] Drive Write Per Day (DWPD): 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.

[7] The product images shown are representations of design models and not accurate product depictions.