Performance Study of
IBM EXP30 Ultra SSD I/O Drawer
on IBM Power Systems

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Executive Overview

In April 2012, IBM announced a new packaging option for attaching solid-state drives (SSDs) to IBM® Power Systems™ servers. By encapsulating a storage device enclosure, storage I/O adapters and SSDs into a single drawer, IBM created a storage solution with higher performance density than ever before, for IBM Power Systems servers. This study utilizes storage I/O subsystem-level tests to assess the performance impacts of the EXP30 Ultra SSD I/O Drawer with RAID configurations on traditional and analytic server applications.

Earlier papers¹ and client experiences have shown that IBM Power Systems servers are built with I/O infrastructures that leverage SSDs. The EXP30 Ultra I/O SSD Drawer studied here brings a new level of high-performance density to the server storage market as well as affordability previously thought to be reserved for hard disk drives (HDDs).

It is well known that SSDs have the potential to provide game-changing storage performance for certain applications, when compared to HDDs. Test results show that the high-performance, densely packed EXP30 Ultra SSD I/O Drawer lowers the cost of systems used for existing applications by lowering the per unit cost of storage performance. The lower performance cost also makes affordable imaginative new solutions that analytically crunch through a myriad of data in a short time period.

Abstract

Throughput of the IBM EXP30 Ultra SSD I/O Drawer was studied with four primitive workloads and a complex workload that emulates analytics applications. Three workloads that simulate online transaction processing (OLTP) applications were also used to show response times that the direct attached storage (DAS) appliance provides. The EXP30 Ultra SSD I/O Drawer can be configured with varying numbers of SSDs and protection levels. In addition to helping readers decide which applications the EXP30 Ultra SSD I/O Drawer is well suited for, results in this paper can be used to help guide system designers define how many SSDs are needed to support application(s). Readers can also use the resultant rules of thumb to help properly size and tune storage I/O subsystems with the EXP30 Ultra SSD I/O Drawer for many applications.

Introduction

Benefits of the EXP30 Ultra SSD I/O Drawer

The feature-rich EXP30 Ultra SSD I/O Drawer, referred to simply as the EXP30 for the remainder of this paper, is more like an appliance than a drawer. Regarding drawer functionality, the EXP30 holds up to 30 SSDs. That is 6 more SSDs than the existing IBM EXP24 6Gb/s SAS-bay-based device enclosure. In addition to accommodating more SSDs, the EXP30 also contains data protection and performance accelerator technology that resides in IBM’s current PCIe 1.8GB Cache RAID Adapters.

PCIe 1.8GB Cache RAID I/O Adapters are standard PCIe form factor full-height cards typically placed into 4U high rack enclosures. Compared to the PCIe 1.8GB Cache RAID I/O Adapters, the

¹ “Performance Value of Solid State Drives using IBM i”

“Driving Business Value on Power Systems with Solid State Drives”

“Performance Impacts of Flash SSDs Upon IBM Power Systems”
EXP30 adapters are better performing due to larger non-volatile and fully redundant cache and quicker microprocessor memory. The result is that more than 6U of storage capacity, speed and function are condensed into a single 1U of standard 19 inch wide rack space, providing more than 6 times improvement in performance and capacity density over previous-generation technology.

The 1U packaging also allows convenient access to key technology components. Having open access to the drive bays on the front and I/O adapters from the rear, makes servicing and upgrading the appliance easy.

**Figure 1. Rear view of an EXP30**

The reliability and availability functions of the EXP30 reside both internally and externally. Some of the internal functions include hot spare SSDs, multiple RAID protection schemes and T10 Data Integrity Fields (DIF). Features visible from outside of the box consist of fully redundant hardware (including redundant battery-less protected cache) and various high availability connection topologies. Figure 2 provides one example of several ways in which the EXP30 can be connected to redundant systems.

**Figure 2. Sample high availability configuration**
Next Generation eMLC NAND Flash SSDs

The NAND Flash SSD cost per performance and cost per capacity curves over time are bending in the favor of SSD use in more and more enterprise server applications. This makes it more practical and affordable for SSDs to replace HDDs in the mass storage memory hierarchy. One lever used to drive the SSD cost curves downward is the use of Multi-Level-Cell (MLC) technology instead of Single-Level-Cell (SLC) NAND Flash. Appliances such as the EXP30 that use enterprise class MLC (eMLC) are now more economical than ever for server applications such as transaction and analytics processing.

Regardless of whether an application is more dependent on command throughput (IO/s or IOPs) or data throughput (MB/s), the eMLC based SSDs used in the EXP30 have approximately two times the throughput of predecessor Power Systems eMLC SSDs. These performance improvements are made possible by advancements in NAND controller raw speed, management algorithms and the interface to the NAND Flash memory modules.

Recent improvements in NAND Flash technology and packaging have increased volumetric density. In addition to doubling throughput, the per unit storage capacity of the 1.8" form factor SSD also more than doubled from 177 GB to 387 GB. Doubling the SSD performance and capacity has allowed purchase price per GB and per IO/s and MB/s to significantly lower entry costs. Depending on electricity cost structures, the largest economic impact SSDs have on a data center may be power consumption. Power consumption with eMLC technology has essentially remained flat. With two times higher speed and capacity per device, lower data center power and cooling costs per IO/s and per GB can enable lower total cost of ownership (TCO) with SSDs than HDD-based storage subsystems with comparable performance.

Since eMLC NAND Flash is the solid-state technology used in the EXP30 SSDs, for the remainder of this paper the term SSD implies eMLC NAND Flash based SSDs.

High-Speed Accelerators (RAID I/O Adapters)

Enabling the efficient migration of mass storage capacity from HDDs to SSDs requires resources in the I/O data path that can take advantage of the speed of multiple SSDs. Previous-generation I/O Adapters (IOAs) have enough horsepower to attach SSDs to Power Systems servers. However, they are limited in the number of SSDs they can attach while squeezing the maximum amount of throughput from each device. Effectively controlling only four-to-eight SSDs, they do not scale up very high. Scale-out configurations, using more of the slower IOAs, are needed for very high-performance environments, which requires more PCI slots and adds more to the system’s cost.

Typically, data center administrators have to attach more storage devices to increase speed. Often the high-performance storage is associated with high cost. However, fewer high-performance resources can translate to cost efficiency. The two IOAs in the EXP30, as well as the PCIe 1.8GB Cache RAID I/O Adapters, more than triple the SSD scale-up ability over preceding Power Systems DAS IOAs. In addition to a lower purchase price, fewer faster IOAs beget higher reliability, lower real estate and lower power consumption for the same amount of application speed. Therefore, faster storage can equate to lower TCO and lower total cost of acquisition (TCA).
The IOAs in the EXP30 have 3.1 GB of customer data cache, mostly used for write requests. In addition to caching functions, they provide RAID 5, RAID 6 and RAID 10 redundancy protection, as well as RAID 0 data striping.

The EXP30 uses a dedicated GX++ bus connection to the CPU memory. The dedicated connection reduces both latency and bandwidth sharing as compared to enclosures that connect I/O via Power GX++ hub adapters, bridge and switch chips.

The dedicated connection gives the EXP30 a shorter and less contentious I/O data path to host-system memory. The impacts of shared bandwidth are obvious and easy to calculate. The impacts to the end user of a more predictable latency probability distribution are not. They are highly dependent upon application design. As shown in Figure 4, by minimizing the probability of higher latency, tighter response time (RT) variance can be achieved. Storage solutions with lower and less variable RT provide acceptable RT to a larger percentage of applications. Less variable RT and bandwidth sharing also lead to fewer performance problems cropping up as I/O workload grows over time.

**Figure 4. Dedicated I/O data path response time advantage**
Test Setup Overview

Figure 5. Power Systems server test configuration

The EXP30 (orderable feature code #5888) attaches to Power Systems servers via two external PCIe cables. Cable lengths supported are 1.5 and 3 meters, with the best option depending upon data center hardware location needs. Our testing configuration utilized the 1.5 meter cable with feature code (FC) EN05.

The external PCIe cables are attached to the application server’s memory buses via GX++ PCIe2 adapters. A single FC EJ03 GX++ LP 2-port PCIe2 x8 Adapter was used to enable both PCIe links for maximum speed and redundancy. Other GX++ PCIe2 adapters, such as the 1 port FC EJ0H low profile adapter, are available for attaching to Power Systems servers. Servers supported include the 2U Power Systems 710 (model number 8231-E1C) and Power Systems 730 (model number 8231-E2C) and 4U Power Systems 720 (model number 8202-E4C) and Power Systems 740 (model number 8205-E6C).

The two RAID IOAs have a custom card identification number (CCIN) of 573C.

Within the EXP30 is a SAS fabric that allows redundant access to its dual-ported devices. Load balancing between the SAS ports within each IOA is automated by the IOAs without OS, application or external management required. Load balancing between the IOAs is controlled by the host operating systems/applications. Balancing is enabled because each addressable logical unit, or LUN, has an optimization affinity assigned to one of the two IOAs via the SIS disk array management utility specific to the host OS.

Along with redundant hot-swap power supply/fan modules and line cords, embedded in each RAID IOA are redundant Enclosure Service Modules (ESMs) that contain a SAS expander and SCSI Enclosure Services (SES) diagnostic module.

30 SSDs (FC ES02) were used for the test. See the web page [http://www-03.ibm.com/systems/power/hardware/peripherals/ssd/details.html](http://www-03.ibm.com/systems/power/hardware/peripherals/ssd/details.html) for more information about the 387 GB SSDs.
IBM AIX Performance Comparisons

We tested RAID 5 since it typically provides the lowest purchase price of a subsystem with data redundancy. Testing of RAID 0 assesses performance with mirroring at levels above the IOAs (typically in the OS). Not enabling the mirroring function in the IBM AIX® OS allowed the raw RAID 0 performance to be assessed. Knowing raw RAID 0 speed allows OS-managed mirroring by any supported OS to be estimated. RAID 10 managed by the IOAs was also measured. This paper does not address RAID 6. The authors intend that subsequent work will include RAID 6 measurements. The technology level in the IOAs suggests RAID 6 may be a cost-effective protection scheme with respect to both capacity and speed. You may want to consider benchmarking RAID 6 with your application if the extra protection is valuable or necessary.

With the IOA running under AIX, users have the ability to disable the redundant, super capacitor-backed write caches. The write caches are enabled by default. Tests were executed with write caches enabled and disabled to show when it helps or hurts the perceived speed of a particular workload. The IOA write cache is managed with the IBM SAS Disk Array Manager utilities that can be started from System Management Interface Tool (SMIT), command line or Diagnostics.

For more details about RAID and cache management see “SAS RAID controllers for AIX” at http://pic.dhe.ibm.com/infocenter/powersys/v3r1m5/topic/p7ebj/p7ebjkickoff.htm.

Analytics Benchmark Description

The workload selected to display EXP30 performance capabilities for analytics applications is complex enough to simulate an entire application server’s generated storage I/O, other than the storage I/O needed to enable the operating system. The workload’s three main functions execute in parallel.

- The first function emulates heavier write percentage traffic. It consists of several different applications of traffic executing with varying average transfer lengths per I/O request. They vary from short (4KB/I/O) to medium length (12KB/I/O) with varying read/write percentages. This function could be considered an example of a data ingest procedure that an analytical software package might execute.
- The second function stresses reads more than writes and simulates querying/processing applications. It is composed of several applications that generate requests, which have transfer lengths varying from 4KB/I/O to 64KB/I/O.
- The third function has 100% writes with transfer lengths larger than the other two functions, to simulate a logging function.

The cumulative write-heavy workload fed to the EXP30 is one example of a realistic application server-generated storage workload. However, this workload example does not play to the traditional strengths of extreme short transfer length, high-read IO/s capability of an all-SSD subsystem. This workload does show the throughput (Tp) and RT in a more realistic light than would a steady-state primitive storage workload that executes only one type of storage request. Since the three functions access different portions of the user space in the EXP30, tools to measure the performance are able to differentiate the performance characteristics of each function. Those results are shown separately along with the cumulative performance numbers. Be careful not to make valuations based on the Tp relative to each of the three functions because the application used to generate the workload controls both the read/write mix of IOs and the mix of IOs being sent by each of the three functions. We can, however, make valuations of the relative RT and of the cumulative Tp.
Analytics Benchmark Results

Figure 6 shows the relative performance difference of several RAID protection schemes. The solid lines denote the default enabled operation of the cache. The dotted lines denote runs performed with the cache disabled. To simulate a typical usage scenario, two of the SSDs were set aside as hot spares, while 28 were actively used.

One observation from this comparison is that with cache disabled, RAID 10 — as expected given its lower write penalty — is faster than RAID 5. With the cache enabled, RAID 5 RT benefited tremendously from the cache algorithms, while the management costs potentially throttlingTp were minimal. RAID 10 RT also benefited, but this workload did exacerbate the cache management costs by holding back RAID 10 Tp. A more detailed discussion of the costs and benefits of cache are addressed on page 11.

For sizing information such as how many EXP30s and how many SSDs are needed for a given application(s), we recommended you utilize the IBM Workload Estimator tool located at http://www-947.ibm.com/systems/support/tools/estimator/index.html.

However, for applications that drive I/O workloads similar to the one shown in Figure 6, if you can define an acceptable RT for the application to stay below such as 1ms, you can estimate how much Tp the EXP30 can support for various RAID levels. Workloads with higher read ratios and/or lower average transfer lengths per I/O will yield higher Tp. The opposite is true for workloads that have lower read ratios and higher average transfer lengths.

Figure 6. EXP30 configuration performance comparison

Figure 7 breaks apart the RAID 5 with cache result shown in Figure 6 into the three separate functions that compose the overall workload. At a given Tp, the higher read rate function has significantly lower RTs. For pure writes there is a significant Tp bandwidth that supports sub-millisecond write times. The sub-millisecond writes, occurring while the other two read-write mixed functions are executing, show the capability of the EXP30 to handle multiple workloads with minimal impact on one another.
Figure 7. Analytics workload function dissection

Figure 8 shows EXP30 cost efficiency for analytics workloads as compared to other storage subsystems. The square shaped icons on the chart represent an IBM DAS IOA / SLC SSD (572F/58B0), two SAN-attached IBM Storwize® V7000 HDD only solutions with (SVC) and without an IBM System Storage® SAN Volume Controller (V7000) and HDD/SDD hybrid IBM DS8000® (DS8K) storage subsystem solutions.

The X-Y plot shows that EXP30 RAID 5 configurations fall between the price/performance points of the cache on and off RAID 10 configurations, but are less expensive in terms of price/capacity.

It is no surprise that this eMLC SSD solution is a leader in price/performance over both HDD and SLC SSD designs, given the technology advances described earlier.

Interestingly, the all SSD EXP30 solution is much more competitive with today’s HDD solutions in terms of price/capacity than older SLC-based DAS and SAN attached SSDs. In some instances it is actually lower priced than solutions with HDDs.

Figure 8. Price-speed-capacity comparisons
OLTP Benchmark Descriptions

Three different workloads were run that mix reads and writes, various transfer lengths, spatial localities and request rates. These workloads simulate the I/O done by various OLTP applications.

- **OLTP1**: Read/write ratio is 60/40 with 4KB I/O size. I/Os are random over full capacity of devices, so there is little opportunity for IOA cache hits.
- **OLTP2**: Read/write ratio is 90/10 with 8KB I/O size. I/Os are random over full capacity of each device, so there are almost no IOA cache hits.
- **OLTP3**: Read/write ratio is 70/30 with 4KB I/O size. Half of reads are random and half are intended to elicit cache hits. 33 percent of writes are random, 33 percent are to logical block addresses recently read, and 34 percent are intended to elicit write cache hits.

OLTP Workload Results

The charts in Figure 9 show the command Tp vs. RT as the load on the subsystem is increased. The load increase of more users and/or applications was simulated with 1, 4, 8, 24, 48, 96, 128 and 256 benchmark processes running concurrently. The previous-generation PCI-X DDR 1.5 GB cache SAS RAID Adapter (CCIN 572F) was limited to 96 processes since the "knees" of the Tp vs. RT curves were exceeded with less than 96 processes. Several of the samples with high numbers of processes were truncated from the attached graphs since they exhibited no additional Tp, just rising RTs.
Figure 9. OLTP workload comparisons

Several observations can be summarized by looking at all environments in the three OLTP workloads.
1. $T_p$ improvements at 1ms RT over previous SSD solution varies from 7 to 19 times.
2. EXP30 minimum RTs reduce by 14 to 70 percent vs. previous SSD solution.
3. Even in 100 percent random spatial locality workloads, caches may help reduce RT significantly.

Figure 10 zeros in on the effects of the IOA caches. If you look closely on the previous graphs you will see similar effects on the previous generation 572F IOA configurations, because they also have non-volatile redundant caches. The EXP30 curves clearly show, with green arrows
pointing down and to the right, that when the caches are not overrun they can significantly reduce RT and increase Tp for a given number of concurrent processes. The graph also shows, with red arrows pointing upwards and to the left, that if the workload demand exceeds the cache abilities, the cost of managing the cache can reverse the RT and Tp advantages.

**Figure 10. Importance of IOA caches**

The crossover point where the advantages reverse is a complex function of the cache size, fill and de-staging algorithms and I/O workload. Predicting the exact impacts on your workloads is difficult. The results we obtained with several workloads suggest that you should assume keeping the caches enabled by default. Only consider disabling the caches after an analysis of the workload and an actual benchmark of the workload that the EXP30 will be used with are performed.

**Primitive Workload Descriptions**
Random Reads: 100 percent reads with 4KB I/O size. I/Os are random over full capacity of the devices.
Random Writes: The same as above except direction is 100 percent writes.
Sequential Reads: 100 percent sequential reads with 256KB and 1MB I/O lengths.
Sequential Writes: 100 percent sequential writes with 256KB and 1MB I/O lengths.

**Primitive Workload Results**
The RAID 5 EXP30 configurations (medium blue lines with larger icons) consist of two 15-SSD arrays. Each array was optimized under separate 573C IOAs. The application used to generate the primitive workloads limited the number of processes per array. With only two arrays and request lengths smaller than the RAID stripe length, only a fraction of the total number of SSDs are utilized at any one instant in time for samples with few processes. For larger numbers of processes, all SSDs are utilized but with shallow command queue depths. To show capabilities with higher queue depths, another set of runs was done with 4KB reads using nine three-and-four-SSD RAID 5 arrays (dark blue lines with smaller icons).
The four primitive workload graphs also pinpoint where IOA write cache provides benefit for short transfer length writes. The cache impact on RAID 5 is much larger than RAID 0.
Figure 12. Long transfer length workloads

The RAID IOAs, with their enhanced DRAM bandwidth and PCIe 2.0 host interfaces, support 6 times faster sequential reads than the previous DAS SSD solution, regardless of protection type. Long writes with the cache enabled are all about four times faster. With cache off, the EXP30 ranges from 4-to-15 times the speed of the 572F IOAs. The redundancy link between the caches on the two 57C3s limits the write bandwidth to approximately 1GB/s.
Conclusion

The following rules of thumb should guide you, along with the throughput and response time numbers shown in this paper and detailed knowledge of application subsystem requirements, to size the impacts of the EXP30 Ultra SSD I/O Drawer (appliance) in numerous server applications.

- For first-generation eMLC SSDs and previous-generation I/O adapters, the SSD-to-HDD relationship was as low as 7:1 (RAID 5) or 18:1 (RAID-0). The second-generation eMLC SSD technology in the EXP30 doubles those relationships to 14:1 and 36:1.
- 57C3 I/O adapter transaction workload Tp is approximately 7 times that of previous-generation Power Systems DAS I/O adapters.
- Using 30 second-generation eMLC SSDs, which are 2 times the speed of first-generation eMLC SSDs, can provide a 10 times speed upgrade per a pair of I/O adapters. If the workload is read intensive or results in very low I/O adapter write cache efficiencies, in order to maximize Tp per SSD it is recommended that the number of SSDs actively used per I/O adapter pair be limited to 22. If desired, the other eight device slots could be populated for storing less frequently accessed data and hot spares.
- It is recommended for the I/O adapter write cache to be kept enabled for response time sensitive applications and/or if there is a high likelihood to get fast write cache hits or IO coalescence. This recommendation is especially important with RAID 5 and RAID 6 protection schemes. Otherwise, it may be worth trying an experiment with the cache disabled running the actual I/O workload the EXP30 will be supporting.
- Although RAID 6 was not benchmarked in this investigation, you may want to consider doing so with your own application if the extra protection RAID 6 provides is desired.

With cost/performance and cost/capacity advances over previous-generation technology, the EXP30 makes it more compelling than ever for data center managers to consider SSDs when upgrading or adding mass storage to their data centers. The reliability, availability, serviceability (RAS) and ease of upgrading for future enhancements to the key I/O adapter (accelerator) and SSD technology within the drawer also contribute to the argument for deciding to utilize this technology. The potentially lower total cost of acquisition and operation of the EXP30 over HDD solutions may be more compelling than the RAS, speed and upgradeability.

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Performance Study of IBM EXP30 Ultra SSD I/O Drawer

For More Information

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