EMC CLARiiON Best Practices for Performance and Availability: Release 30.0 Firmware Update

Applied Best Practices

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About this Document

This document examines best practices for achieving high performance and availability with EMC® CLARiiON® CX4™ series storage systems. It discusses factors influencing CLARiiON availability and performance at the host, network, and storage system level.

In some cases, we offer more than one recommendation. The recommendation you follow will depend on your application and business priorities. For example, when configuring a storage system, you may need to decide whether *availability* or *performance* is more important, and provision your system accordingly.

If you are not familiar with something discussed in this paper, please refer to the *EMC CLARiiON Storage Fundamentals for Performance and Availability* white paper. *Fundamentals* follows the same format as this *Best Practices* paper, so it is easy to use *Fundamentals* as a reference for this paper. We recommend that you read *Fundamentals* if you are not familiar with storage systems or CLARiiON storage systems.

The "Sizing example" section at the end of this document discusses how to size a CLARiiON storage system for performance and capacity. This section is *not* a substitute for the proprietary software tools available to EMC sales and technical professionals.

Throughout this document, there are references to EMC white papers that are available on www.emc.com and Powerlink. We recommend that you read these documents to gain a fuller understanding of a feature, its best practices and their effects.

This version of *Best Practices* applies to the FLARE® release 30.0 firmware. Additions and changes to this revision of *Best Practices* include:

- Fully Automated Storage Tiering (FAST)
- FAST Cache
- Virtual Provisioning enhancements (thick LUNs and LUN Compression)
- Miscellaneous corrections

In this document, the term *drive* refers to both *mechanical hard drives* and *Enterprise Flash drives* (*Flash drives* or *EFDs*). Flash drives are non-volatile, NAND memory-based drives that are sometimes referred to as solid state disks (SSDs) in the IT industry. Mechanical drives and Flash drives are similar in function. However there are some differences, which are discussed in this document. Also, a glossary at the end of this paper defines EMC-specific terms.

Note that tuning parameters and software features change from revision to revision of FLARE. Out-of-date parameters used in tuning the host, network, or storage system may not work, or have unexpected results. If you need guidance with CLARiiON CX3 and the earlier CLARiiON series storage systems, please see the

EMC CLARiiON Best Practices for Fibre Channel Storage: FLARE Release 26 Firmware Update white paper available on Powerlink.

How to use this paper

You can read this paper as a tutorial, or use this as a reference. To use it as a reference, decide which subsystem (host, network, or CLARiiON) you want to optimize. Then, decide whether you need help with performance, availability, or both, and read the *entire* section that pertains to your concerns.

This paper is divided into the following sections that discuss storage-related performance and availability best practices for the three subsystems in a storage system, and also includes a section about how to size a storage system:

- Host best practices
- Performance best practices for the host
- Availability best practices for the host
- Network best practices
- Performance best practices for the SAN
- Availability best practices for the SAN
- CLARiiON storage system
- Performance best practices for the CLARiiON
- Availability best practices for the CLARiiON
- Storage system sizing and performance planning: what to consider when configuring a storage system for a workload

Please note that some best practices in these sections will also affect both the performance and the availability of the entire storage system.

Audience

The intended audience for this document is technical personnel who require guidance with the best approaches to implementing CLARiiON CX4 and AX4 series storage. An understanding of the basics of hosts (servers) and storage system networks (SAN, iSCSI LAN, DAS), and knowledge of CLARiiON storage system fundamentals are needed.

Related documents

The following white papers can be found on www.EMC.com and Powerlink:

- *An Introduction to EMC CLARiiON CX4 Disk-Drive Spin Down Technology*
- *An Introduction to EMC CLARiiON and Celerra Unified Storage Platform Storage Device Technology*
- *EMC CLARiiON Global Hot Spares and Proactive Hot Sparing*
- *EMC CLARiiON Asymmetric Active/Active Feature*
- *EMC CLARiiON Best Practices for Fibre Channel Storage: FLARE Release 26 Firmware Update*
- *EMC CLARiiON and Celerra Unified FAST Cache*

- *EMC CLARiiON High Availability (HA) — Best Practices Planning*
- *EMC CLARiiON MetaLUNs — A Detailed Review*
- *EMC CLARiiON Virtual Provisioning — Applied Technology*
- *EMC CLARiiON Storage Solutions: Microsoft Exchange 2007 — Best Practices Planning*
- *EMC CLARiiON Storage System Fundamentals for Performance and Availability*
- *EMC FAST for CLARiiON — A Detailed Review*
- *Introduction to the EMC CLARiiON CX4 Series Featuring UltraFlex Technology*
- *Using diskpar and diskpart to Align Partitions on Windows Basic and Dynamic Disks*

The following product documentation can be found on Powerlink:

- *EMC Navisphere Analyzer Administrator's Guide* (release 19 only, see Navisphere Help for newer releases)
- *EMC Networked Storage Topology Guide*
- *EMC PowerPath Version 5.3 Product Guide*
- *Installation Roadmap for CLARiiON Storage Systems*
- *Native Multipath Failover Based on DM-MPIO for v2.6.x Linux Kernel and EMC Storage Arrays*
- *Navisphere Command Line Interface (CLI) Reference*
- *Navisphere Manager version 6.29 online help*
- *Unified Flash Drive Technology Technical Notes*
- *Using EMC CLARiiON Storage with VMware vSphere and VMware Infrastructure TechBook*
- *CX4 Model 960 Systems Hardware and Operational Overview*

Chapter 1 General Best Practices

There are rarely simple answers on how to design, configure, and tune large, complex, computer-based systems. However, the following are general best practices for getting optimal performance and availability from the storage system:

- Read the manual.
- Install the latest firmware.
- Know the workload.
- Resolve problems quickly.
- Use the default settings.

Read the manual: Become familiar with CLARiiON's hardware by reading the *Introduction to the EMC CLARiiON CX4 Series Featuring UltraFlex Technology* white paper, and the Hardware and Operational Overview for your model CX4. (For example, the overview for the CLARiiON CX4-960 is the *CX4 Model 960 Systems Hardware and Operational Overview.)* In addition, familiarize yourself with CLARiiON's software by browsing the *Navisphere Manager version 6.29 online help*. Many answers to questions can be found there. The help information is directly available on the CLARiiON storage system and is downloadable from Powerlink. The *EMC CLARiiON Storage System Fundamentals for Performance and Availability* also provides helpful background on how the CLARiiON works.

Install the latest firmware: Maintain the highest firmware release and patch level practical. Stay current with the regularly published release notes for CLARiiON. They provide the most recent information on hardware and software revisions and their effects. This ensures the highest level of performance and availability known to EMC. Have a prudent upgrade policy and use the CLARiiON's Non-disruptive Update (NDU) to upgrade, and maintain the highest patch level available without adversely affecting the workload. Follow the procedure for *CLARiiON Software Update (Standard)* available on Powerlink to update CLARiiON's firmware to the latest revision.

Know the workload: To implement best practices, you should understand a storage system's workload(s). This includes knowledge of the host applications. Please remember that when the workload's demands exceed the storage system's performance capabilities, applying performance best practices has little effect. Also, it is important to maintain historical records of system performance. Having performance metrics *before* applying any best practices to evaluate results saves considerable time and labor. Finally, be aware of any changes in the workload or overall system configuration so that you can understand the change's effect on overall performance. EMC recommends using Unisphere™ Analyzer to monitor and analyze performance. Monitoring with Analyzer provides the baseline performance metrics for historical comparison. This information can give early warning to unplanned changes in performance.

Resolve problems quickly: The storage system continuously monitors itself and can be configured to generate alerts, warnings, and centralized, comprehensive logs and reports. Be proactive, and practice handling common problems, like failed drive replacement. To avoid a more serious problem later, you should periodically review the logs and generate and review system reports. Also, know how to quickly respond to alerts and warnings, such as a failed drive with the appropriate action.

Use the default settings: Not all workloads require tuning to make the best use of the CLARiiON storage system. The CLARiiON default configuration settings provide a high level of performance and availability for the largest number of workloads and storage system configurations. When in doubt, accept the defaults. In addition, use conservative estimates with configuration settings and provisioning when making changes.

Chapter 2 Host Best Practices

Host best practices advise on the software and hardware configurations of the server-class computers attached to the storage systems, and the effect they have on overall storage system performance and availability.

Performance

Application design

The host application's design, configuration, and execution determine the behavior of the overall system. Many important applications, such as Microsoft Exchange and Oracle, have integrated performance and availability features. *In many cases, proper application configuration or application tuning yields greater performance increases than either network or storage system tuning.*

I/O types

The operational design of the system's applications—how they are used, and when they are used—affects the storage system load. Being able to characterize the I/O is important in knowing which best practices to apply. The I/O produced by application workloads has the following characteristics:

- Sequential versus random
- Writes versus reads
- Large-block size versus small-block size
- Steady versus bursty
- Multiple threaded versus single threaded

Sequential versus random I/O

An application can have three types of I/O:

- Sequential
- Random
- Mixed

How well the CLARiiON handles writes and reads depends on whether the workload is mainly sequential or random I/O. Random refers to successive reads or writes from or to non-contiguous storage locations. Small random I/Os use more storage system resources than large sequential I/Os. Random I/O is characterized by throughput. Applications that only perform sequential I/O have better bandwidth than applications performing random or mixed I/O. Working with workloads with both I/O types requires analysis and tradeoffs to ensure both bandwidth and throughput can be optimized.

The type of I/O an application performs needs to be known and quantified. The best practices for either sequential I/O or random I/O are well understood. Knowing the I/O type will determine which best practices to apply to your workload.

Writes versus reads I/O

Writes consume more CLARiiON resources than reads. Writes to the write cache are mirrored to both storage processors (SPs). When writing to a RAID group with parity, the SP's CPU must calculate the parity, which is redundancy information that is written to disks. Writes to mirrored RAID groups (RAID 1 and 1/0) create redundancy by writing two copies of the same data instead of using parity data protection techniques.

Reads generally consume fewer CLARiiON resources. Reads that find their data in cache (a *cache hit*) consume the least amount of resources and can have the highest throughput. However, reads not found in cache (a *cache miss*) have much higher response times because the data has to be retrieved from drives. Workloads characterized by random I/O have the highest percentage of cache misses. Whether a read operation is a cache hit or miss affects the overall throughput of read operations.

Generally, workloads characterized by sequential I/O have the highest bandwidth. Sequential writes have lower SP and drive overhead than random writes. Sequential reads using read-ahead techniques (called *prefetching*) have a greater likelihood of a cache hit than do random reads.

The ratio of writes to reads being performed by the application needs to be known and quantified. Knowing the ratio of writes to reads being performed by the application determines which best practices to apply to your workload.

Large block size versus small I/O

Every I/O has a fixed and a variable resource cost that chiefly depends on the I/O size. For the purposes of this paper, up to and including 16 KB I/Os are considered small, and greater than 64 KB I/Os are large. Doing large I/Os on a CLARiiON delivers better bandwidth than doing small I/Os. If a large RAID group or a large metaLUN is the destination of large I/Os, the back-end bus speed may become the limiting performance factor.

Small-block random access applications such as on-line transaction processing (OLTP) typically have much higher access times than sequential I/O. This type of I/O is constrained by maximum drive operations per second (IOPS). When designing for high throughput workloads, like OLTP, it is important to use drive-based IOPS ratings, not bus-based bandwidth ratings from the recommendations found in this document.

On a CLARiiON storage system, both write caching and prefetching are bypassed when I/O reaches a certain size. By default, the value of this parameter (the **Write Aside** size) is 2048 blocks. The prefetch value (the **Prefetch Disable** size) is 4097 blocks. These values are changeable through Unisphere Secure CLI. Caching and prefetching for Virtual Provisioning-based storage cannot be changed. The decision to use a large request or break it into smaller sequential requests depends on the application and its interaction with the cache.

It is important to know the I/O size, or the distribution of sizes, performed by the applications. This determines which best practices to apply to your workload.

Steady versus bursty I/O

I/O traffic to the storage system can be steady (with high regularity) or bursty (sporadic). The traffic pattern can also change over time, being sporadic for long periods, and then becoming steady. It is not uncommon for storage systems configured for a random-access application during “business hours” to require good sequential performance during backups and batch processes after hours. An example is an OLTP system, whose behavior is bursty during normal operation and becomes steady during the nightly backup.

Bursts, sometimes called *spikes*, require a margin of storage system performance to be held in reserve. This reserve, especially of write cache, is needed to handle the “worst case” demand of the burst. Otherwise, user response times may suffer if spikes occur during busy periods.

The type of I/O performed by the application needs to be known and quantified. Knowing the I/O pattern, when the I/O pattern changes, and how long the I/O pattern is in effect will determine which best practices to apply to your workload.

Multiple threads versus single thread

The degree of concurrency of a workload is the average number of outstanding I/O requests made to the storage system at any time. *Concurrency* is a way to achieve high performance by engaging multiple service centers, such as drives, on the storage system. However, when there are more I/O requests the service centers become busy and I/O starts to queue, which can increase response time. However, applications can achieve their highest throughput when their I/O queues provide a constant stream of I/Os.

The way those I/O requests are dispatched to the storage system depends on the threading model.

A *thread* is a sequence of commands in a software program that perform a certain function. Host-based applications create processes, which contain threads. Threads can be *synchronous* or *asynchronous*. A synchronous thread waits for its I/O to complete before continuing its execution. This wait is sometimes called *pending*. Asynchronous threads do not pend. They continue executing, and may issue additional I/O requests, handling each request as they complete, which may not be the order in which they were issued.

Single-threaded access means only one thread can perform I/O to storage (such as a LUN) at a time. Historically, many large-block sequential workloads were single threaded and synchronous. Asynchronous single threads can still achieve high rates of aggregate performance as the multiple I/Os in their queues achieve concurrency. *Multithreaded* access means two or more threads perform I/O to storage at the same time. I/O from the application becomes parallelized. This results in a higher level of throughput. In the past, small-block random workloads were multithreaded. However, it is now common to find large-block sequential workloads that are multithreaded.

It is important to know which I/O threading model is used for your storage system’s LUNs. This determines which best practices to apply to your workload.

Application buffering, and concurrency

Many applications perform their own I/O buffering to coalesce file updates. Some mature products such as Microsoft Exchange, Microsoft SQL Server, and Oracle use application buffering to intelligently manage I/O and provide low response times. For example, some databases periodically re-index themselves to ensure low response times.

Detailed information on buffer configuration (also referred to as cache configuration) for many specific applications is available on Powerlink. For example, the white paper *EMC CLARiiON Storage Solutions: Microsoft Exchange 2007 - Best Practices Planning* specifically advises on cache configuration for the application.

Application concurrency (or parallelism) in an application allows the host to keep a number of drives busy at the same time. This utilizes the storage system most efficiently, whether for the random I/O of multiple

Microsoft Exchange databases, or in high-bandwidth applications that are benefited by the distribution of a large I/Os across multiple RAID groups. Application concurrency addresses the conflicting requirements for simultaneous reads and updates within the application to a single object or table row. It attempts to avoid overwriting, non-repeatable reading (reading a previously changed value), and blocking. The higher the I/O concurrency is, then the better the system's performance is. Applications can be configured to adjust concurrency internally. Review the workload application's configuration documentation for their best practices on concurrency configuration.

Volume managers

The greatest effect that host volume managers have on performance has to do with the way they stripe CLARiiON LUNs. The technique used is also known as a plaid or stripe on stripe. There are three different plaid techniques:

- Dedicated RAID group
- Multisystem
- Cross

The following figure shows the three plaid techniques.

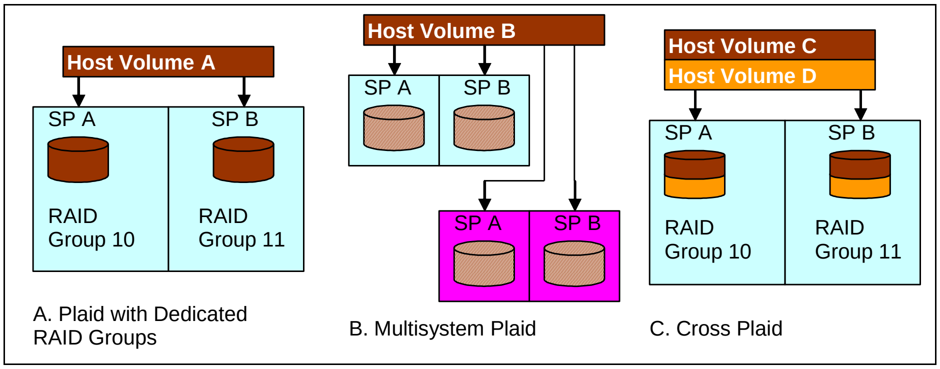


Figure 1 Plaid types

Dedicated RAID group

Only one storage processor can service a single LUN or metaLUN at a time. Configuration A in Figure 1 shows a plaid that allows distribution of a high-bandwidth load across both SPs.

Note that to fully drive each active path to a CLARiiON SP, a Fibre Channel host bus adapter (HBA) on the host for each SP is needed. For example, when planning to drive I/O simultaneously through two ports on SP A and two ports on SP B, at least four single-port Fibre Channel HBAs are needed on the host to achieve maximum bandwidth.

An iSCSI SAN requires a different configuration; it is best to use a TCP/IP-Offload-Engine (TOE) NIC or an iSCSI HBA. Otherwise, the combined traffic may overload either the host NIC or the host when the host CPU is handling the iSCSI-to-SCSI conversion.

Multisystem

Spanning storage systems is shown in configuration B in Figure 1. This configuration is suggested only when file-system sizes and bandwidth requirements warrant such a design. Note a software upgrade or any storage system fault—such as deactivation of the write cache due to a component failure on one storage system—may adversely affect the entire file system. A good example of a candidate for multisystem plaid is a 30 TB information system database that requires a bandwidth exceeding the write-bandwidth limits of one storage system.

The cross plaid

It is not uncommon for more than one host volume to be built from the same CLARiiON RAID groups (a cross plaid—see configuration C in Figure 1). The rationale for this design is a burst of random activity to any one volume group is distributed over many drives. The downside is determining interactions between volumes is extremely difficult. However, a cross plaid may be effective when:

- I/O sizes are small in size (8 KB or less) and randomly accessed.
- The volumes are subjected to bursts at different times of the day, not at the same time.

Plaid do’s

- Set the host manager stripe depth (stripe element) equal to the CLARiiON LUN stripe size. Use an integer multiple of the stripe size, but it is best to keep the stripe element at 1 MB or lower. For example, if the CLARiiON stripe size is 512 KB, make the host stripe element 512 KB or 1 MB.
- For simplicity, build host manager stripes from CLARiiON base LUNs. Do not build them from metaLUNs.
- Use LUNs from separate RAID groups; the groups should all have the same configuration (stripe size, drive count, RAID type, drive type, and so forth).

Plaid don’ts

- Avoid using host-based RAID implementations requiring parity (for example, RAID 3, 5, or 6). This consumes host resources for parity protection better handled by the storage system.
- Don’t stripe multiple LUNs from the same RAID group together. This causes large drive seeks. When combining multiple LUNs from one RAID group, concatenate contiguous LUNs—do not use striping.
- Don’t make the host stripe element less than the CLARiiON RAID stripe size.
- Don’t plaid together LUNs from RAID groups with differing RAID types, stripe sizes, or radically different drive counts. The result is not catastrophic, but it is likely to give uneven results.

Plaids for high bandwidth

- Plaids are used in high-bandwidth applications for several reasons:
- Plaids can increase concurrency (parallel access) to the storage system.
- Plaids allow more than one host HBA and CLARiiON SP to service a single volume.
- Very large volumes can be split across more than one CLARiiON system.

Increasing concurrency

Plaids are useful when applications are single-threaded. If the application I/O size fills the volume manager stripe, the volume manager can access the LUNs making up the volume concurrently.

Plaids and OLTP

OLTP applications are hard to analyze and suffer from hot spots. A hot spot is a RAID group with a higher-than-average drive utilization. Plaids are an effective way to distribute I/O across many hard drives. An application that can keep many drives busy benefits from a high drive count.

Note some volume managers recommend small host stripes (16 KB to 64 KB). This is not correct for CLARiiON LUNs, which use a striped RAID type. For OLTP, the volume manager stripe element should be set to the CLARiiON stripe size (typically 128 KB to 512 KB). The primary cost of a plaid for OLTP purposes is most users end up with a cross plaid.

HBAs

The network topology used for host attach depends on the goals of the system. More than one HBA is always recommended for both performance and availability. The positive performance effect of HBAs is in their use for multipathing. Multiple paths give the storage system administrator the ability to balance a load across CLARiiON resources. The "PowerPath" section on page 25 has a description of CLARiiON multipathing.

Keep HBAs and their driver behavior in mind when tuning a storage system. The HBA firmware, the HBA driver version used, and the operating system of the host can all affect the maximum I/O size and the degree of concurrency presented to the storage system. The *EMC Support Matrix* service provides suggested settings for drives and firmware, and these suggestions should be followed.

Each HBA port should be configured on its switch with a separate zone that contains the HBA and the SP ports with which it communicates. EMC recommends a single-initiator zoning strategy.

File systems

Proper configuration of the host's file system can have a significant positive effect on storage system performance. Storage can be allocated to file systems through volume managers and the operating system. The host's file systems may support shared access to storage from multiple hosts.

File system buffering

File-system buffering reduces load on the storage system. Application-level buffering is generally more efficient than file-system buffering. Buffering should be maximized to increase storage system performance.

There are, however, some exceptions to the increased buffering advantage. The exceptions are:

- When application-level buffering is already being applied
- Hosts with large memory models

Ensure that application-level buffering and file-system buffering do not work to cross purposes on the host. Application-level buffering assumes the application (for example, Oracle) can buffer its I/O more intelligently than the operating system. It also assumes the application can achieve better I/O response time without the file system's I/O coalescing.

The extent of the file system resident in host memory should be known. With 64-bit operating systems, hosts can have up to 128 GB of main memory. With these large memory model hosts, it is possible for the entire file system to be buffered. Having the file system in memory greatly reduces the response times for read I/Os, which might have been buffered. Write I/Os should use a write-through feature to ensure persistence of committed data.

File-system coalescing

File-system coalescing can assist in getting high bandwidth from the CLARiiON. In most sequential-access operations, use the maximum contiguous and maximum physical file-system settings (when available) to maximize file-system coalescing. This increases the I/O size to the storage system, which helps improve bandwidth.

For example, this technique can be used with backup programs to coalesce 64 KB writes into full-stripe writes. Full stripe writes are very efficient with parity RAID groups when the write cache can be bypassed.

File-system I/O size

Coordinating the file-system I/O size with the application and the storage system may result in a positive performance effect.

Minimum I/O size: Ensure the application and file system are not working at cross purposes over minimum I/O size. File systems can be configured for a minimum I/O extent size. This is the smallest indivisible I/O request given to the storage system. Typical values are 4 KB, 8 KB, 16 KB, or 64 KB. Applications performing I/O at sizes smaller than the file system's extent size cause unnecessary data movement or read-modify-write activity.

Note that storage configured as raw partitions, whose request sizes are not limited by a file-system I/O size, do not have this constraint.

Review both the workload's applications and operating system's file-system documentation for recommendations on resolving the optimal minimum I/O size setting.

Maximum I/O size: If the goal is to move large amounts of data quickly, then a larger I/O size (64 KB and greater) will help. The storage system is very efficient at coalescing sequential writes in cache to full stripes on the RAID groups, as well as pre-reading large sequential reads. Large I/O sizes are also critical in getting good bandwidth from host-based stripes since they will be broken into smaller sizes according to the stripe topology.

File-system fragmentation

When the percentage of storage capacity utilization is high, file system defragmentation of FLARE LUNs can improve performance. EMC does not recommend that you defragment pool-based LUNs or FAST Cache LUNs.

A fragmented file system decreases storage system throughput by preventing sequential reads and writes. In a fragmented file system the hard drives seek more frequently and over a larger portion of the drive than they would if the data were located contiguously on the hard drive. In general, the longer a file system is in use, the more fragmented it becomes.

Fragmentation noticeably degrades performance when the drive's capacity starts to exceed 80 percent. In this case, there is likely to be difficulty finding contiguous drive space for writes without breaking them up into smaller fragments.

It is important to monitor the fragmentation state of the file system. You should regularly defragment the file system hosted on FLARE LUNs with defragmentation tools appropriate to the file system. Defragmentation should always be performed during periods of low storage system activity (off-hours).

Pool-based LUNs do not usually benefit from file system defragmentation the way FLARE LUNs do. The pool's allocation algorithms are such that defragmentation of files does not guarantee an increase in available pool capacity or performance. Thick LUNs may receive some benefit. Thin LUNs will receive no benefit or only the smallest benefit.

Thick LUNs pre-allocate their capacity within the pool. Because of this, there is the potential for some benefit in defragmenting them. More heavily fragmented thick LUNs benefit the most.

It is inadvisable to defragment thin LUNs. Defragmenting a thin LUN may reclaim space for the file system, but it does not return that capacity to the pool, just to the file system. The potential performance benefit of file consolidation also may not be realized. The defragmented files will likely not result in an optimal re-organization within the pool's storage. The highest pool performance comes when data is widely distributed across the pool's RAID groups. A thin LUN defragmentation may compact data that was previously widely and distributed into a small portion of a smaller number of RAID groups. This reduces overall pool performance.

You can shrink a host LUN to reclaim the defragmented file system capacity for the pool. LUN shrinks should only be used when severely fragmented pool LUNs have been defragmented. This is because a LUN shrink cannot reduce capacity below 50 percent of the original LUN's capacity.

In addition, pools implementing the FAST feature or supported by FAST Cache should not be defragmented. Defragmentation makes assumptions about the physical layout and physical locality of data based on the file system's logical locality. This assumption is not correct within a tiered pool or a pool supported by a secondary cache. Depending on the file system's allocation granularity the operation of the defragmentation may have an adverse effect on performance by changing the previously algorithmically selected contents of the tiers or the secondary cache. A small granularity, for example 4 KB, will result in changes that may require re-warming the tiers or cache. Larger sized granularity is likely to have no effect.

Defragmentation tools

EMC does not recommend any defragmentation tool over another. File-system fragmentation occurs independently of the operation of the storage system. The actions of any defrag tool are simply treated as I/O by the storage system.

Before using any defragmentation tool it is prudent to perform a full backup to ensure the safety of the file system. An effective alternative method to tool-based file-system defragmenting is to perform a file-level copy to another LUN, or by executing a backup and restore of the file system.

File-system alignment

A file system aligned with RAID group striping has reduced latency and increased throughput. However, only certain types of I/O will see any benefit from alignment. File-system misalignment adversely affects performance in two ways:

- Misalignment causes drive crossings.
- Misalignment makes it hard to stripe-align large uncached writes.

In a drive crossing, an I/O is broken across two drives. This is the most common misalignment case. The splitting of the I/O lengthens its duration. An aligned file system would quickly service the I/O with a single drive. Even if the drive operations are buffered by cache, the effect can be detrimental, as it will slow flushing from cache. Random reads, which by nature require drive access, are also affected. They are affected directly (they must wait for two drives to return data) and indirectly (the RAID group's drives are busier than they need to be).

The most common example is shown in Figure 2. Intel-based systems are misaligned due to metadata written by the BIOS. In an aligned system, the 64 KB write would be serviced by a single drive.

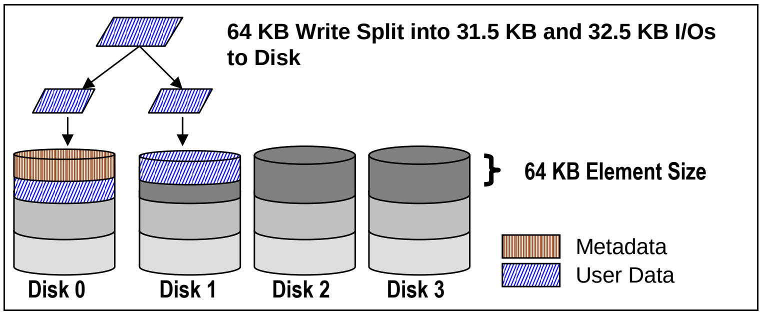


Figure 2 Effect of misalignment with a 63-block metadata area

Knowing the I/O type and size of the workload is important in understanding the benefits of alignment. The type and size of a data transfer is application-dependent.

A partition that has been aligned has a noticeable positive effect on response time when there is a high percentage of random I/O with block sizes of 16 KB or greater. Workloads of predominantly 4 KB I/Os will see a small advantage from alignment. Applications such as databases (Oracle, SQL Server, or IBM UDB/DB2) supporting multiple block sizes will see a positive performance effect from alignment when the larger (8 KB and 16 KB) block size is used.

With its default 64 KB stripe element size, all I/O larger than 64 KB will involve drive crossings. To minimize the number of crossings, partitions can be aligned on a stripe boundary. If a specific file system or application encourages the use of an aligned address space, and the offset is declared, EMC recommends using a host operating system drive utility be used to adjust the partitions. The Unisphere LUN bind offset facility should be used with caution, since it can adversely affect layered application synchronization rates.

File-system alignment procedure

Detailed information and instructions for performing file-system alignments for host operating systems can be found on Powerlink. For Microsoft-based file systems refer to the white paper *Using diskpar and diskpart to Align Partitions on Windows Basic and Dynamic Disks*. For VMware alignment, the *Using EMC CLARiiON Storage with VMware Infrastructure and vSphere Environments TechBook* is a good source. With Linux, align the partition table first using the fdisk utility with instructions provided on the `man` page.

Microsoft-based file-system alignment procedure

Microsoft Windows Server 2008, partitions are offset by the OS to 1 MB. This provides good alignment for the power-of-two stripe element sizes typically used by the storage system. In addition, be aware that Windows Server 2008 defaults to a smaller power-of-two offset for small drives.

Use the DiskPart command utility to align Microsoft Windows Server 2003 SP1 or later. To align a basic disk, use the align parameter to create a partition:

```
diskpart> create partition primary align = 1024
```

This makes the partition start at sector 2048. After aligning the drive, assign a drive letter to the partition before NTFS formatting. For more information about using the DiskPart command please refer to Microsoft Windows Server 2003 or 2008 documentation.

You cannot use the align command for dynamic disks; you must use the DiskPart command utility.

Linux file-system alignment procedure

The following procedure using `fdisk` may be used to create a single aligned partition on a second Linux file `sda` or `sdc` file-system LUN utilizing all the LUN's available capacity. In this example, this partition will be:

`/dev/nativedevicename.`

The procedure is:

```
fdisk /dev/nativedevicename # sda and sdc
n # New partition
p # Primary
1 # Partition 1
<Enter> # 1st cylinder=1
<Enter> # Default for last cylinder
 # Expert mode
b # Starting block
1 # Partition 1
128 # Stripe element = 128
w # Write
```

Aligning Linux file-system very large LUNs

To create an aligned partition larger than 2 TB the GUID Partition Table (GPT) drive partitioning scheme needs to be used. GPT is part of the Extensible Firmware Interface (EFI) initiative. GPT provides a more flexible mechanism for partitioning drives than the older Master Boot Record (MBR) partitioning scheme.

By default, a GPT partition is misaligned by 34 blocks. In Linux, use the **parted** utility to create and align a GPT partition.

The following procedure describes how to make a partition larger than 2 TB. In this example, this partition will be `/dev/sdx`. The `mkpart` command aligns a 2.35 TB partition to a 1 MB starting offset.

Following are the Linux commands needed to create a GPT partition:

```
# parted /dev/sdb
GNU Parted 1.6.19
Using /dev/sdb
(parted) mklabel gpt
(parted) p
Disk geometry for /dev/sdb: 0.000-2461696.000 megabytes
Disk label type: gpt
Minor    Start       End     Filesystem  Name                  Flags
(parted) mkpart primary 1 2461696
(parted) p
Disk geometry for /dev/sdb: 0.000-2461696.000 megabytes
Disk label type: gpt
Minor    Start       End     Filesystem  Name                  Flags
1          1.000 2461695.983
(parted) q
# mkfs.ext3 /dev/sdb1 # Use mkfs to format the file system
```

Availability

PowerPath

Failover is the detection of an I/O failure and the automatic transfer of the I/O to a backup I/O path. The host-resident EMC PowerPath® software integrates failover, multiple path I/O capability, automatic load balancing, and encryption. If available on the OS, we recommend PowerPath—whether for a single-attach system through a switch (which allows host access to continue during a software update), or in a fully redundant system.

A recommended introduction to PowerPath and its considerations is available in the latest revision of the *EMC PowerPath Product Guide* available on Powerlink.

Port load balancing

PowerPath allows the host to connect to a LUN through more than one SP port. This is known as *multipathing*. PowerPath optimizes multipathed LUNs with load-balancing algorithms. It offers several load-balancing algorithms. Port load balancing equalizes the I/O workload over all available channels. We recommend the default algorithm, ClarOpt, which adjusts for number of bytes transferred and for the queue depth.

Hosts connected to CLARiiONs benefit from multipathing. Direct-attach multipathing requires at least two HBAs; SAN multipathing also requires at least two HBAs. Each HBA needs to be zoned to more than one SP port. The advantages of multipathing are:

- Failover from port to port on the same SP, maintaining an even system load and minimizing LUN trespassing
- Port load balancing across SP ports and host HBAs
- Higher bandwidth attach from host to storage system (assuming the host has as many HBAs as paths used)

While PowerPath offers load balancing across all available active paths, this comes at some cost:

- Some host CPU resources are used during both normal operations, as well as during failover.
- Every active and passive path from the host requires an initiator record; there are a finite number of initiators per system.
- Active paths increase time to fail over in some situations. (PowerPath tries several paths before trespassing a LUN from one SP to the other.)

Because of these factors, active paths should be limited, via zoning, to two storage system ports per HBA for each storage system SP to which the host is attached. The exception is in environments where bursts of I/O from other hosts sharing the storage system ports are unpredictable and severe. In this case, four storage system ports per HBA should be used.

The *EMC PowerPath Version 5.5 Product Guide* available on Powerlink provides additional details on PowerPath configuration and usage.

Other multipath I/O applications (MPIO)

Applications other than PowerPath may be used to perform the MPIO function. These applications perform similarly to PowerPath, although they may not have the all the features or as close integration with the CLARiiON of PowerPath.

Microsoft Multi-Path I/O

Microsoft Multi-Path I/O (MPIO) as implemented by MS Windows Server 2008 provides a similar, but more limited, multipathing capability than PowerPath. Features found in MPIO include failover, failback, Round Robin Pathing, weighted Pathing, and I/O Queue Depth management. Review your Microsoft Server OS's documentation for information on available MPIO features and their implementation.

Linux MPIO

Linux MPIO is implemented by Device Mapper (`dm`). It provides a similar, but more limited, multipathing capability than PowerPath. The MPIO features found in Device Mapper are dependent on the Linux release and the revision. Review the *Native Multipath Failover Based on DM-MPIO for v2.6.x Linux Kernel and EMC Storage Arrays Configuration Guide* available on Powerlink for details and assistance in configuring Device Mapper.

ALUA

Asymmetric Logical Unit Access (ALUA) can reduce the effect of some front- and back-end failures to the host. It provides path management by permitting I/O to stream to either or both CLARiiON storage processors without trespassing. It follows the SCSI SPC-3 standard for I/O routing. The white paper *EMC CLARiiON Asymmetric Active/Active Feature* available on Powerlink provides an in-depth discussion of ALUA features and benefits.

Host considerations

PowerPath versions 5.1 and later are ALUA-compliant releases. Ensure usage of PowerPath version 5.1 or later, and reference "PowerPath" on page 25 for host compliance.

PowerPath load balances across optimized paths. It only uses non-optimized paths if all the original optimized paths have failed. For example when an optimized path to the original owning SP fails, it sends I/O via the non-optimal path to the peer SP. If path or storage processor failures occur, PowerPath initiates a trespass to change LUN ownership. That is, the non-optimized path becomes the optimized path, and the optimized path becomes the non-optimized paths.

Not all multipathing applications or revisions are ALUA compliant. Verify that your revision of MPIO or other native host-based failover application can interoperate with ALUA.

When configuring PowerPath on hosts that can use ALUA, use **Failover Mode 4**. This configures the CLARiiON for asymmetric Active/Active operation. This has the advantage of allowing I/O to be sent to a LUN regardless of LUN ownership. Details on the separate failover modes 1 through 4 can be found in the *EMC CLARiiON Asymmetric Active/Active Feature — A Detailed Review* white paper, available on Powerlink.

OS considerations

To take advantage of ALUA features, host software needs to be ALUA-compliant. Several operating systems support native failover with Active/Passive (A/P) controllers.

The next table shows the current ALUA status of some common operating systems.

Table 1 ALUA and Active/Passive Failover compliant OSs

Operating system	PowerPath with ALUA	Native with ALUA	PowerPath with A/P	Native with A/P
MS Windows Server 2008	Yes	Yes	Yes	No
W2K3	PP 5.1 and later	No	Yes	No
Win2K	PP 5.1 and later	No	Yes	No
HP-UX 11i v1 and v2	PP 5.1.1 and later	No	Yes	Yes (LVM)
HP-UX 11i v3	PP 5.1.1 and later	Yes	No	No
Solaris 9/10	PP 5.1 and later	Yes	Yes	Yes
Linux (RH and SuSE)	Yes	SLES 10 SP1 RHEL 4.6, 5.4	Yes	Yes
AIX	No	No	Yes	AIX 5.3 and higher
VMware ESX 3.x	No	No	No	Yes
VMware ESX 4.x	PP/VE 5.4 and later	Yes	PP/VE 5.4 and later	Yes

PowerPath with ALUA: ALUA features are provided when the specified PowerPath release is used with the noted operating system.

Native with ALUA: ALUA features are provided when using the noted operating system alone. (PowerPath is not required.)

PowerPath with A/P: Standard Active/Passive failover (not ALUA) is provided by PowerPath with the noted operating system. (PowerPath issues trespass commands to enable alternate paths by changing SP LUN ownership.)

Native with A/P: Standard Active/Passive failover (not ALUA) is provided when using the noted operating system alone. (OS issues trespass commands to enable alternate paths.)

Performance considerations

The optimized path is the normal operation path. ALUA has no effect on optimized path performance.

Performance is adversely affected on the non-optimized path.

Host I/O requests received over non-optimized paths are received by the storage processor not owning the destination LUN. These requests are then forwarded to the peer storage processor owning the LUN. This storage processor executes the I/O as though the request had been received directly. When the I/O completes, data or acknowledgements are forwarded back through the peer to be transmitted to the host.

The redirection, from storage processor to peer storage processor and back, increases I/O response time. The duration of the delay is dependent on the overall storage system, storage processor workloads, and the size of the I/O. Expect a 10-20 percent decrease in maximum IOPS, and up to a 50 percent decrease in bandwidth with non-optimum path usage.

Monitoring ALUA performance

A number of metrics have been created to describe requests arriving over optimized versus non-optimized paths. This path usage can be monitored through Unisphere Analyzer. In addition, metrics exist for total

I/O over all paths. These metrics describe the utilization of paths and the differences in performance. Information on how to use Unisphere Analyzer can be found in the *EMC Navisphere Analyzer Administrator's Guide*, available on Powerlink.

Queuing, concurrency, queue-full (QFULL)

A high degree of request concurrency is usually desirable, and results in good resource utilization. However, if a storage system's queues become full, it will respond with a **queue-full (QFULL)** flow control command. The CX4 front-end port drivers return a QFULL status command under two conditions:

- The practical maximum number of concurrent host requests at the port is above 1600 (port queue limit).
- The total number of requests for a given LUN is (14 * (the number of data drives in the LUN)) + 32

The host response to a QFULL is HBA-dependent, but it typically results in a suspension of activity for more than one second. Though rare, this can have serious consequences on throughput if this happens repeatedly.

The best practices 1600 port queue limit allows for ample burst margin. In most installations, the maximum load can be determined by summing the possible loads for each HBA accessing the port and adjusting the HBA LUN settings appropriately. (Some operating system drivers permit limiting the HBA concurrency on a global level regardless of the individual LUN settings.) In complex systems that are comprised of many hosts, HBAs, LUNs, and paths, it may be difficult to compute the worst-case load scenario (which may never occur in production anyway). In this case, use the default settings on the HBA and if QFULL is suspected, use Unisphere Analyzer (release 30 or later) to determine if the storage system's front-end port queues are full by following the steps described below. Information on how to use Unisphere Analyzer can be found in the Unisphere online help.

HBA queue depth settings usually eliminate the possibility of LUN generated QFULL. For instance, a RAID 5 4+1 device would require 88 parallel requests ((14*4) + 32) before the port would issue QFULL. If the HBA queue-depth setting is 32, then the limit will never be reached. A common exception is for RAID 1 (or RAID 1/0 (1+1)). For example, if the HBA queue-depth default setting was altered to a larger value (such as 64) to support greater concurrency for large metaLUNs owned by the same host, the RAID 1 device could reach queue-full because its limit is 46 requests(1*14)+32).

QFULL is never generated as a result of a drive's queue-depth.

Port statistics are collected for Unisphere Analyzer; this data includes several useful statistics for each individual port on the SP:

- Port queue-full – a counter has been added showing the number of QFULL signals issued due to port queue overflow
- Per-port bandwidth and IOPS

Usage

Consider all hosts connected to the storage system, and which LUNs they access. If necessary, set HBA throttles to limit concurrent requests to each LUN. Depending on the operating system, it may be possible to globally limit the total outstanding requests per HBA or per target. Set the HBA throttles of the hosts sharing a port so the total cannot exceed the port queue limit. Remember that multipathing to one LUN via multiple ports on the same SP may lead to exceeding the port queue limit.

If high concurrency is suspected and performance problems occur, check port statistics reported by Unisphere Analyzer for queue-fulls, and lower the HBA throttles if appropriate.

Storage network adapters and HBAs

Hosts use Fibre Channel HBAs to attach to Fibre Channel storage networks. A network interface card (NIC), iSCSI HBAs, and TCP/IP Offload Engines (TOE) with iSCSI drivers connect a host to an Ethernet network for iSCSI storage network support. HBAs, NICs, and TOEs share the host’s I/O bus bandwidth.

Host bus

Ensure the network adapter’s full bandwidth is supported by the host’s I/O bus hardware. (The host’s I/O bus is sometimes called the *peripheral bus*.) Knowing the number, distribution, and speed of the host’s buses is important to avoid bottlenecks within the host.

Entry-level and legacy hosts may have less internal I/O bus bandwidth than their network adapters or HBAs. For this reason it is important to verify that your host can handle the bandwidth of the network interfaces when using these protocols: Fibre Channel networks that are faster than 4 Gb/s; 10 Gb/s Ethernet; and 10 Gb/s Fibre Channel over Ethernet (FCoE). In addition, when more than one adapter is present on a host I/O bus, remember that these adapters share the available bus bandwidth, and it is possible for the summed bandwidth requirement of the adapters to exceed the host’s available bus bandwidth.

The ratio of network adapter ports to buses needs to be known. A host may have more than one internal bus. The distribution of bus slots accepting network adapters to buses is not always obvious. Review the number of network adapters, and the number of ports per network adapter that are being attached to each of a host’s individual buses. Ensure that network adapters are connected to fast (>66 MHz) and wide (64-bit) PCI, PCI-X, and four-lane (x4) or greater PCI Express (PCIe) 1.1 or 2.0 host buses. In all cases, the host I/O bus bandwidth needs to be greater than the summed maximum bandwidth of the network adapters to avoid a bottleneck.

HBAs

High availability requires two HBA connections to provide dual paths to the storage network or if directly connected, to the storage system.

It is a best practice to have redundant HBAs. Either multiport (dual or quad) or multiple single-port HBAs may be used. Using more than one single-port HBA enables port- and path-failure isolation, and may provide performance benefits. Using a multiport HBA provides a component cost savings and efficient port management that may provide a performance advantage. For example, multiport HBAs are useful for hosts with few available I/O bus slots. The liability is a multiport HBA presents a single point of failure for several ports. Otherwise, with a single-ported HBA, a failure would affect only one port. HBAs should also be placed on separate host buses for performance and availability. Note this may not be possible on smaller hosts that have a single bus or a limited number of bus slots. In this case, multiport HBAs are the only option.

Always use an HBA rated for or exceeding the bandwidth of the storage network’s maximum bandwidth. Ensure that legacy 1 Gb/s or 2 Gb/s HBAs are not used for connections to 4 Gb/s or higher SANs. FC SANs reduce the speed of the network path to the HBA’s lower speed either as far as the first connected switch, or to the storage system’s front-end port when directly connected. This may bottleneck the overall network when bandwidth is intended to be maximized.

Finally, using the current HBA firmware and driver from the manufacturer generally has a positive effect on performance and availability. The CLARiiON Procedure Generator (installation available through Powerlink) provides instructions and the configuration settings for HBAs specific to your storage system.

Network interface cards (NIC), TCP/IP offload engines (TOE), and iSCSI host bus adapters (HBA)

Three host devices connect hosts to iSCSI SANs: NICs, TOEs, and iSCSI HBAs. The differences in the devices include cost, host CPU utilization, and features (such as security). The same server *cannot* use both NICs and HBAs for paths to iSCSI storage systems.

NICs are the typical way of connecting a host to an Ethernet network. They are supported by software iSCSI initiators on the host.

Ethernet networks will auto-negotiate down to the lowest common device speed. Using a lower-rated NIC may bottleneck the storage network’s bandwidth. When possible, use a NIC rated for or exceeding the bandwidth of the available Ethernet network. Do not use legacy 10 Mb/s or 100 Mb/s NICs for iSCSI SAN connections to 1 Gb/s or higher Ethernet networks.

A TOE is a faster type of NIC. A TOE has on-board processors to handle TCP packet segmentation, checksum calculations, and optionally IPSec (security) offload from the host CPU on to themselves. This allows the host CPU(s) to be used exclusively for application processing.

In general, iSCSI HBAs are the most scalable interface. On iSCSI HBAs the TCP/IP and iSCSI processing is offloaded to the HBA. This reduces host CPU utilization. An iSCSI HBA also allows booting off an iSCSI target. This is an important consideration when considering diskless host booting. HBAs also typically provide for additional services such as security.

The decision to use an iSCSI HBA versus a TOE, versus a NIC is dependent on the percentage CPU utilization of the host when it is processing workload(s). On small hosts, and hosts with high CPU utilizations, a TOE or iSCSI HBA can lower the host’s CPU utilization. However, using an HBA or TOE may increase workload response time. In addition, an iSCSI HBA or TOE costs more than a conventional NIC. On large hosts or hosts not affected by high CPU utilization, we recommend a conventional NIC. Note that to work on an iSCSI SAN, the NIC must support the iSCSI protocol on the host. Check with the NIC’s manufacturer for the appropriate driver support.

Redundant NICs, iSCSI HBAs, and TOEs should be used for availability. NICs may be either single or multiported. A host with a multiported NIC or more than one NIC is called a *multihomed* host. Typically, each NIC or NIC port is configured to be on a separate subnet. Ideally, when more than one NIC is provisioned, they should also be placed on separate host buses. Note this may not be possible on smaller hosts having a single bus or a limited number of bus slots, or when the on-board host NIC is used.

All NICs do not have the same level of performance. This is particularly true of host on-board (mainboard) NICs, 10 Gb/s NICs, and 10 Gb/s HBAs. For the most up-to-date compatibility information, consult the *EMC Support Matrix* (ESM), available through *E-Lab Interoperability Navigator* (ELN) at: http://elabnavigator.EMC.com.

Finally, using the current iSCSI initiator, NIC, TOE, or iSCSI HBA firmware and driver from the manufacturer generally has a positive effect on performance and availability. You can use the web page at http://corpusweb130.corp.emc.com/upd_prod_CX4/ to create custom documentation that provides instructions and configuration settings for NICs and TOEs in your storage system configuration.

Chapter 3 Network Best Practices

Network best practices advise on the software and hardware configurations of the iSCSI and Fibre Channel network infrastructure that attaches hosts to storage systems and their effect overall storage system performance and availability.

A recommended introduction to storage system networks and networking performance considerations can be found in the *EMC Networked Storage Topology Guide* available on Powerlink.

Performance

iSCSI LAN

Avoiding iSCSI network congestion is the primary consideration for iSCSI LAN performance. It is important to take network latency and the potential for port oversubscription into account when configuring your network. Network congestion is usually the result of poor network configuration or improper network settings. Network settings include IP overhead and protocol configuration of the network's elements. The following recommendations should be implemented as a minimum to ensure the best performance.

Network latency

Both bandwidth and throughput rates are subject to network conditions and latency.

It is common for network contentions, routing inefficiency, and errors in VLAN configuration to adversely affect iSCSI performance. It is important to profile and periodically monitor the network carrying iSCSI traffic to ensure the best iSCSI connectivity and SAN performance. In general, simple network topologies offer the best performance.

Latency can contribute substantially to iSCSI system performance. As the distance from the host to the CLARiiON increases, a latency of about 1 millisecond per 200 kilometers (125 miles) is introduced. This latency has a noticeable effect on WANs supporting sequential I/O workloads. For example, a 40 MB/s 64 KB single stream would average 25 MB/s over a 200 km distance. EMC recommends increasing the number of streams to maintain the highest bandwidth with these long-distance, sequential I/O workloads.

Network separation

It is important to separate the storage processor management ports into separate subnets from the iSCSI network ports. Also, try to separate the CLARiiON's storage processors onto separate subnet addresses. Do this by placing SP A's ports on one subnet address and SP B's ports on a different subnet address. VLANs are a convenient way to configure the network this way. (See the "VLANs" sections next.)

Note that the private 192.168.x.x and 128.221.x.x subnets must *not* be used for iSCSI or CLARiiON management port traffic. These subnets are used internally by the CLARiiON. If necessary use the 10.x.x.x or 172.16.0.0 through 172.31.255.255 private networks in their stead.

Bandwidth-balanced configuration

A balanced bandwidth iSCSI configuration is when the host iSCSI initiator's bandwidth is greater than or equal to the bandwidth of its connected storage system's ports. Generally, configure each NIC or HBA port to only two storage system ports (one per SP). One storage system port should be configured as active, and the other to standby. This avoids oversubscribing a host's ports.

Network settings

Manually override auto-negotiation on the host NIC or HBA and network switches for the following settings. These settings improve flow control on the iSCSI network:

- Jumbo frames
- Pause frames
- Delayed ACK

Jumbo frames

On a standard Ethernet network the frame size is 1500 bytes. Jumbo frames allow packets configurable up to 9,000 bytes in length. Using jumbo frames can improve iSCSI network throughput by up to 50 percent. When supported by the network, we recommend using jumbo frames to increase bandwidth.

Jumbo frames can contain more iSCSI commands and a larger iSCSI payload than normal frames without fragmenting (or less fragmenting depending on the payload size). If using jumbo frames, all switches and routers in the paths to the storage system must support and be capable of handling and configured for jumbo frames. For example, if the host and the CLARiiON's iSCSI ports can handle 4,470-byte frames, but an intervening switch can only handle 4,000 bytes, then the host and CLARiiON's ports should be set to 4,000 or greater bytes. (The CX4 series supports 4,000, 4,080, or 4,470 MTUs.)

Pause frames

Pause frames are an optional flow-control feature that permits the host to temporarily stop all traffic from the storage system. Pause frames are intended to enable the host's NIC or HBA, and the switch, to control the transmit rate. Due to the characteristic flow of iSCSI traffic, pause frames should be disabled on the iSCSI network because they may cause the delay of traffic unrelated to specific host port to storage system links.

Delayed ACK

On MS Windows-, Linux-, and ESX-based hosts, *Delayed ACK* delays an acknowledgement for a received packet. Delayed ACK should be disabled.

When enabled, an acknowledgment is delayed up to 0.5 seconds or until two packets are received. Storage applications may time out during this delay. A host sending an acknowledgment to a storage system after the maximum of 0.5 seconds is possible on a congested network. Because there was no communication between the host computer and the storage system during that 0.5 seconds, the host computer issues Inquiry commands to the storage system for all LUNs based on the delayed ACK. During periods of congestion and recovery of dropped packets, delayed ACK can slow down the recovery considerably, resulting in further performance degradation.

General iSCSI usage notes

The following general recommendations apply to iSCSI usage:

- iSCSI is not recommended with applications having the highest bandwidth requirements, including high-performance remote replication.
- When possible, use a dedicated LAN for iSCSI storage traffic, or segregate storage traffic to its own virtual LAN (VLAN).
- Use the most recent version of the iSCSI initiator supported by EMC, and the latest version NIC driver for the host supported by EMC; both are available on the EMC E-Lab Interoperability Matrix.
- Configure iSCSI 1 Gb/s (GigE) and 10 Gb/s (10 GigE) ports to Ethernet full duplex on all network devices in the initiator-to-target path.
- Use CAT6 cabling on the initiator-to-target path whenever possible to ensure consistent behavior at GigE speeds.
- Use jumbo frames and TCP flow control for long-distance transfers or with networks containing low-powered servers.
- Use a ratio of 1:1 SP iSCSI ports to NICs on GigE SANs for workloads with high read bandwidths. 10 GigE SANs can use higher ratios of iSCSI ports to NICs.
- Ensure the Ethernet connection to the host is equal to or exceeds the bandwidth rating of the host NIC.
- Ensure the Ethernet connection to the CLARiiON is equal to or exceeds the bandwidth of the CLARiiON's iSCSI FlexPort.

Availability

FC SAN

Dual or multiple paths between the hosts and the storage system are required. This includes redundant HBAs, a robust fabric implementation, strictly following management policies and procedures, and dual attachment to storage systems. Path management software such as PowerPath and dynamic multipathing software on hosts (to enable failover to alternate paths and load balancing) are recommended.

For device fan-in, connect low-bandwidth devices such as tape, and low utilized and older, slower hosts to edge switches or director blades.

iSCSI LAN

Redundancy and configuration

We recommend Dual Ethernet networks to ensure redundant communications between hosts and storage systems.

Separation

We recommend that you use a dedicated storage network for iSCSI traffic. If you do not use a dedicated storage network, iSCSI traffic should be either separated onto a separate physical LAN, separate LAN segments, or a *virtual* LAN (VLAN).

With VLANs, you can create multiple *virtual* LANs, as opposed to multiple *physical* LANs in your Ethernet infrastructure. This allows more than one network to share the same physical network while maintaining a logical separation of the information. FLARE release 29.0 and later support VLAN tagging (IEEE 802.1q) on 1 Gb/s and 10 Gb/s iSCSI interfaces. Ethernet *switch-based* VLANs are supported by all FLARE revisions.

VLAN tagging with the compatible network switch support isolates iSCSI traffic from general LAN traffic; this improves SAN performance by reducing the scope of the broadcast domains. For more information about VLANs and VLAN tagging, please refer to the *VLAN Tagging and Routing on EMC CLARiiON* white paper available on Powerlink.

The following table shows the number of VLANs that may be active per iSCSI port.

Table 2 Maximum VLANs per iSCSI port

iSCSI FlexPort speed	Max. VLANs
1 Gb/s	2
10 Gb/s	8

Chapter 4 Storage System Best Practices

Storage system best practices advise on the software and hardware configurations of the CLARiiON CX4 series and AX4 series storage systems, and affect overall storage system performance and availability.

A recommended introduction to the storage system can be found in the white paper *Introduction to the EMC CLARiiON CX4 Series Featuring UltraFlex Technology*.

Performance

Front-end ports

All CX4 series models come with both iSCSI and FC front-end ports. Front-end ports are located on UltraFlex I/O modules. Each module has two or more ports of the same type, either iSCSI or FC.

iSCSI ports

All CX4 models offer GigE iSCSI ports running at a maximum of 1 Gb/s as part of their standard configuration. To maximize IOPS in iSCSI communications, connect 10 Gb/s iSCSI ports to only 10 Gb/s Ethernet networks. 10 GigE iSCSI ports are available as a CLARiiON upgrade. 10 GigE iSCSI ports are supported by FLARE 29.0 and later. (For more information, see the "Network Best Practices" chapter.)

GigE iSCSI ports accept copper cabling; we recommend CAT6. 10 GigE iSCSI ports accept optical cabling; for full speed operations we recommend that you use Shortwave Optical OM2 at ≤50m or OM3 for <380m.

iSCSI front-end ports do not auto-negotiate downward to all Ethernet speeds. CLARiiON iSCSI ports do not support 10 Mb/s connections. If the Ethernet storage network infrastructure is designed with 100 Mb/s switches and components, the GigE ports will run at 100 Mb/s. The 10 GigE iSCSI ports will *not* auto-negotiate downward: they will only run at 10 Gb/s. Check with the ESM for supported Ethernet speeds and configurations.

Storage systems can be connected to iSCSI ports on one host and Fibre Channel hosts on another host at the same time. However, a storage system cannot be connected to the Fibre Channel and iSCSI data ports of a single host. In addition, a server cannot be connected to the same storage system through both NICs and iSCSI HBAs.

iSCSI processing requires more SP CPU resources than Fibre Channel processing. Workloads made up of small I/O requests with a high cache hit rate can cause high SP CPU utilization. T*his is particularly true with 10 GigE iSCSI.* EMC recommends a Fibre Channel connection for workloads with the highest transaction rate.

Each CX4 series model has at least two GigE UltraFlex iSCSI I/O controller modules, one per SP. A single UltraFlex iSCSI controller drives a pair of iSCSI ports. The two ports share the controller's total bandwidth and its IOPS. The write bandwidth is not shared equally between the ports when both ports are used at the same time. The following table shows the IOPS and bandwidth available for iSCSI ports.

Table 3 iSCSI port bandwidth and IOPS

	GigE iSCSI	
	Both ports	**Single port**
Bandwidth (MB/s)		
Reads	220	110
Writes	158	110
IOPS		
Reads	30,000	15,000
Writes	15,000	11,000

GigE iSCSI

The controller can drive both ports at once to full Gb/s bandwidth for reads. Writes are different. When both ports are active, available per-port write bandwidth is not double the single port rate.

When processing iSCSI I/O sizes larger than 64k, there may be limits imposed by either host and network, or storage system variations on implementation. Block size and workload determine iSCSI performance. For large block and sequential workloads on 1 Gb/s networks, bandwidth is limited by the ports' capability of about 100 MB/s per iSCSI port. For small block random workloads with a 2:1 read/write ratio on RAID 5 with 240 drives (CX4-240 and CX4-480, two iSCSI ports per SP), iSCSI ports scale linearly to about 20,000 front-end IOPS. Throughput of iSCSI closely follows FC performance in this range. A CX4-120 with 120 drives is located midway in this range. The CX4-960 with three iSCSI ports per SP scales linearly to about 30,000 front-end IOPS provided a drive bottleneck is avoided with enough drives. To achieve higher rates, EMC recommends using FC connections. Use Fibre Channel when you expect high bandwidth workloads.

10 GigE iSCSI

The 10 Gb/s iSCSI ports offer more IOPS than the 1 Gb/s ports. In addition they support a greater number of VLAN ports. These ports are useful if you want to have many iSCSI hosts share a single port. For high bandwidth workloads, we recommend that you use 8 Gb/s Fibre Channel front-end ports.

Additional ports

Additional iSCSI ports are configurable with all models. The additional iSCSI ports reduce the number of Fibre Channel ports configurable.

Table 4 CX4 maximum iSCSI ports per SP

Maximum iSCSI Ports	CX4-120	CX4-240	CX4-480	CX4-960
GigE (only)	8	12	12	16
GigE and 10 GigE	4	6	6	6 or 8
10 GigE (only)	2	2	4	4

Usage

For best performance distribute the load equally across all front-end ports. For the production workload, the front-end bandwidth of the storage system's ports should ideally be about the same for both SPs. Splitting the workload's bandwidth needs between both SPs lowers SP utilization. This results in lower response time. Balancing the bandwidth may require trespassing LUNs between SPs or adding additional front-end connections to a host. For high availability, hosts should always have at least one front-end port connection to each SP on the storage system.

Adding additional ports helps to achieve the full storage system bandwidth performance in a wider range of configurations. They do not increase previous SP maximums (Table 8 on page 40 has more information), since the memory bandwidth remains the same.

For small-block random workloads, extra buses and ports make little performance difference.

FC ports

All CX4 models offer Fibre Channel ports running at a maximum of 4 Gb/s as part of their configuration. 8 Gb/s UltraFlex Fibre Channel ports are an available upgrade. You need to have FLARE revision 29.0 (or later) to install 8 Gb/s ports.

Maximize available bandwidth by connecting Fibre Channel ports to 4 Gb/s or faster SANs. (See the "Network Best Practices" chapter.)

Connections to Fibre Channel and iSCSI hosts are supported simultaneously. However, a host can only be connected a storage system's FC ports or iSCSI ports; it cannot be connected to both types at the same time.

All CX4 models have at least two Fibre Channel ports per SP, with additional ports as an added option. The use of additional front-end connections for hosts can reduce the number of Fibre Channel switches needed in the storage network. All available bandwidth should be distributed across all ports. For high availability, hosts should always have at least one front-end FC port connection to the storage system's peer SP.

To receive the full benefit of the FC port bandwidth, a 4 Gb/s or higher FC SAN is required. The standard CX4 FC ports have the following bandwidth capability:

Table 5 Fibre Channel port bandwidth

FC port speed	Bandwidth (MB/s) per FC port
4 Gb/s	360
8 Gb/s	700

Usage

Note the high bandwidth available with the 8 Gb/s Fibre Channel front-end port. Using 8 Gb/s front-end ports, it is possible to reduce the number of SAN switch ports connecting to the storage system. For example, two 4 Gb/s front-end ports can be merged into one 8 Gb/s port. At full duplex, both ports of the dual 8 Gb/s channel module cannot be active at their maximum bandwidth,

If the 4 Gb/s ports are connected to a SAN with a 1 Gb/s or 2 Gb/s FC infrastructure, the CX4's 4 Gb/s FC ports will run at that speed. The 8 Gb/s FC ports will run connected to a 2 or 4 Gb/s FC SAN with reduced bandwidth performance. Note that 8 Gb/s FC ports will not auto-negotiate to 1 Gb/s.

Additional Fibre Channel ports

Additional Fibre Channel ports are configurable with all models. The additional Fibre Channel ports reduce the number of iSCSI ports configurable. The number of back-end ports of all CX4 models is fixed, with the exception of the CX4-960. Table 8 has more information.

Table 6 shows the maximum front-end Fibre Channel ports per SP. For example, the maximum number of CX4-480 front-end FC ports is 16. This maximum could be reached with a combination of eight 8 Gb/s FC front-end ports and eight 4 Gb/s front-end FC ports on a storage system.

Table 6 Maximum Fibre Channel ports per SP

	CX4-120	CX4-240	CX4-480	CX4-960
Max FC ports	2 or 6	2 or 6	4 or 8	4, 8, or 12*

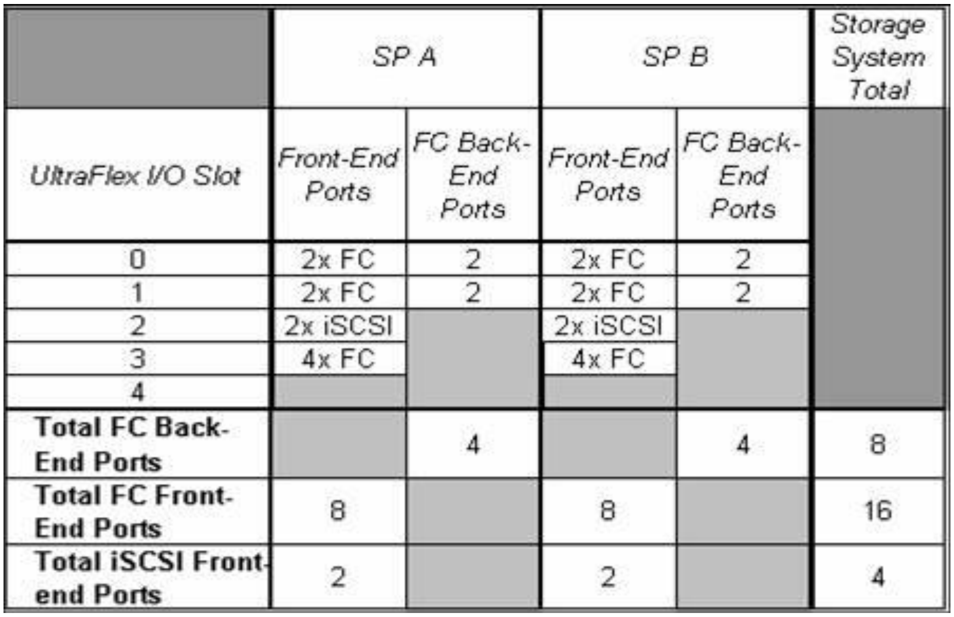
* with CX4-960 drive expansion enabler installed options may vary.

An extended example may help to illustrate the addition of ports. A CX4-480 has five UltraFlex I/O slots per SP. Note that this maximum configuration only fills four of the five available UltraFlex I/O slots on each SP.

In its baseline configuration three I/O slots per SP are used. The baseline CX4-480 starts out with eight front-end FC ports (four per SP), eight back-end FC ports (four per SP), and four front-end iSCSI ports (two per SP). This configuration leaves four I/O slots (two per SP) available for expansion to the CX4-480's maximum of 12 FC ports. The baseline configuration already contains the maximum eight FC back-end ports (four per SP).

Four additional FC ports can be installed in each of two available slots. This would configure the CX4-480 to its maximum FC port configuration: eight front-end FC ports per SP for a total of 16 (eight per storage processor) for the storage system. Table 7 shows the final configuration. Note the table does not show a maximally provisioned storage system.

Table 7 16x FC front-end port CX4-480



	SP A		SP B		Storage System Total
UltraFlex I/O Slot	Front-End Ports	FC Back-End Ports	Front-End Ports	FC Back-End Ports	
0	2x FC	2	2x FC	2	
1	2x FC	2	2x FC	2	
2	2x iSCSI		2x iSCSI		
3	4x FC		4x FC		
4					
Total FC Back-End Ports		4		4	8
Total FC Front-End Ports	8		8		16
Total iSCSI Front-end Ports	2		2		4

Storage processor

EMC's CX4 line of storage systems differs from the previous generation in capacities and capabilities. In general, the differences include:

- Faster multi-cored, SP CPUs with increased cache memory
- Increased main memory
- Larger number of hard drives supported
- Newer, larger capacity, Fibre Channel hard drives; large capacity, energy-efficient SATA hard drives; and solid state Flash drives are supported
- 4 Gb/s Fibre Channel, and 1 Gb/s iSCSI ports standard, with several configuration options including 8 Gb/s Fibre Channel and 10 Gb/s iSCSI as upgrades
- More than one 4 Gb/s Fibre Channel back-end bus on most models (CX4-120 is the exception)

The characteristics of the CX4 family of storage processors are shown in Table 8. Refer to this table to resolve features and functions having a model-based dependency.

Table 8 CX4 family characteristics

Components/ Connectivity	CX4-120	CX4-240	CX4-480	CX4-960
Processor architecture per SP[1]	1 (Dual core) processor 1.2 GHz	1 (Dual-core) processor 1.6 GHz	1 (Dual-core) processor 2.2 GHz	2 (Quad-core) processor 2.33 GHz
Physical memory per SP	3 GB	4 GB	8 GB	16 GB
Back-end 4-Gb/s FC ports per SP[2]	1	2	4	4 or 8[3]
Max drives per storage system	120	240	480	960
Min drives per storage system	5	5	5	5
Max hot spares per storage system	115	235	475	955
Max initiators per storage system	512	1024	2048	8192
Max H/A hosts per storage system	128	256	256	512
Max LUNs per storage system	1024	2048	4096	8192
Max RAID groups per storage system	60	120	240	480
Max drives per RAID group	16	16	16	16
Max LUNs per RAID group	256	256	256	256

Write cache configuration

The CLARiiON CX4 series has larger caches than previous CLARiiONs. These caches are highly configurable. The allocation of read and write cache can be tuned to achieve optimal performance for individual workloads.

[1] All models in the CX4 series have two SPs.

[2] Application available only on the front-end FC ports.

[3] Enabler software is required for 8 back-end buses.

The amount of SP memory available for read and write cache depends on the CLARiiON model. For optimal performance, always allocate all the memory available for caching to read and write cache. Note that the use of the FAST Cache and LUN Compression features (FLARE revision 30.0 and later) decreases the amount of memory available for read/write cache usage. See the “FAST Cache” and “LUN compression” sections for details.

If you wish, you may allocate all of the storage system’s memory be used as write cache. The following table shows the maximum possible cache allocations. Storage system write cache is mirrored between SPs so that write cache’s contents will not be lost if there is a system failure. A single write cache allocation applies to both SPs. Because of this mirroring, allocating write cache consumes twice the amount of the allocation. (Each of the two SPs receives the same allocation taken from memory.) For example, if you allocate 250 MB to write cache, 500 MB of system memory is consumed.

Read cache is not mirrored. When you allocate memory for read cache, you are only allocating it on one SP. Because of this, SPs always have the same amount of write cache, but they may have different amounts of read cache. To use the available SP memory efficiently, in practice it’s best to allocate the same amount of read cache to both SPs.

Table 9 Maximum cache allocations in FLARE 29

	CX4-120	CX4-240	CX4-480	CX4-960
Maximum Storage System Cache (MB)	1196	2522	8996	21520
Maximum Storage System Write Cache (MB)	598	1261	4498	10760/6000*
Maximum Read Cache per SP (MB)	598	1261	4498	10760

*** CX4-960 write cache is a lower number with a 2 Gb/s DAE 0 installed.**

Allocating read and write cache recommendations

Generally, for storage systems with 2 GB or less of available cache memory, use about 20 percent of the memory for read cache and the remainder for write cache. For larger capacity cache configurations, use as much memory for write cache as possible while reserving about 1 GB for read cache. Specific recommendations are as follows:

Table 10 CX4 recommended cache settings

	CX4-120	CX4-240	CX4-480	CX4-960
Write Cache (MB)	498	1011	3600	9760
Read Cache (MB)	100	250	898	1000
Total Cache (MB)	598	1261	4498	10760

Watermarks

Watermarks help manage write cache flushing. The goal of setting watermarks is to avoid forced flushes while maximizing write cache hits. Using watermarks, cache can be tuned to decrease response time while maintaining a reserve of cache pages to match the workload's bursts, and system maintenance.

CLARiiON has two watermarks: high and low. These parameters work together to manage the flushing conditions. Watermarks only apply when write cache is activated. The margin of cache above the high watermark is set to contain bursts of write I/O and to prevent forced flushing. The low watermark sets a minimum amount of write data to maintain in cache. It is also the point at which the storage system stops high water or forced flushing. The amount of cache below the low watermark is the smallest number of cache pages needed to ensure a high number of cache hits under normal conditions. This level can drop when a system is not busy due to idle flushing.

The default CLARiiON watermarks are shown in the following table:

Table 11 Default watermark Settings

CLARiiON Default Cache Watermarks		
	High	Low
CLARiiON CX-series (All models)	80	60

The difference between the high watermark and the low watermark determines the rate and duration of flushing activity. The larger the difference is, the less often you will see watermark flushing. The flushing does not start until the high watermark is passed. Note that if there is a wide difference between the watermarks, when flushing does occur, it will be very heavy and sustained. Intense flushing increases LBA sorting, coalescing, and concurrency in storage, but it may have an adverse effect on overall storage system performance. The smaller the difference between the watermarks, the more constant the flushing activity. A lower rate of flushing permits other I/Os (particularly reads) to execute.

In a bursty workload environment, lowering both watermarks will increase the cache's "reserve" of free pages. This allows the system to absorb bursts of write requests without forced flushing. Generally, with the mid-model CLARiiON arrays (CX4-480) and lower, the high watermark should be 20 percent higher than the low watermark. Otherwise, the high watermark may be set to be 10 percent higher than the low watermark

The amount of storage system configurable cache is reduced when the optional FAST Cache feature is enabled. The smaller cache affects the storage system's ability to handle bursts of I/O activity. Adjust the watermarks after installing the FAST Cache enabler to handle expected I/O with the reduced amount of write cache.

Vault drives

The first five drives 0 through 4 in DAE0 in a CLARiiON CX4 are the system drives that contain the saved write cache in the event of a failure, the storage system's operating system files, the Persistent Storage Manager (PSM), and the FLARE configuration database. These drives are also referred to as the system drives.

System drives can be used just as any other drives on the system. However, system drives have less usable capacity than data drives because they contain storage system files. In addition, avoid if possible placing any response-time-sensitive data on the vault drives. Also, the reserved LUN pool LUNs, clone private LUNs, write intent logs, clone, and mirror LUNs should not be placed on the vault drives.

Vault drive capacity

Vault drives on the CX4 series use about 62 GB of their per-drive capacity for system files.

Bind the vault drives together as a RAID group (or groups). This is because when vault drives are bound with non-vault drives into RAID groups, all drives in the group are reduced in capacity to match the vault drive's capacity.

Vault and PSM effects

The first four drives of the vault contain the SP's operating system. After the storage system is booted, the operating system files are only occasionally accessed. Optimal performance of the storage system's OS requires prompt access. To ensure this performance, EMC recommends using high-performance Fibre Channel, SAS, and Flash drives for the vault.

The first three drives of the vault contain the PSM and FLARE configuration database. The PSM and FLARE configuration database are used for storing critical storage system state information. SP access to the PSM is light, but the system requires undelayed access to the drives to avoid a delayed response to Unisphere Manager commands.

All five of the vault drives are used for the cache vault. The cache vault is only in use when the cache is dumping, or after recovery when it is being reloaded and flushed to the drives. With the CX4 series persistent cache, this is an uncommon event. However, during these times, host I/O response to these drives will be slowed.

Vault drives may be used for moderate host I/O loads, such as general-purpose file serving. For these drives, restrict usage to no more than shown in the table below.

Table 12 Maximum host I/O loads for vault drives

Vault hard drive type	Max. IOPS	Max. bandwidth (MB/s)
Fibre Channel	100	10
SAS	100	10
SATA	50	5
Flash drive	1500	60

In general, when planning LUN provisioning, distribute busy LUNs equally over the available RAID groups. If LUNs are provisioned on RAID groups composed of vault drives do not assume the full bandwidth of these RAID groups will be available. Plan bandwidth utilization for LUNs on vault drives as if they are sharing the drives with an already busy LUN. This will account for the CLARiiON's vault drive utilization.

Flash drives as vault drives

Starting with FLARE revision 28.5, Flash drives and SATA drives can be configured as vault drives. SATA drives and Flash drives have the same vault capacity restrictions as Fibre Channel and SAS drives. Flash drives installed in vault drive locations cannot be used to create a FAST Cache. (See the "FAST Cache" section.) This is restricted through FLARE.

Starting with release 30, Flash drives are available with either SATA or Fibre Channel attachments. The same configuration rules apply to Flash drives of all attachment types.

Note that Flash drives with both attachments and mechanical Fibre Channel drives can be hosted together in the same DAE. Flash drives and mechanical SATA hard drives *cannot* share a DAE. In addition, Fibre Channel and mechanical SATA drives *cannot* be provisioned to share the same DAE.

Different drives have different bandwidth and IOPS restrictions. Flash drives have more bandwidth and IOPS than mechanical hard drives. Fibre Channel or SAS drives have more IOPS and bandwidth than SATA drives. So, it is important not to provision busy LUNs on RAID groups made up of SATA vault drives. However, using Flash drives as vault drives allows you to provision user LUNs with higher workload demands to RAID groups including these drives. You should always be careful if you use a vault drive to support a user workload; do not greatly exceed the recommendation found in Table 13.

For example, assume five equally busy LUNs need be provisioned. The LUNs need be allocated to three RAID groups. One of these RAID groups is necessarily composed of the vault drives. Place two of the new LUNs on each of the two non-vault drive RAID groups (for a total of four LUNs). Place a single new LUN on the vault drive's RAID group. Why? Because before the new LUNs are provisioned, the RAID group built from the vault drives already has a busy LUN provisioned from the CLARiiON.

Recommendations for AX4-5 and earlier CLARiiON storage systems

For AX4-5 and the earlier CLARiiON systems, the CX4 considerations above apply. The reserved LUN pool, clone private LUNs, write intent logs, clone, and mirror LUNs should not be placed on the vault drives. Also, avoid placing any response-time sensitive data on the vault drives.

On CLARiiONs that do not have the Improved Write Cache Availability, a vault drive failure will normally result in rebuild activity on these drives and a disabled write cache. The HA vault option in Unisphere should be clear, if response-time sensitive access to data on these drives is needed under this condition.

With the HA vault disabled, the cache stays enabled during a vault drive rebuild, at the expense of a small amount of protection for cached data. This is especially important with systems using SATA drives in the vault, due to the long time needed for these drives to rebuild and for the cache to re-enable.

Load balancing

There is a performance advantage to evenly distributing the workload's requirement for storage system resources across all of the available storage system's resources. This balancing is achieved at several levels:

- Balancing I/O across storage system front-end ports is largely performed by PowerPath in addition to a careful assignment of ports and zoning to hosts. The "PowerPath" section has more information.
- Balancing across storage processors is performed by LUN provisioning in anticipation of the workload's requirements. The "LUN provisioning" section has more information.
- Balancing across back-end ports is performed by RAID group creation in anticipation of the workload's requirements for performance, capacity, and availability. The "RAID group bus balancing" section has more information.

Failback

Should an SP fail, LUNs owned by that SP are trespassed by host multipathing applications to the surviving peer SP. When a failure-related trespass occurs, performance may suffer, because of increased load on the surviving SP. Failback is the ownership return of trespassed LUNs to their original owning SP.

For best performance, after a failure-related trespass ensure that LUN ownership is quickly and completely restored (either automatically or manually) to the original owning SP.

When PowerPath is installed on the host, failback is an automatic process. The host OS may also support automatic failback without PowerPath. For example, HP-UX natively supports failback. Review the host OS's documentation to determine if, and how it supports a failback capability. Failback is manual process when PowerPath is not installed, and the host OS does not support failback. When not automatic, policies and procedures need to be in place to perform a manual failback after a trespass to ensure the original level of performance.

Detailed information on failback, and the effects of trespass can be found in the *EMC CLARiiON High Availability (HA) — Best Practices Planning* white paper available on Powerlink.

Back-end considerations

The CLARiiON's back-end buses and drives constitute the back end. The number of drives per DAE, the DAE to bus attachments, the RAID type (mirrored or parity), the type of drives (Fibre Channel, SAS, SATA, or Flash drive), and the distribution of the LUN's information on the drives all affect system performance.

UltraPoint DAEs

UltraPoint™ refers to the DAE2P, DAE3P, and DAE4P CLARiiON DAE delivered with CLARiiON CX4 and CX3 series storage systems. (In Unisphere, UltraPoint DAEs are shown as type DAE-2P.) UltraPoint is a 4 Gb/s point-to-point Fibre Channel DAE. UltraPoint can host 4 Gb/s or 2 Gb/s hard drives.

DAE2 refers to the 2 Gb/s Fibre Channel DAE delivered with the earlier CLARiiON CX series. The DAE2-ATA is a legacy 2 Gb/s DAE used with PATA drives on earlier CLARiiON models.

To ensure high performance and availability, we recommend that you only use UltraPoint DAEs and hard drives rated with 4 Gb/s interfaces on CLARiiON CX4 series storage systems.

Using either 2 Gb/s drives or 2 Gb/s rated DAEs in a CLARiiON CX4 sets the connected CX4 bus (pair of loops, one to each SP) to a 2 Gb/s speed; all 4 Gb/s DAEs and their 4 Gb/s hard drives will run at the slower 2 Gb/s bus speed. Performance on the bus will be adversely affected, particularly in high bandwidth workloads. After installing 2 Gb/s drives onto a 4 Gb/s bus use the Unisphere "Backend Bus Speed Reset Wizard" to complete the reconfiguration. Both SPs must be rebooted at the same time to complete the reconfiguration.

Note that CLARiiON CX, CX3, and CX4 Fibre Channel hard drives have been qualified for operation at 2 Gb/s. Contact your EMC representative for the part numbers of 2 Gb/s qualified hard drives. Native 4 Gb/s DAEs may be operated at a lower 2 Gb/s back-end bus speed when 2 Gb/s drives are installed. SATA hard drives can only operate installed in 4 Gb/s capable DAEs operating at 4 Gb/s.

Best practices performance numbers for the CLARiiON CX4 are generated with 4 Gb/s back-end buses and 4 Gb/s hard drives, except where noted. It may not be possible to achieve published bandwidth if some or all of the back-end buses are running at 2 Gb/s.

In addition to having increased bandwidth and hard drive hosting options, UltraPoint has increased availability over previous versions of DAEs. UltraPoint DAEs can isolate a fault to a single hard drive. UltraPoint DAEs use a switch within the DAE to access the drives. The previous DAE technology used a Fibre Channel loop technology. The current switch technology enables the CLARiiON to test hard drives individually before they are brought online or when an error is detected.

The recommended approach for using non-UltraPoint DAEs or 2 Gb/s hard drives with CLARiiON CX4 storage systems is:

- When a storage system is taken out of service, swap the DAE2s for UltraPoint DAEs, if possible.
- Separate all non-UltraPoint DAEs onto the same down-rated 2 Gb/s CX4 back-end bus(es).
- If possible, do not use 2 Gb/s DAEs on bus 0 of the CX4-960. This limits the amount of write cache that can be allocated
- Separate all the 2 Gb/s interfaced hard drives to their own DAE(s) on down-rated 2 Gb/s back-end buses.
- Provision LUNs without mixing 2 Gb/s interfaced hard drives with 4 Gb/s interfaced hard drives.
- Assign LUNs using the 2 Gb/s drives and back-end loops to workloads without high bandwidth requirements.

Plan ahead before adding DAEs to the storage system. Changing the bus or enclosure number of a configured DAE is not easily done once a DAE is provisioned. If a DAE has been configured as Bus X Enclosure Y, with RAID groups and LUNs created there, the bus and enclosure address cannot be changed because the storage system will no longer recognize the RAID groups and their LUNs. A LUN migration would be needed to change the bus or enclosure address and preserve the LUN's data.

Hot sparing

Hot spares are hard drives used to replace failed drives. Proactive sparing is the automatic activation of a hot spare when a drive indicates its likely failure. Proactive sparing on the CLARiiON automatically selects hot spares from a pool of designated global hot spares. Careful provisioning ensures the efficient use of available capacity and best performance until a replacement drive is installed. Otherwise, it is possible for a less appropriate hot spare to be used as a replacement. For example, a SATA hard drive could be automatically selected as a spare for a Fibre Channel RAID group's failed hard drive, resulting in possible performance degradation.

If there were no hot spares configured of appropriate type and size when a drive fails, no rebuild occurs. The RAID group with the failed drive remains in a degraded state until the drive is replaced; then the failed drive's RAID group rebuilds from parity or its mirror drive, depending on the RAID level.

The hot spare selection process uses the following criteria in order:

1. **Failing drive in-use capacity -** The replacement algorithm attempts to use the smallest capacity hot spare that can accommodate the capacity of the failed drive's LUNs.

2. **Hot spare location -** Hot spares on the same back-end bus as the failed drive are preferred over other like-size drives. Ensure an appropriate (type, speed, and capacity) hot spare is located on the same bus of the hard drives it's replacing. Standard racking of DAEs alternates the redundant back-end buses across adjacent DAEs, with the first DAE being bus 0, the next DAE bus 1, and so on. Note that standard racking may not be in use, and the bus attachment should always be verified. When provisioning hot spares, verify how many back-end buses the storage system has, and their connection to the storage system's DAEs.

3. **Drive type -** Any hard drive can act as a hot spare. Flash drives are an exception. Only a Flash drive can hot spare for another Flash drive. In addition, proactive hot sparing does not support drives configured into a RAID 0 type group.

When provisioning hot spares on storage systems having mixed types of drives (for example, both Fibre Channel and SATA), mixed drive speeds (for example, 10k rpm and 15k rpm), or mixed sizes (for example, 300 GB and 1 TB), set up at least one hot spare for each type and speed of drive. Hot spares must be of a type and speed such that they have enough capacity for the highest capacity drive they may be replacing.

In-use capacity is the most important hot spare selection criteria. It is a LUN-dependent criterion, not a drive capacity dependency. The in-use LUN capacity of a failing drive is unpredictable. This can lead to an unlikely hot spare selection. For example, it is possible for a smaller hot spare on a different bus to be automatically selected over a hot spare drive identical to, and in the same DAE as the failing drive. This occurs because the formatted capacity of the smaller, remote hot spare (the highest-order selection criteria) matches the in-use capacity of the failing drive's LUNs more closely than the identical local hot spare.

Finally, availability requires that there be a minimum of one hot spare for every in-use 30 drives (1:30). On storage systems with mixed types, speeds, and capacities, a larger number of hot spares (resulting in a lower ratio) may be needed to ensure a match between the hot spare and the failed hard drive. This will give the best performance until the failed hard drive is replaced.

Hot sparing and FAST Cache

Hot spares should be allocated for the Flash drive-based FAST Cache feature. Hot sparing for FAST Cache works in a similar fashion to hot sparing for FLARE LUNs made up of Flash drives. However, the FAST Cache feature's RAID 1 provisioning affects the result.

If a RAID-provisioned FAST Cache Flash drive fails, the normal FLARE RAID recovery described above attempts to initiate a repair with an available hot spare and a RAID group rebuild. If a hot spare is not available, then FAST Cache remains in degraded mode. In degraded mode, the cache page cleaning algorithm increases the rate of cleaning.

A double drive failure within the FAST Cache may cause data loss. This can occur if there are any dirty cache pages in the cache at the moment both drives fail. It is possible that the Flash drives' data can be recovered through a service diagnosis procedure. However, generally, a dual drive failure has the same outcome as with a single parity drive or mirrored protected RAID group.

Hot sparing best practices

The following summarizes the hot spare best practices:

- Have at least one hot spare of every speed, maximum needed capacity and type hard drive on the storage system.
- Position hot spares on the same buses containing the drives they may be required to replace.
- Maintain a minimum 1:30 ratio (round to one per two DAEs) of hot spares to data hard drives.
- Flash drive storage devices can only be hot spares for, and be hot spared by, other Flash drive devices.

An in-depth discussion of hot spares can be found in the *EMC CLARiiON Global Hot Spares and Proactive Hot Sparing* white paper available on Powerlink.

Hot sparing example

The following is an availability example of hot sparing. A customer owns a CX4-240 (two redundant back-end buses). The storage system has four DAEs (0 thru 3). The storage system is to be provisioned with the following hard drives:

- 14x 7.2k rpm, 1 TB SATA hard drives configured in a single, 14 hard drive RAID 6 group (12+2)
- 40x 15k rpm, 300 GB Fibre Channel hard drives configured in eight, 5 hard drive RAID 5 groups (4+1)

How many hot spares should be used to complete the provisioning for this storage system? Where should they be positioned? The answers to these questions are found next.

Configuring the storage system for hot spares

The following table summarizes the hot spare provisioning of the storage system for availability.

Table 13 Hot spare provisioning example

DAE	Back-end bus	Vault drives	Data drives	Hot spares	Total DAE drives
DAE0	0	5x FC	10x FC	0	15
DAE1	1	0	14x SATA	1x SATA	15
DAE2	0	0	15x FC	0	15
DAE3	0	0	10x FC	1x FC	11
			Total FC data drives		49
			Total FC hot spares		1
			Total SATA drives		14
			Total SATA hot spares		1
			Total all drives		65

Fifteen 300 GB 15k rpm Fibre Channel hard drives are configured on DAE0. Five of these hard drives are used by the vault. Note that hot spares are not provisioned in the vault. (This gives a total of 15 hard drives in DAE0 on Bus 0.)

Configure DAE1 to be on bus 1. Provision it with 10x 7.2k rpm 1 TB SATA hard drives. In addition, provision it with a single 7.2k rpm 1 TB SATA hot spare. Note a SATA hot spare identical in type, speed, and capacity to the data drives is provisioned on the SATA data drive's bus. (This gives a total of 11 hard drives in DAE1 on Bus 1.)

Configure DAE2 to be on bus 0. Provision it with 15 Fibre Channel hard drives. (This gives a total of 15 hard drives in DAE2.)

Configure DAE3 to be on Bus 0. Note this is non-standard racking. Provision it with 10 Fibre Channel hard drives. In addition, provision it with a single 15k rpm 300 GB Fibre Channel hot spare (a total of 11 hard drives in DAE3 on bus 0). The Fibre Channel hot spare that is identical in type, speed, and capacity to the Fibre Channel data drives is provisioned on bus 0 "spares" for the 15 drives in each of DAE0 and DAE2, and the 10 drives in DAE3. Note that the ratio of Fibre Channel drives to hot spares is higher than 30:1. However, taking into account the SATA hot spare in DAE1, the overall ratio of hot spares to data drives is lower than 30:1.

RAID groups

Each RAID level has its own resource utilization, performance, and data protection characteristics. For certain workloads, a particular RAID level can offer clear performance advantages over others.

Note the number of configurable RAID groups is dependent on the maximum number of drives that can be hosted on the CX4 storage system model.

CLARiiON storage systems support RAID levels 0, 1, 3, 5, 6, and 1/0. Refer to the *EMC CLARiiON Fibre Channel Storage Fundamentals* white paper to learn how each RAID level delivers performance and availability.

RAID groups and I/O block size

Try to align the stripe size of the RAID group with the I/O block size for best performance. This is particularly true for RAID groups used for large-block random workloads or uncached (cache disabled for the LUN) operation. The "evenness" of the stripe size has little or no effect on small block random or sequential access. Alignment matches the I/O block size to the stripe size or a multiple of the stripe size. Note this alignment is most effective when the I/O size is known and the I/O size is not too varied.

In general this results in RAID groups with stripe sizes that are a power of two. RAID 5 examples are (2+1), (4+1), and (8+1). An odd-sized stripe with a large I/O block size results in the I/O wrapping to the next stripe on a single drive. This delays the I/O. For example, on a RAID 1/0 group of six drives (3+3) the stripe is 192 KB (3 * 64 KB). If the I/O block size is 256 KB, it results in wrapping to the next stripe by one drive. This is less optimal for high bandwidth, large-block random I/O.

RAID capacity utilization characteristics

The different RAID levels have different levels of capacity utilization. To decide the type of RAID group and the number of drives to use in the RAID group you must consider the required capacity, availability, performance during operational and degraded states, and the available number of drives.

With parity RAID groups, the data-to-parity ratio in a RAID group is different depending on the RAID level chosen. This ratio describes the number of drives capacity-wise within the group dedicated to parity and not used for data storage. The data-to-parity ratio depends on the number of drives in the RAID group. The maximum number of drives in a group is 16. The minimum number is dependent on the RAID level. Note a low ratio of data-to-parity limits the utility of parity RAID groups with the minimum number of drives. For example, a four-drive RAID 6 group (2+2) is not recommended.

For parity RAID levels 3 and 5 the drive-equivalent capacity of the RAID group's drives dedicated to parity is one; for parity RAID level 6 the equivalent capacity is two. Note that in RAID 5 and RAID 6 groups, no single drive is dedicated to parity. In these RAID levels, a portion of all drives is consumed by parity. In RAID 3 there is a single dedicated parity drive.

The relationship between parity RAID group type and RAID group size is important to understand when provisioning the storage system. The percentage of drive capacity in a RAID group dedicated to parity decreases as the number of drives in the RAID group increases. This is an efficient and economical use of the available drives.

With mirrored RAID groups, the storage capacity of the RAID group is half the total capacity of the drives in the group.

RAID 0 is a special case. With RAID level 0, the storage capacity of the RAID group is the total capacity of the formatted drives in the group. Note that RAID level 0 offers the highest capacity utilization, but provides no data protection.

In summary, some percentage of available drive capacity is used to maintain availability. Configuring the storage system's drives as parity-type RAID groups results in a higher percentage of the installed drive capacity available for data storage than with mirror-type RAID groups. The larger the parity RAID group is, the smaller the *parity storage percentage penalty* becomes. However, performance and availability, in addition to storage capacity, need to be considered when provisioning RAID types.

RAID performance characteristics

The different RAID levels have different performance and availability depending on the type of RAID and the number of drives in the RAID group. Certain RAID types and RAID group sizes are more suitable to particular workloads than others.

When to use RAID 0

We do not recommend using RAID 0 for data with any business value.

RAID 0 groups can be used for non-critical data needing high speed (particularly write speed) and low cost capacity in situations where the time to rebuild will not affect business processes. Information on RAID 0 groups should be already backed up or replicated in protected storage. RAID 0 offers no level of redundancy. Proactive hot sparing is not enabled for RAID 0 groups. A single drive failure in a RAID 0 group will result in complete data loss of the group. An unrecoverable media failure can result in a partial data loss. A possible use of RAID 0 groups is scratch drives or temp storage.

When to use RAID 1

We do not recommend using RAID 1. RAID 1 groups are not expandable. Use RAID 1/0 (1+1) groups as an alternative for single mirrored RAID groups.

When to use RAID 3

For workloads characterized by large block sequential reads, RAID 3 delivers several MB/s of higher bandwidth than the alternatives. RAID 3 delivers the highest read bandwidth under the following conditions:

- Drives create the bottleneck, such as when there are a small number of drives for each back-end loop.
- The file system is not fragmented or is using raw storage.
- The block size is 64 KB or greater.

RAID 3 can be used effectively in backup-to-disk applications. In this case, configure RAID groups as either (4+1) or (8+1). Do not use more than five backup streams per LUN.

In general, RAID 5 usage is recommended over RAID 3. RAID 3 should only be used for highly sequential I/O workloads, because RAID 3 can bottleneck at the parity drive on random writes. Also, when more than one RAID 3 group is actively running sequential reads on a back-end bus, the bus can rapidly become the bottleneck and performance is no different from RAID 5.

When to use RAID 5

RAID 5 is favored for messaging, data mining, medium-performance media serving, and RDBMS implementations in which the DBA is effectively using read-ahead and write-behind. If the host OS and HBA are capable of greater than 64 KB transfers, RAID 5 is a compelling choice. These following applications are ideal for RAID 5:

- Random workloads with modest IOPS-per-gigabyte requirements
- High performance random I/O where writes are less than 30 percent of the workload
- A DSS database in which access is sequential (performing statistical analysis on sales records)
- Any RDBMS tablespace where record size is larger than 64 KB and access is random (personnel records with binary content, such as photographs)
- RDBMS log activity
- Messaging applications
- Video/media

RAID 5 is the recommended RAID level for Flash, Fibre Channel, and SAS drives. It has the best ratio of usable to raw capacity for parity-protected RAID groups. Provision RAID 5 level groups to be *at least* four drives (3+1) and larger. The preferred RAID grouping is five drives (4+1). This size offers the best compromise of capacity, performance, and availability for the largest number of workloads.

When to use RAID 6

RAID 6 offers increased protection against media failures and simultaneous double drive failures in a parity RAID group. It has similar performance to RAID 5, but requires additional storage for the additional parity calculated. This additional storage is equivalent to adding an additional drive that is not available for data storage, to the RAID group.

We *strongly* recommend using RAID 6 with high-capacity SATA drives. High capacity is 1 TB or greater in capacity. In particular, when high-capacity SATA drives are used in Virtual Provisioning pools, they should be configured in RAID 6.

RAID 6 groups can be four to 16 drives. A small group is up to six drives (4+2). A medium group is up to 12 drives (10+2), with large groups being the remainder. Small groups stream well. However, small random writes de-stage slowly and can adversely affect the efficiency of the system write cache. Medium-sized groups perform well for both sequential and random workloads. The optimal RAID 6 groups are 10 drive (8+2) and 12 drive (10+2) sized. These groups have the best compromise of user capacity over capacity used for parity and performance.

The ratio of data to parity is an important consideration when choosing a RAID 6 group size. There is a reduction in user capacity equivalent of two drives with each RAID 6 group. In addition, the additional parity computation has an effect on I/O performance. For example, a five-drive RAID 5 (4+1) group would need to migrate to a six-drive RAID 6 (4+2) group of equal capacity drives to have the same user data capacity.

Comparison of RAID 6 to RAID 5 and RAID 1/0 performance

For random workloads, RAID 6 performs the same as RAID 5 with regard to read operations when the same number of drives is used. Random writes are different. The additional parity drive over RAID 5 increases the RAID 6 back-end workload by 50 percent for writes. This affects the performance in a CLARiiON as the number of drives scales. In addition, the additional overhead of RAID 6 could lead to a full cache state earlier than on RAID 5. However, as long as workload can be destaged from cache without forced flushing, RAID 5 and RAID 6 have similar behavior from a host response time point of view.

For sequential workloads with the same number of drives, read performance is nearly identical. Sequential write workloads are about 10 percent lower for RAID 6 performance-wise.

However, RAID 6 can survive two drive failures on any drives in the group. This offers higher availability than even RAID 1/0. The failure of a RAID 1/0 drive and its mirroring drive would be fatal for a RAID 1/0 group. So, RAID 6 has a capacity advantage, and availability advantage over RAID 1/0, while RAID 1/0 continues to offer superior small-block write performance over any parity RAID type.

Due to its double-drive protection, RAID 6 groups are well suited for the default (High) priority rebuilds, because of their higher availability. Assuming that the rebuild rate is bottlenecked by a single shared bus, large RAID 6 groups rebuild at approximately the same rate as large RAID 5 groups. Medium-size RAID 6 groups require about 10 percent longer to rebuild than RAID 5 groups with the same number of data drives. Small-size RAID 6 groups take 25 percent longer than the same size RAID 5 group. When RAID groups are spread across buses, RAID 5 has a speed advantage over RAID 6 for any group size.

Unlike the other RAID levels, FLARE revisions 30.0 and earlier do not support RAID 6 group defragmentation.

RAID 6 rules of thumb

- Ten-drive (8+2) and 12-drive (10+2) RAID 6 groups have good data-to-parity ratios, IOPS capability, and streaming characteristics. The 8+2 should be the first candidate for consideration due to its 512 KB stripe size.
- Sixteen-drive (14+2) groups have the best RAID 6 data-to-parity ratio and scale random workloads the best. However, it does not run sequential streams better than eight-drive (6+2), 10-drive (8+2), and 12-drive (10+2) RAID 6 groups.
- A six-drive RAID 6 (4+2) group has 20 percent more available IOPS than a five-drive RAID 5 (4+1) group. You can consider using this as a high availability alternative to (4+1), if the read/write mix does

not exceed drive capability. Otherwise, use (6+2).

- The overhead of RAID 6 over RAID 5, particularly with random writes, needs to be considered when making replacement choices. A 10-drive RAID 6 (8+2) group cannot service as many random writes as two RAID 5 groups of five drives (4+1).
- RAID 6 groups lend themselves to “bus balancing.” A 10-drive (8+2) group can be evenly distributed over two DAEs located on separate buses, five drives per DAE. Twelve-drive (10+2) groups can be evenly distributed over three or four DAEs on separate buses.

When to use RAID 1/0

RAID 1/0 provides the best performance on workloads with small, random, write-intensive I/O. A write-intensive workload’s operations consist of greater than 30 percent random writes. Some examples of random, small I/O workloads are:

- High transaction rate OLTP
- Large messaging (email) installations
- Real-time data/brokerage records

RDBMS data tables containing small records, such as account balances being updated frequently

RAID 1/0 also offers performance advantages during certain degraded modes. These modes include when write cache is disabled or when a drive has failed in a RAID group. RAID 1/0 level groups of (4+4) have a good balance of capacity and performance.

RAID group bus balancing

There is a performance advantage to distributing in-use hard drives across as many back-end buses and as evenly as possible on a storage system.

The extreme case would be to have each hard drive of a RAID group on a separate back-end bus. (This is sometimes referred to as *Vertical Provisioning*.) This often is not practical given the storage system’s back-end configuration. Not all storage systems models have the number of back-end resources for this type of distribution. Finally, provisioning in this fashion is time consuming to set up and maintain; it is not recommended

An easier and more practical recommendation is to distribute RAID groups across back-end buses as evenly as possible. In round-robin order define each RAID group to be on a separate bus. (This is referred to as *Horizontal Provisioning*.) Large RAID groups, and RAID 1/0 groups used for the highest availability, benefit from being distributed over two back-end buses, as explained below.

Note that vertical and horizontal provisioning techniques described do not apply to the automated and labor-saving Virtual Provisioning feature.

For example, a CX4-960 has eight back-end buses per storage processor, and the storage to be placed on the system is expected to be *uniform* I/O, meaning it will be either all random I/O or all sequential I/O. If initially eight RAID groups of the same size and expected IOPS load are required, place one RAID group on each of the storage processor’s buses.

The exception to the rule is workloads that are *not* uniform. In that case, a subset of the available buses can be used for drives servicing each type I/O. For example, random I/O on one set of buses, and another set for sequential loads.

Dual drive ownership

Dual ownership by either storage system SP of hard drives is supported by the CLARiiON CX4. All hard drives are dual ported and can accept I/O from both SPs at the same time.

Dual ownership may result in less predictable drive behavior than single ownership. Each SP operates somewhat independently when issuing requests to any drive. Dual ownership may subject the drives to deeper queue usage. This may result in higher response times than single ownership. However, dual ownership is valid in certain circumstances. For example, when creating metaLUNs over large drive pools, dual ownership may be required to get an even distribution of load over the back-end buses.

In summary, single ownership of a drive is preferred. However, if maximum throughput is required through data distribution, drives can be configured with dual ownership.

Binding

There are different ways to bind drives to increase performance and availability. The dependency is with the type of RAID group (parity or mirror) involved in the binding.

Implementing the following binding recommendations requires familiarity with the Navisphere Command Line Interface (CLI); specifically with the `creatrg` command. To learn about CLI commands refer to the *Navisphere Command Line Interface (CLI) Reference* available on EMC Powerlink.

Binding across DAEs

Binding of drives across DAEs on the same back-end bus has a slight availability advantage. The advantage is dependent on the RAID configuration, and in all cases the differences are slight.

Parity RAID groups (RAID 3, RAID 5, RAID 6)

Binding parity RAID groups so each drive is in a separate DAE does not help performance. However, there is a small increase in data availability in this approach. Binding like this can be unwieldy and time consuming; if very high availability is required, use RAID 1/0.

Mirrored RAID groups (RAID 1, RAID 1/0)

There is no advantage in binding a RAID 1/0 group in more than two DAEs, but it is not harmful in any way.

Binding across back-end buses

All CX4 models except the CX4-120 and the AX4-5 have more than one set of dual back-end FC loops for attaching to their DAEs. A RAID group can be made up of drives from one, two, or all buses. The standard racking of DAEs alternates the buses across adjacent DAEs, with the DPE or first DAE being bus 0, the next DAE bus 1, and so on. With a multibus model CLARiiON that has standard racking, splitting a RAID group’s drives between adjacent DAEs places them on separate buses.

Parity RAID groups

Parity RAID groups of 10 drives or more benefit from binding across two buses, as this helps reduce rebuild times. For example, when you bind a 10-drive (8+2) RAID level 6 group, bind five drives in one DAE, and bind the remaining five drives in another DAE that is on a different bus.

Navisphere CLI usage to bind across buses

Binding RAID groups across buses requires the use of the Navisphere CLI to configure the RAID group or define a dedicated LUN. (The Unisphere wizard does not automatically perform this.) When designating the drives, Navisphere CLI uses the drive ordering given in the `createrg` or bind command to create Primary0, Mirror0, Primary1, Mirror1, and so on, in order. Drives are designated in Bus_Enclosure_Disk notation. The following example demonstrates binding the first two drives from enclosure on each bus:

```
      Navicli –h <ip address> createrg 55  0_1_0  1_1_0  0_1_1  1_1_1
```

Binding with DAE0 drives

In a total power-fail scenario, the standby power supply (SPS) supplies battery-backed power to the SPs and the enclosure containing the vault drives. This allows the storage system to save the contents of the write cache to drives.

However, the power to the non-vault storage system DAEs is not maintained. When the storage system reboots, LUNs with I/Os outstanding are checked, using the background verify (BV) process. This checks to make sure that there were no writes in progress (during the power fail) that resulted in partial completions.

BV is a prioritized operation. The operation loads the storage system at ASAP, High, Medium, and Low rates in much the same way that rebuild operations affect the storage system, although at about half the drive rates found in rebuilds. The default priority for BV is Medium. This setting has only a modest effect on production workloads, especially during recovery from an SP outage.

In the event of a drive failure, a LUN bound with drives in the vault enclosure (DPE, enclosure 0, or the first DAE, depending on the CLARiiON model) *and* drives outside the vault enclosure may require a rebuild. To avoid a rebuild on boot, create groups with all drives either in or out of the vault enclosure.

If groups are split, follow these guidelines:

- Do not split RAID 1 groups across the vault enclosure and another DAE.
- For RAID 5, make sure at least two drives are outside the vault enclosure.
- For RAID 6, make sure at least three drives are outside the vault enclosure
- For RAID 1/0, make sure at least one mirror (both the primary and secondary drive in a pair) is outside the vault enclosure.

LUN provisioning

LUNs are a logical structure overlaid on the physical RAID group. As with the underlying RAID group and its drives, when provisioning a LUN on a storage system you need to consider the workload’s primary I/O type, capacity requirements, and the LUN’s utilization. The section “RAID groups” on page 49 will help you understand the performance implications of creating different types and capacity RAID groups.

When large capacity LUNs or LUN expansion is needed, use metaLUNs or storage pools. (For more information, see the “MetaLUNs” section and the “Virtual Provisioning: thin and thick LUNs” section).

LUN provisioning by I/O type

In a workload environment characterized by random I/O, it is prudent to distribute a workload’s LUNs across as many RAID groups as is practical given the available drives and configured RAID groups.

In a workload characterized by sequential I/O, it is advantageous to distribute the workload's LUNs across as few RAID groups as possible to keep the RAID groups performing the same I/O type.

When more than one I/O type is handled by the storage system, the LUNs supporting the different I/O types should be kept as separate as possible. That is, if possible, do not put LUNs supporting workloads with mostly random I/O on the same RAID group as LUNs supporting workloads with most sequential I/Os.

LUN provisioning by percentage utilization

Ideally, all the active RAID groups in the storage system should have a similar percentage of utilization. (LUNs are a host visible logical construct built upon one or more RAID groups create RAID group utilization.) This would be the most efficient use of the storage system's resources. However, this is rarely the case. At any time, some LUNs may be *hot LUN*s, and other LUNs may be essentially idle. A hot LUN is a LUN participating in a workload causing its underlying RAID group to have drive utilization significantly higher than the average of similarly tasked RAID groups on the storage system. A leveling of RAID group drive utilization across the storage system should be sought to get the best performance from the storage system.

Unisphere Analyzer provides information on drive utilization to determine how to distribute the LUNs across the storage system. Information on how to use Unisphere Analyzer can be found in the *EMC Navisphere Analyzer Administrator's Guide*, available on Powerlink.

When more than one LUN shares a RAID group, try to achieve an average utilization by matching high-utilization with low-utilization LUNs, or average-utilization with other average-utilization LUNs on RAID groups to achieve an overall average RAID group utilization for the LUNs on the storage system. When the workload is primarily random, the averaging will be across as many RAID groups as is practical to meet capacity, availability, and performance requirements. When the workload is sequential, the averaging will be across as few as is practical to meet capacity, availability, and performance requirements.

Another way to distribute LUNs is by when they are used (*temporal allocation*). It may be that not all LUNs are constantly active. For example, LUNs supporting a business day workload from 8 A.M. to 8 P.M. will have their highest utilization during this period. They may have either low utilization or be idle for much of the time outside of this time period. To achieve an overall average utilization, put LUNs that are active at different times over a 24-hour period in the same RAID group.

If high utilization LUNs from the same workload must be placed in the same RAID group together, place them next to each other on the RAID group (that is, without any intervening LUNs between them). This will minimize the drive seek distance (time) and get the highest performance between these highly utilized LUNs. The Navisphere CLI is needed to perform this operation.

MetaLUNs

Multi-RAID group metaLUNs increase available IOPS by adding drives. MetaLUNs also allow for provisioning LUNs with increased storage capacity over single RAID group hosted LUNs.

An in-depth discussion of metaLUNs, including how to create them, can be found in the *EMC CLARiiON MetaLUNs - A Detailed Review* white paper available on Powerlink.

On a CLARiiON storage system, metaLUNs are implemented as a layer above the RAID groups. They are functionally similar to the application of a volume manager on a host. However, there are some important distinctions between metaLUNs and a volume manager.

Single SCSI target versus many

To create a volume manager stripe, all of the component LUNs must be made accessible to the host. To create a metaLUN, only a single SCSI LUN is mapped to the host; the host does not see the multiple LUNs that make up the metaLUN. This benefits the administrator when:

- Their hosts have limited LUNs available due to OS limits
- Adding LUNs to their host causes a renumbering of SCSI devices; often a kernel rebuild is necessary to clean up the device entries
- In these cases, using a metaLUN instead of a volume manager simplifies administration on the host.

When there is no volume manager

Not all operating systems have volume manager support. Microsoft Windows Server 2000/2003 clusters using Microsoft Cluster Services (MSCS) cannot make use of dynamic disks. In this case, metaLUNs allow you to provide expandable, striped, and/or concatenated volumes for these systems.

Replication of the volume

If the volume is to be replicated on the storage system using the CLARiiON layered products (SnapView™, MirrorView™, or SAN Copy™), a usable image requires consistent handling of splits. A metaLUN will simplify replication.

Volume access sharing

When a striped or concatenated volume must allow shared access between hosts, and a volume manager will not permit shared access, a metaLUN can be used. The metaLUN is placed in both hosts' storage groups.

Storage processor bandwidth

An important distinction between a volume manager volume and a metaLUN is that a metaLUN is addressed entirely by one storage processor on one CLARiiON storage system. If very high bandwidth is required for a single volume, a volume manager is still the best approach, as the volume can be built from LUNs on different SPs. A volume manager allows the user to access storage at an aggregate bandwidth of many storage processors.

Volume managers and concurrency

As pointed out in the "Plaids for high bandwidth" section, the use of a host-striped volume has the effect of multithreading requests consisting of more than one volume stripe segment. This increases concurrency to the storage system. There is no multithreading effect with a metaLUN, as the multiplexing of the component LUNs is done on the storage system.

MetaLUN usage and recommendations

The three types of metaLUNs are striped, concatenated, and hybrid. This section presents general recommendations.

Component LUN type

When binding a LUN to be included in a metaLUN, the type of LUN you bind should reflect the I/O pattern expected for the metaLUN. Match the I/O pattern with the recommendations made in this paper for different RAID types.

When binding component LUNs, the following recommendations apply:

- Always use the default stripe element size (128 blocks) when binding LUNs for use in metaLUNs.
- Always activate read and write cache. Use the default setting.
- Ensure the write-aside size for component LUNs is the default 2048.
- Use RAID 5 groups of at least four drives (3+1) and larger (we recommend 4+1).
- Use RAID 1/0 groups of at least four drives (2+2) and larger.
- Use RAID 6 groups of at least eight drives (6+2) where you expect to expand the RAID groups in the future. Otherwise use the recommended groups of 10 drives (8+2).
- Do not use the component LUN offset to adjust for stripe alignment. MetaLUNs have their own offset value.

MetaLUN type

In general, use striped metaLUN components wherever possible as they yield the most predictable performance. Concatenation of a single LUN to a metaLUN is intended for convenience; this may be appropriate for expanding a volume that is not performance sensitive.

Hybrid metaLUN combines concatenation with striping. This approach is used to overcome the cost of striped expansion. A striped metaLUN can be expanded by concatenating another striped component. This preserves the predictable performance of a striped component, and allows an expansion of a striped metaLUN without restriping existing data (performance is affected while the restriping operation is under way). The next figure illustrates this point.

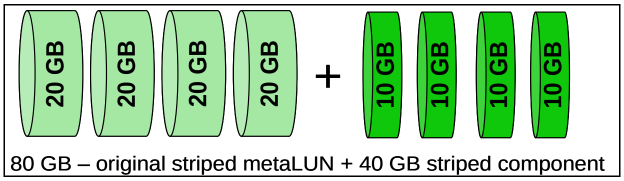


Figure 3 Hybrid striped metaLUN

Ideally, the LUNs in the expansion stripe set are distributed over RAID groups of the same RAID type and geometry as the original striped component. The most direct way to achieve this is to use the same RAID groups as the base component. The RAID groups are expanded first, in order to make space available.

MetaLUN stripe multiplier

The stripe multiplier determines the metaLUN stripe segment size:

MetaLUN stripe segment size = stripe multiplier * base LUN stripe size

The largest I/O a metaLUN can receive, will be the smaller of either a 2 MB (due to cache limitations) and the metaLUN stripe segment size.

Both high bandwidth performance and random distribution call for metaLUN stripe elements of about 1 MB. Also, the underlying RAID groups may be expanded. Ensure the metaLUN stripe element is big enough to write full stripes to expanded component LUNs.

Use these rules to set the stripe multiplier:

- Unless using RAID 0, use groups of at least four drives to make up the RAID groups hosting the component LUNs.
- Determine the number of effective drives for the group size chosen. For example, a six-drive (3+3) RAID 1/0 is 3. Five-drive (4+1) RAID 5 is four.
- Select the multiplier for the number of effective drives from the metaLUN stripe multipliers table.

Table 14 MetaLUN stripe multipliers

Effective drives in component RAID group	MetaLUN stripe multiplier	MetaLUN stripe element
2	8	1024
3	6	1152
4	4	1024
5 – 7	3	960 - 1344
8	2	1024

If in doubt, use the default four (4) for the metaLUN stripe multiplier.

For example, what is the best stripe multiplier for a metaLUN that is used for general file serving and made up of two five-drive (4+1) RAID 5 groups? The ideal would be to ensure 1 MB I/Os to the metaLUN. The metaLUN's base LUN, a 4+1, has a 256 KB (4 * 64 KB) stripe size. Therefore, a metaLUN stripe segment size of four (1 MB / 256 KB) would be appropriate. Note that four is also the default.

MetaLUN alignment offset

When planning to use SnapView or MirrorView with a metaLUN, leave the metaLUN alignment offset value at zero. Use disk utilities to adjust for partition offsets.

MetaLUNs and rebuilds

A single drive failure in a metaLUN's RAID group will adversely affect the entire metaLUN's performance until the metaLUN is rebuilt. In general, for SATA and FC drives, the increased IOPS available to multi-RAID group metaLUNs (compared to individual RAID group LUNs) during normal operation outweigh the relatively infrequent rebuild penalty incurred if one of the component RAID groups experiences a drive failure. For ASAP rebuild, the percentage decrease in a metaLUN's throughput can be roughly approximated by the percentage of drives involved in the rebuilding RAID group relative to the metaLUN's full drive width. However, if the rebuild setting is High, Medium, or Low, the rebuilding RAID group will itself incur less than 10 percent degradation, and the overall metaLUN will run very close to production speed.

MetaLUN expansion strategies

There are several strategies for using metaLUNs for a long-term expansion plan. To develop a strategy, first identify the goals. The goals of the approach presented in the following section are:

- Distribution of localized bursts of otherwise random data over many drives
- Good sequential/bandwidth performance
- Efficient use of capacity

- Flexible expansion of devices
- These goals apply to the majority of metaLUN users.

Expansion model initial configuration

The general rules for the initial setup of this solution are shown in Figure 4. The rules are:

- Deploy the required drives for initial deployment capacity.
- Create modest-size RAID groups:
- For RAID 1/0, use four or six drives (3+3).
- For RAID 5 or RAID 3, use five drives (4+1).
- For RAID 6 use 10 drives (8+2).
- Organize the RAID groups into sets of four to eight groups. (Use more groups per set if very high rates of random I/O are required.)
- For each metaLUN, determine the RAID group set to which it will belong.
- Define the component LUN size for each planned metaLUN by dividing metaLUN size by the number of RAID groups in its RAID group set.
- Create a component LUN for each metaLUN from *each* RAID group in its set.
- Form metaLUNs from LUNs distributed across all the RAID groups in their respective sets. Figure 4 is an example of a set of metaLUNs and their RAID group set.

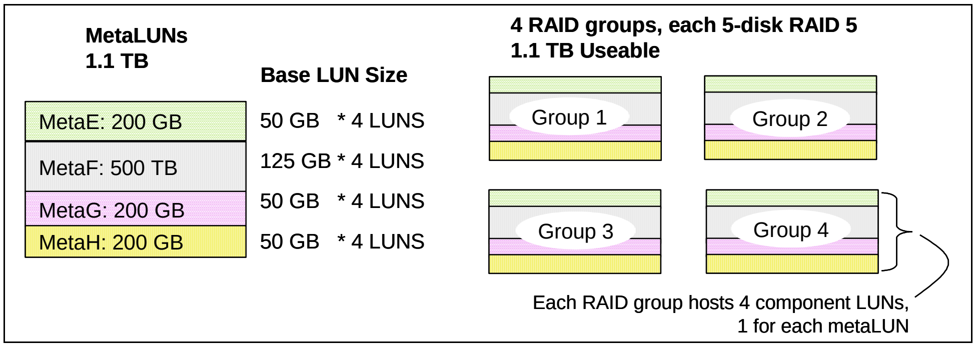


Figure 4 Initial distribution of storage for metaLUNs

Note in Figure 4, each metaLUN consists of one LUN per RAID group. Each LUN's load is evenly distributed across all RAID groups in the set. However, these metaLUNs are fenced off from data access to *other* RAID group sets.

Why use RAID group sets? If we do not allow a metaLUN to extend outside of its set, we can determine a level of fencing, controlling interactions at the drive level. For instance, one RAID group set may be for a large number of file servers, while another is used for RDBMS data tables—and an ordinary pair of RAID 1 groups may be used as the RDBMS log devices. Figure 5 illustrates this.

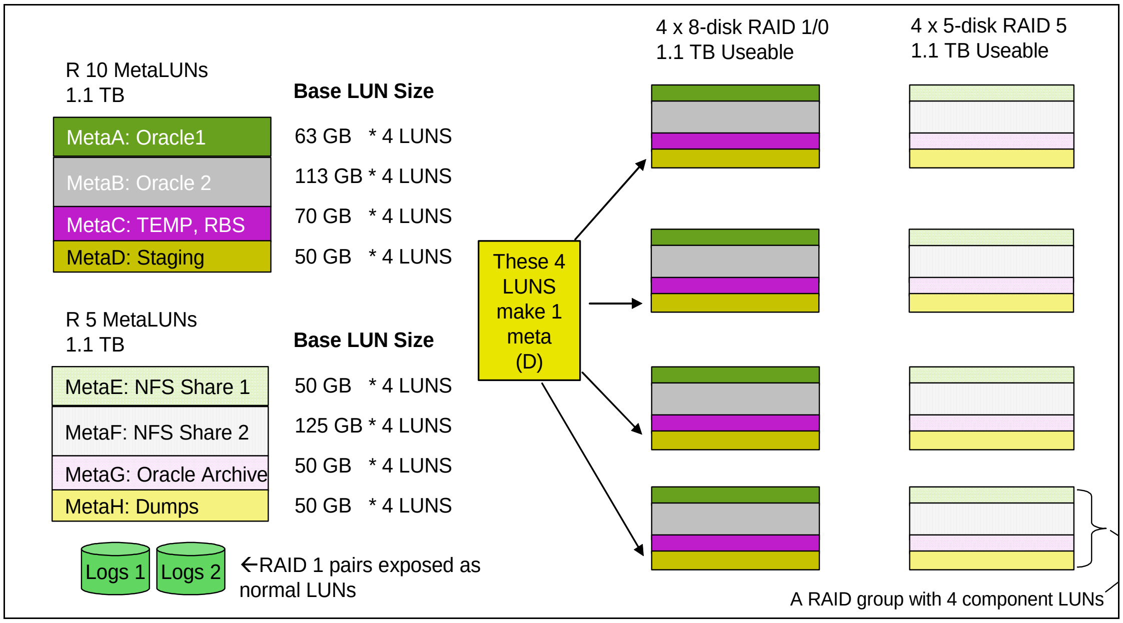


Figure 5 Example of data fencing with RAID group sets and metaLUNs

In the example shown in Figure 5, access to the NFS share metaLUNs will not interfere with the Oracle servers' access to their data tables or to their logs.

MetaLUN expansion

The next step is to set up the strategy for expansion. The goals for expansion are:

- Maintain distribution of data across many drives.
- Use capacity efficiently.
- The approach to achieve these goals is:
- When capacity is *anticipated* for a metaLUN, add drives to existing RAID groups in the set.
- Bind expansion LUNs on the RAID groups of the metaLUN's set.
- Add expansion LUNs to metaLUNs as a new striped component.

MetaLUN base LUN stacking or base LUN rotation

When creating more than one metaLUN from a set of RAID groups, rotate the RAID group of the base LUN for each metaLUN. Rotation puts the base LUN of each metaLUN on a different RAID group of the RAID groups making up the metaLUN. Doing this evenly spreads the I/O load across all the metaLUN's RAID groups. An example is if there are four metaLUNs A through D created on LUNs using four RAID groups labeled RAID Group 1, RAID Group 2, RAID Group 3, and RAID Group 4. Define the base LUN of the first metaLUN (Meta A) to be on RAID Group 1. Define the base LUN of the second metaLUN (Meta B) to be on RAID Group 2. Define the base LUN of Meta C to be on RAID Group 3. Define the base LUN of MetaLUN D to be on RAID Group 4. In Figure 6 the example is illustrated. Each color stripe denotes a different metaLUN; the base LUN for each meta is on a different RAID group.

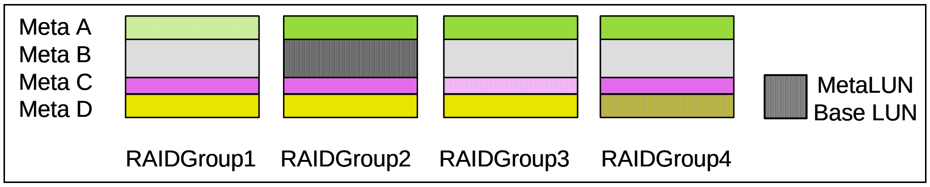


Figure 6 MetaLUN base LUN stacking

The opposite of LUN rotation in metaLUNs is called LUN *vertical striping*. Vertical striping puts all the base LUNs on the same RAID group. Avoid vertical striping of LUNs within a metaLUN. Vertical striping puts all of the LUNs metadata on the same RAID group. Frequently, this will cause a single drive of the RAID group to have very high utilization. In addition large I/Os or sequential I/Os may send requests to several, widely-separated areas of a vertically striped RAID group. This results in high drive seeks for every request, which increases the response time for all the LUNs on the RAID group.

Further information

Further information on metaLUNs is available in the *EMC CLARiiON MetaLUNs* white paper. This paper is available on Powerlink.

LUN shrink

Conventional LUNs, metaLUNs, and pool-based LUNs (thick and thin) may have their capacity reduced to reclaim unused storage capacity. This process is called *LUN shrink*. LUN shrink is a FLARE revision-dependent feature. It is available on FLARE revision 29.0 and later for traditional LUNs. Pool LUN shrink is a feature found in FLARE revision 30.0 and later. LUN shrink is only supported by hosts with the Microsoft Server 2008 operating system and later.

LUN shrinking is a two-step process consisting of a host-volume shrink followed by a LUN-volume shrink. Host-volume shrink is performed from the MS Server host though its Disk Administration function. LUN volume shrink is directed by the user on the host, and executed on the CLARiiON. Both steps may be performed while a workload is present. The LUN volume shrink step requires that the “DISKRAID.EXE” application be installed on the host. It is performed automatically, after the first step. A LUN shrink requires several seconds (less than a minute) to perform.

A host file system defragmentation should be performed before a LUN shrink to consolidate the LUN’s capacity. This yields the largest amount the LUN can be shrunk.

Shrinking a LUN may leave the LUN’s underlying RAID group in a fragmented state. You may need to perform a RAID group defragmentation to achieve the maximum RAID group capacity that is provided by a LUN shrink.

FLARE revisions 30.0 and earlier do not support RAID 6 group defragmentation. This means that you may not be able to utilize the aggregated capacity on a RAID 6 group after shrinking RAID 6 LUNs. See the “RAID groups” section for the recommendation of defragmenting RAID 6 groups.

Virtual Provisioning: thin and thick LUNs

Virtual Provisioning provides for the provisioning of thin and thick provisioning of LUNs. Virtual Provisioning is a licensable feature and requires FLARE revision 28.0 or later.

Storage pools can support both thin and thick LUNs. Thin LUNs present more storage to an application than is physically available. Relative to thin LUNs, thick LUNs provide guaranteed allocation for LUNs within a storage pool, as well as more deterministic performance. Note that thick LUNs require FLARE version 30.0 or later. The presentation of storage not physically available avoids over-provisioning the storage system and under-utilizing its capacity. Thin LUNs incrementally add to their in-use capacity. When a thin LUN requires additional physical storage, capacity is non-disruptively and automatically added from a storage pool. Thick LUNs reserve their full in-use capacity from the pool when they are created. Thin and thick LUNs may be provisioned within the same pool.

When creating storage pools:

- If the goal is the most efficient use of capacity - provision the pool with thin LUNs.
- If the goal is the highest pool-based performance - provision the pool using thick LUNs.

In addition, the storage pool's capacity can be non-disruptively and incrementally added to with no effect on the pool's LUNs.

You can provision pool LUNs using Unisphere or the CLI.

Once created, pool provisioned LUNs are largely automatic in their upkeep. This simplifies and reduces the administrative actions required in maintaining the storage system. An initial investment in planning to correctly provision the storage pool will result in the best on-going pool LUN performance, capacity utilization and availability.

Conceptually, the storage pool is a file system overlaid onto a traditional RAID group of drives. This file system adds overhead to performance and capacity utilization for thin and thick LUNs. Thick LUNs have less of a performance overhead than thin LUNs due to the granularity of space allocation and mapping between virtual and physical layers.

In addition, availability should be considered when implementing pools. A pool with a large number of drives will be segmented into multiple private RAID groups. Data from many LUNs will be distributed over one or more of the pool's RAID groups. The availability of the pool includes the availability of *all* the pool's RAID groups considered as one. (Availability is at the single RAID group level with traditional LUNs.) Workloads requiring the highest level of performance, availability, and capacity utilization should continue to use traditional FLARE LUNs. As with traditional LUNs, storage pool drive count and capacity need to be balanced with expected LUN count and workload requirements. To get started quickly, begin with the recommended initial pool size, expand in the recommended increments, and don't greatly exceed the recommended maximum pool size found in the "Quick Guidelines" section below.

An in-depth discussion of Virtual Provisioning can be found in the *EMC CLARiiON Virtual Provisioning* white paper, available on Powerlink.

Creating storage pools

For the most deterministic performance create few homogeneous storage pools with a large number of storage devices. A homogeneous pool has the same type, speed, and size drives in its initial allocation of drives. Heterogeneous pools have more than one type of drive. See the "Fully Automated Storage Tiering (FAST) Virtual Provisioning" section for heterogeneous pool management.

A single RAID level applies to all the pool's private RAID groups. Pools may be created to be of RAID types 5, 6, or 1/0. Use the general recommendations for RAID group provisioning of FLARE LUNs when selecting the provisioning of the storage pool's RAID types.

When provisioning a pool with SATA drives with capacities of 1 TB or larger, we *strongly* recommend RAID level 6. All other drive types can use either RAID level 5 or 1/0.

Expanding pools

You may not be able to create a large pool in a single step. In addition, you may not be able to add a large number of drives at the same time. This restriction allows a pool to initialize and become fully functional on-demand.

The maximum number of drives that you can add to a pool at one time or use to create a pool is model-dependent, and is listed in Table 15. This number is lower than the maximum number of pool drives per model.

Table 15 Pool drive increments for different CLARiiON models

	Maximum pool drive incremental increases
CX4-120	40
CX4-240	80
CX4-480	120
CX4-960	180

To create a pool with a greater number of drives than the maximum pool drive increment, create the pool and then add increments of drives until the pool has the desired number of drives. (The pool can be expanded again after a delay of one or two minutes.) The amount of time between increments depends on the storage system model, the drives added, and number of drives.

For example, the maximum number of drives that can be added to a CX4-960 pool is 180. To create a 480 Fibre Channel drive pool, you should do it in three equal provisioning steps. First, create an initial pool with 160 drives. Note this will create a pool of 32 (4+1) RAID groups, in a RAID 5 configured pool. Second, expand it with an increment of 160 drives. A third and final expansion of 160 drives would bring the pool to 480 drives.

Number of storage pools

The number of storage pools per storage system is model-dependent.

Table 16 shows the maximum number per CLARiiON model.

Table 16 Thin provisioning storage pools per storage system

CLARiiON model	Maximum thin storage pools per storage system
CX4-120	20
CX4-240	40
CX4-480	40
CX4-960	60

Storage pool size

The maximum number of drives in a storage pool is storage system model-dependent. Generally, EMC recommends that you configure storage system pools as RAID 5. This results in the highest percentage of usable pool capacity with the fewest number of drives.

Table 17 Virtual Provisioning storage pool storage device configurations, FLARE 30.0

CLARiiON model	Minimum RAID 5 pool size (drives)	Maximum pool size (drives)	Maximum total drives in all pools (drives)
CX4-120	3	115	115
CX4-240	3	235	235
CX4-480	3	475	475
CX4-960	3	955	955

EMC recommendations for creating homogeneous pools are as follows:

- We recommend Fibre Channel hard drives for Virtual Provisioning pools with thin LUNs due to their overall higher performance and availability.
- Create pools using storage devices that are the same type, speed, and size for the most predictable performance. It may be advisable to keep Fibre Channel and SATA hard drives in separate pools to service different workloads with varying performance and storage utilization needs.
- Usually, it is better to use the RAID 5 level for pools. It provides the highest user data capacity per number of pool storage devices and proven levels of availability across all drive types. Use RAID 6 if the pool is composed of SATA drives and will eventually exceed a total of 80 drives. Use RAID 6 if the pool is made up of any number of large capacity (≥ 1 TB) SATA drives.
- Initially, provision the pool with the largest number of hard drives as is practical within the storage system's maximum limit. For RAID 5 pools the initial drive allocation should be at least five drives and a quantity evenly divisible by five. RAID 6 pool initial allocations should be evenly divisible by eight. RAID 1/0 pool initial allocations should be evenly divisible by eight.
  - If you specify 15 drives for a RAID 5 pool - Virtual Provisioning creates three 5-drive (4+1) RAID groups. This is optimal provisioning.
  - If you specify 18 drives for a RAID 5 pool – Virtual Provisioning creates three 5-drive (4+1) RAID

groups and one 3-drive (2+1) RAID group. This provisioning is less optimal.

- If you specify 10 drives for a RAID 6 pool – Virtual Provisioning creates one 10-drive (8+2) RAID group. This is larger than standard, because an additional group cannot be created. It is acceptable, because the RAID groups are the same size.
- If you specify 10 drives for a RAID 1/0 pool – Virtual Provisioning creates one 8-drive (4+4) and one 2-drive (1+1) RAID group. This is *not* optimal, because some pool resources will be serviced by a single drive pair. For RAID 1/0 pools, if the number of drives you specify in pool creation or expansion isn't divisible by eight, and if the remainder is 2, the recommendation is to add additional drives or remove two drives to that disk count to avoid a private RAID group of two drives being created.

♦ In a storage pool, the *subscribed capacity* is the amount of capacity that has been assigned to thin and thick LUNs. When designing your system, make sure that the expected subscribed capacity does not exceed the capacity that is provided by maximum number of drives allowed in a storage system's pool. This ensures that increased capacity utilization of thin LUNs can be catered for by pool expansion as necessary.

Expanding homogeneous storage pools

A homogeneous pool is a storage pool with drives of a single type. For best performance expand storage pools infrequently, maintain the original character of the pool's storage devices, and make the largest practical expansions.

Following are recommendations for expanding pools:

♦ Adjust the **% Full Threshold** parameter (Default is 70%) to the pool size and the rate applications are consuming capacity. A pool with only a few small capacity drives will quickly consume its available capacity. For this type of pool you should have lower alerting thresholds. For larger pools slowly consuming capacity you should use higher thresholds. For example, for the largest pools, a good initial **% Full Threshold** parameter value is 85%.

♦ Expand the pool using the same type and same speed hard drives used in the original pool.

♦ Expand the pool in large increments. For RAID level 5 pools use increments of drives evenly divisible by five, not less than five. RAID 6 pools should be expanded using eight-drive evenly divisible increments. Pools may be expanded with any amount of drives. You should expand the pool with the largest practical number of drives. Pools should *not* be expanded with fewer than a single RAID group's number of drives. The performance of the private RAID groups within the pool by a smaller, later expansion may be different from the pool's original RAID groups. Doubling the size of a pool is the optimal expansion.

♦ Be conservative about the eventual maximum number of hard drives in the pool. More pools with a smaller number of storage devices will have better availability than fewer pools with a greater number of storage devices.

♦ Pool LUNs should not be defragmented. This includes RAID group defragmentation and host file system defragmentation. RAID group defragmentation is not an option for pool-based LUNs.

♦ The expansion drives do *not* need to have the same capacity as the initial allocation of hard drives. However, it is recommended that all the drives in the expansion be of the same capacity to maintain a consistent level of distributed pool capacity utilization balanced with performance.

Quick guidelines for creating and expanding storage pools

Table 18 provides recommendations for quickly creating and extending well-balanced RAID 5-based storage pools. Note that workloads vary greatly in their requirements for capacity, performance, and availability. These recommendations may need to be tailored using the information in the preceding sections to address individual requirements.

For example, the minimum RAID 5 pool size is specified as three drives, although five maintains performance and capacity utilization, while the recommended value or greater (in numbers evenly divisible by five) may offer better performance depending on workloads and distribution of access across pool resources.

Table 18 Recommended storage pool storage device allocations

CLARiiON model	Recommended initial RAID 5 pool size (drives)	Recommended incremental RAID 5 expansion (drives)	Recommended maximum RAID 5 pool size (drives)	Recommended thin storage pools per storage system (pools)
CX4-120	5	5	20	5
CX4-240	10	10	40	10
CX4-480	20	20	60	30
CX4-960	20	20	80	50

Creating pool LUNs

The general recommendations toward traditional LUNs apply to pool LUNs. (See the “LUN provisioning” section on page 55.)

The largest capacity pool LUN that can be created is 14 TB.

The number of thin LUNs created on the storage system subtracts from the storage system’s total LUN hosting budget. A large number of pool LUNs are creatable per storage pool (Table 20). In the table, the column “Maximum storage system LUNs all types” refers to traditional LUNs, metaLUNs, snapshot LUNs, and pool LUNs. The maximum number of LUNs visible to a host is shown separately in the table. Be aware of the number and types of LUNs already created or anticipated for creation. A few thin pools with a lot of thin LUNs can easily account for a substantial part of a storage system’s maximum host visible LUN count.

Table 19 Thin provisioning thin LUN provisioning recommendations

CLARiiON model	Maximum storage system LUNs all types	Maximum host visible LUNs	Maximum LUNs per storage pool
CX4-120	1636	1024	512
CX4-240	1636	1024	1024
CX4-480	5220	4096	2048
CX4-960	6244	4096	2048

Avoid trespassing pool LUNs. Changing a pool LUN’s SP ownership may adversely affect performance. After a pool LUN trespass, a pool LUN’s private information remains under control of the original owning SP. This will cause the trespassed LUN’s I/Os to continue to be handled by the original owning SP. This results in both SPs being used in handling the I/Os. Involving both SPs in an I/O increases the time used to complete an I/O. Note that the private RAID groups servicing I/O to trespassed pool LUNs may also be servicing I/O to non-trespassed pool LUNs at the same time. There is the possibility of dual SP access for the period some pool LUNs are trespassed. If a host path failure results in some LUNs trespassing in a shared pool, the failure should be repaired as soon as possible and the ownership of those trespassed LUNs be returned to their default SP.

Eventually, the CLARiiON's ALUA feature will link both the trespassed pool LUNs and their private information under the sole control of the new owning SP. However, response time will be higher until this occurs.

Pools with high bandwidth workloads

When planning to use a pool LUNs in a high bandwidth workload, the required storage for the LUN should be pre-allocated. For FLARE revision 30.0 and later, thick LUNs should be used. For virtual provisions using earlier versions of FLARE a pre-allocation of the storage should be performed.

Pre-allocation results in sequential addressing within the pool's thin LUN ensuring high bandwidth performance. Pre-allocation can be performed in several ways including migrating from a traditional LUN; performing a full format of the file system, performing a file write from within the host file system; or creating a single Oracle table from within the host application. In addition, only one concurrent pre-allocation per storage pool should be performed at any one time. More than one thin LUN per pool being concurrently pre-allocated can reduce overall SP performance.

Capacity overhead

There is a fixed capacity overhead associated with each LUN created in the pool. Take into account the number of LUNs anticipated to be created, particularly with small allocated capacity pools.

A pool LUN is composed of both metadata and user data, both of which come from the storage pool. A pool LUN's metadata is a capacity overhead that subtracts from the pool's user data capacity. Thin and thick LUNs make different demands on available pool capacity when they are created. Note the User Consumed Capacity of a thin LUN is some fraction of the User Capacity of the LUN.

Any size thin LUN will consume about 3 GB of pool capacity: slightly more than 1 GB of capacity for metadata, an initial 1 GB of pool capacity for user data. An additional 1 GB of pool capacity is prefetched before the first GB is consumed in anticipation of more usage. This totals about 3 GB. The prefetch of 1 GB of metadata remains about the same from the smallest though to the largest (>2 TB host-dependent) LUNs. Additional metadata is allocated from the first 1 GB of user data as the LUN's user capacity increases.

To estimate the capacity consumed for a thin LUN follow this rule of thumb:

```
        Consumed capacity = (User Consumed Capacity * 1.02) + 3GB.
```

For example, a thin LUN with 50 0GB of user data (User Consumed Capacity) written consumes 513 GB ((500 GB * 1.02) +3 GB) from the pool.

Any size thick LUN will likewise consume additional pool capacity beyond the User Capacity selected. However, because thick LUNs reserve their capacity, they expose the full metadata immediately in the reported consumed capacity from the pool. To estimate the capacity consumed for a thick LUN follow the same rule for thin LUNs.

Plan ahead for metadata capacity usage when provisioning the pool. Two pools with 10 LUNs each have higher pool capacity utilization than one pool with 20 LUNs. With multi-terabyte pools the percentage of the pools capacity used for metadata shrinks to less than 1% and should not be a concern. With small capacity pools the percentage of capacity used by metadata may be a considerable amount. Create pools with enough initial capacity to account for metadata usage and any initial user data for the planned number of LUNs. In addition, be generous in allocating capacity to a created thin LUN. This will ensure the highest percentage of pool capacity utilization.

Fully Automated Storage Tiering (FAST) Virtual Provisioning

Storage systems with FLARE 30.0 or later support the optionally licensable Fully Automated Storage Tiering (FAST) feature.

FAST provides tiered LUN-based storage by relocating heavily accessed data onto the highest performing drives in a pool. In-use, infrequently accessed data may be moved to higher-capacity drives with more modest performance if there is not enough capacity available on the high-performance tier. The relocations are performed automatically in the background and require no operator intervention. FAST applies to pools only. It requires its LUNs be part of a single pool. FAST supports both thick and thin LUNs.

FAST collects statistics on the accesses and rate of access for LUN data and relocates subsets of that data as determined by user policy settings on the LUN so the most frequently accessed data is stored on higher-performance storage devices. An example would be relocating heavily used data from SATA to Fibre Channel drives. This provides lower host response time for I/O. Less frequently accessed data may be pushed to lower-performance, high-capacity storage if the higher-performance tiers are full. Users can monitor and control the timing and the capacity of the data relocation to balance its effect on overall storage system performance.

FAST tiers

FAST tiers are based on drive type. There are three types of tiers supported where all drives in the tier are made up of that type:

- Flash drive
- Fibre Channel
- SATA

Drives of the same type, with different capacities and speeds, may be provisioned in the same tiers; however, this is *not* recommended. Mixing drives of different capacities and speeds results in varying I/O response times *within* the tier. This results in an overall less predictable host response time.

The performance of a FAST tier is dependent on the workload's I/O characteristics and the tier's provisioning. Performance can range from very high to quite modest. For example, the highest FAST performance is with a small-block random workload to a Flash drive-based tier. More modest performance results from a small-block random workload to a SATA-based tier. The capacity of a tier is typically the inverse of its performance. That is, Flash-drive-based tiers have fewer, more modest capacity drives. A SATA-based tier is likely to have a larger number of high-capacity drives. For example, a three-tiered FAST pool may have a *capacity* distribution of:

- 5% Flash drives
- 20% Fibre Channel drives
- 75% SATA drives

For example, consider a 10 TB three-tiered pool. The capacity allocation would likely be 500 GB contributed by Flash drives, 2 TB contributed by Fibre Channel drives, and 7.5 TB by SATA drives.

If Flash drives aren't available for a pool tier, create a two-tiered pool, then increase the Fibre Channel tier to be 25 percent of the total LUN capacity.

A Virtual Provisioning pool can be partitioned into the following number of tiers, based on the composition of the pool's drives:

Three tiers: Flash drive, Fibre Channel, and SATA

Three tiers require all the supported drive types to be present in the pool. This tiering structure provides the highest to moderate performance depending on the workload. We recommend that you consider using Flash drives as a FAST Cache with a two-tiered pool before using Flash drives to create a third tier.

Two tiers: Flash and Fibre Channel - Highest performance

This configuration gives the highest performance when the tiers are provisioned with the CLARiiON's highest-performing drives. We recommend that you consider using FAST Cache with a single-tiered pool before using Flash drives in a two-tiered pool.

Two tiers: Flash and SATA - High performance

When configuring this way, the Flash tier must be large enough in capacity to contain the workload(s)' most actively accessed data. Configuring the Flash tier to be slightly larger than the working set's capacity is preferable. In this configuration, placement of new data or access to data that has found its way onto SATA drives due to lower activity must be tolerated by the application until that data can be migrated to the higher tier.

Two tiers: Fibre Channel and SATA - Moderate performance with highest potential capacity

This is the recommended FAST provisioning. It has modest performance for large amounts of infrequently used data stored on large-capacity SATA drives, and high performance for I/O on frequently used data on Fibre Channel drives. Use a 20 percent Fibre Channel with an 80 percent SATA drive capacity allocation. Use the Highest allocation method with this configuration. Additional performance can be achieved when FAST Cache is enabled for this pool. Approximately 5 percent of the pool's capacity should be replicated by FAST Cache capacity.

Single tier: Flash, Fibre Channel or SATA - High to modest performance

Single tiering is the result of having the pool provisioned with drives of all the same type. The performance of single tier provisioning ranges from the highest to the most modest performance, depending on the type of drive used. Single tiering has the most predictable performance, because there is no tier warm-up or relocation. Its pool-based provisioning has the benefit of ease of provisioning over traditional RAID groups and LUNs.

Tier configuration: Initial data placement

When pool LUNs are created with FAST, there are several options available for data placement. When a pool LUN is created, its placement mode must be set. Changing a LUN's placement from its original setting may result in relocation of data to adjacent tiers as long as that tier has less than 90 percent in-use capacity. The change takes effect in the next scheduled relocation interval.

The data placement options are:

- Lowest
- Highest
- Auto (Default)
- No Movement

Lowest placement initially loads the LUN data in the lowest performance tier available. Note that on occasion the highest-performance tier may be at capacity, and the next highest-performance tier will be used. Subsequent relocation is upward through the tiers. That is, the most frequently accessed addresses are promoted into higher-performing storage devices.

Highest placement initially loads the LUN data in the highest-performance tier. Subsequent relocation is downwards through the tiers. That is, more active data in lower tiers may move up to displace data into lower-performing storage devices. FAST attempts to maintain the data in the highest tier as long as the tier does not exceed the maximum used space unless the pool is already over its allocated maximum.

Auto placement initially loads data by distributing it in an equal fashion across all available tiers. Factors used to determine the distribution include number of tiers, tier capacity, tier type, storage system bus location, and storage processor ownership. FAST balances capacity utilization across private resources in each tier, but it relocates data to higher-performing tiers as soon as possible, as long as less than maximum capacity in higher tiers is already in use. Auto is the default placement type. In pools where the Flash drives are installed and the Flash drives make up the smaller percentage of the pool's aggregate capacity, Auto limits their initial use. Auto shows a preference for available SATA or Fibre Channel drives. Subsequent I/O is used to quickly determine the data that should be promoted into the Flash tier.

No Movement maintains the LUN's data in its current tier or tiers. This disables FAST relocation.

The data placement option has a significant effect on the efficiency of the tiering process. The recommended placement is Highest. Highest results in the highest performance in the shortest amount of time; a bias will be shown for initially placing data in the highest-performing tiers over lower-performing tiers.

FAST relocations

FAST will monitor activity to all LUNs in each pool at a sub-LUN granularity equal to 1 GB. At an interval of every hour, a *relative temperature* is calculated across all 1 GB slices for each pool. This temperature uses an exponential moving average so historical access will have a lowering effect as that access profile ages over time. At each interval the pool properties display the number of slices that indicate hotter activity between tiers and as such, how much data is proposed to move up, and how much data that displaces downwards to lower tiers. Until the higher tiers reach their maximum utilization, you will always see data proposed to move up. When the higher tiers are heavily utilized, the remaining headroom is for new slices to be allocated for new data. If that occurs, on the next relocation schedule, slices will be moved down from the higher tiers to maintain a small margin of capacity within the tier in preparation for new slice allocation.

If the aggregate of allocated capacity of LUNs with their allocation policy set to Highest Tier exceeds the available space in the highest tier, some slices must be allocated from the next available tier. During FAST calculations and relocations, these slices propose and move between the tiers they occupy based on their relative temperature due to activity levels.

If you require LUNs using the Auto-Tier method to place active data on the highest tier during relocation, you must ensure any highest tier only LUNs do not consume all of the 90 percent of that highest tier for that pool, otherwise the only time an auto-tier LUN may get a slice from that highest tier is when it is first allocated and used, but it will be pushed down on the next relocation.

FAST will attempt to maintain each tier with a maximum of 90 percent allocation unless the pool capacity is already over 90 percent in use. If the pool's capacity is running at 95 percent in use, FAST tries to maintain the same level of capacity usage on the highest tier (for example, 95 percent).

Evaluation of candidate data for relocation is performed hourly. Actual relocation of data is performed at intervals that are either set manually or via the scheduler (where you set a start time and duration to perform slice relocation in hours and minutes). The scheduler invokes relocations on all pools that have FAST enabled, whereas manual relocation is invoked on a per-pool basis.

FAST warm-up

Warm-up is the filling of the highest-level FAST tiers with the workload's working set. The highest-level FAST tiers need to be completely warmed up for optimal FAST performance. The efficient operation of the FAST depends on locality; the higher the locality of the working set, the higher the efficiency of the tiering process. Likewise, the time it takes for the highest-level tiers to warm up depends on locality in the workload.

Additional FAST information

Additional information on FAST can be found in the *EMC FAST for CLARiiON* white paper available on Powerlink.

LUN compression

LUN compression is a separately licensable feature available with FLARE 30.0 and later.

Compression performs an algorithmic data compression of pool-based LUNs. All compressed LUNs are thin LUNs. Compressed LUNs can be in one or more pools. FLARE LUNs can also be compressed. If a FLARE LUN is provisioned for compression, it will be converted into a designated pool-based thin LUN. Note that a Virtual Provisioning pool with available capacity is required before a FLARE LUN can be converted to a compressed LUN.   The conversion of a FLARE LUN to a compressed thin LUN is considered a LUN *migration*.

Compression candidate LUNs

Not all LUNs are ideal candidates for compression. In general, the data contents of a LUN need to be known to determine if the LUN is a suitable candidate for compression. This is because some CLARiiON LUN types and types of stored data do not benefit from data compression. Reserved LUNs cannot be compressed. Examples of reserved LUNs include metaLUN components, snapshot LUNs, or any LUN in the reserved LUN pool. Stored data varies widely in how much it can be compressed. Certain types of user LUNs can have their capacity usage substantially reduced because their data can be easily compressed. For example, text files are highly compressible. Data that is already compressed, or that is very random, will not reduce or significantly reduce its capacity through compression. For example, already compressed data is codec compressed image, audio, and mixed media files. They cannot be compressed further to decrease their capacity usage.

In addition, the host I/O response time is affected by the degree of compression. Uncompressible or host-compressed stored data that does not need to be decompressed by the storage system will have a short I/O response time. Highly compressible data stored on a compressed LUN will have a longer response time, as it must be decompressed.

Settings and configurations

Compression can be turned ON or OFF for a LUN. Turning it ON causes the entire LUN to be compressed and subsequent I/O to be compressed for writes and decompressed for reads. Compression is a background process, although read I/Os will decompress a portion of a source LUN immediately. Writes to a compressed LUN cause that area to be decompressed and written as usual, then it is recompressed as a background process. The background process may be prioritized to avoid an adverse effect on overall storage system performance. The priorities are: High, Medium, and Low, where High is the default.

Compression can be turned OFF for a LUN. This will cause the LUN to "decompress." Decompressing a LUN can take 60 minutes or longer depending on the size of the LUN. We recommend that you enable the Write Caching at the pool level for a decompressing LUN.

The number of compressed LUNs, the number of simultaneous compressions, and the number of migrations is model-dependent. Table 20 shows the compression model dependencies. Note these are entire LUNs.

Table 20 Compression operations by CLARiiON model

	Maximum Compressed LUNs	Maximum LUN Compressions Per Storage Processor	Maximum LUN Migrations per Storage System
CX4-120	512	5	8
CX4-240	1024	5	8
CX4-480	2048	8	12
CX4-960	2048	10	12

Compressed LUN performance characteristics

Compression should only be used for archival data that is infrequently accessed. Accesses to a compressed LUN may have significantly higher response time accesses to a Virtual Provisioning pool-based LUN. The duration of this response time is dependent on the size and type of the I/O, and the degree of compression. Note that at the host level, with a fully operational write cache, delays for writes to compressed LUNs are mitigated.

Small-block random reads have the shortest response time; they are very similar to those of a typical pool-based LUN. Large-block random reads are somewhat longer in duration. Sequential reads have a longer response time than random reads. Uncached-write I/O generally has a longer response than read I/O. Small-block random write operations have the longest response time.

Note that the degree to which the data has been compressed, or is compressible, also affects the response time. Data that is minimally or not compressible has a short response time. Highly compressed data has a longer response time.

In addition, the effects of I/O type and compressibility are cumulative; small-block random writes of highly compressible data have the highest response time, while small-block random reads of data that is not compressible have the lowest response time.

Storage administrators should take into account the longer response times of compressed LUNs when setting timeout thresholds.

In addition, there is an overall storage system performance penalty for decompressions. Large numbers of read I/Os to compressed LUNs, in addition to having a lower response time, have a small effect on storage processor performance. Write I/Os have a higher response time, and may have a larger adverse effect on storage system performance. If a significant amount of I/O is anticipated with an already compressed LUN, you should perform a *LUN migration* ahead of the I/O to quickly decompress the LUN to service the I/O. This assumes available capacity for the compressed LUN's decompressed capacity.

Storage devices

The CLARiiON CX4 series supports the following types of storage devices:

- Fibre Channel 15k rpm and 10k rpm hard drives
- SATA 7.2k rpm and 5.4k rpm hard drives
- Flash drives (SSDs)

These storage devices have different performance and availability characteristics that make them more or less appropriate to different workloads. Note that all storage devices are not supported on all models of CX4 and AX4.

Drive type hosting restrictions

There are restrictions on which types of storage devices can be installed together within a CX4 or AX4 DAE.

The following table shows the restrictions. A “check” in the box indicates hosting within the same DAE is permitted, otherwise it is prohibited. For example from the table, hosting Fibre Channel and SATA drives within the same DAE is prohibited.

Table 21 Drive type DAE hosting restrictions

Drive Type DAE Hosting Restrictions				
Drive Types	Fibre Channel	SAS	SATA	Flash
Fibre Channel	▨			√
SAS		▨	√	
SATA		√	▨	
Flash	√			▨

Fibre Channel and SAS drive storage

The Fibre Channel and SAS hard drives with 15k rpm rotational speed reduce the service times of random read and write requests and increase the sequential read write bandwidth. Use these types of drives when request times need to be maintained in workloads with strict response time requirements.

SATA drive storage

Knowledge of the workload’s access type is needed to determine how suitable 7.2k rpm SATA drives are for the workload. SATA drives are economical in their large capacity; however they do not have the high performance or availability characteristics of Fibre Channel or SAS hard drives. The following recommendations need be considered in using SATA drives:

- For *sequential reads*: SATA drive performance approximates Fibre Channel hard drive performance.
- For *random reads*: SATA drive performance decreases with increasing queue depth in comparison with Fibre Channel drives.
- For *sequential writes*: SATA drive performance is comparable with Fibre Channel performance.
- For *random writes*: SATA drive performance decreases in comparison to Fibre Channel performance with increasing queue depth.

In addition to the 7.2k rpm SATA drives, there are the 5.4k rpm 1 TB SATA drives. These hard drives provide high-capacity, low-power consumption, bulk storage. Only full DAEs (15 hard drives) of these drives can be provisioned.

In summary, we do not recommend SATA drives for *sustained* random workloads at high rates, due to their duty cycle limitations. However, SATA drives provide a viable option for sequential workloads.

Enterprise Flash Drive (Flash drive) storage

Flash drives are a semiconductor-based storage device. They offer a very low response time and high throughput in comparison to traditional mechanical hard disks and under the proper circumstances can provide very high throughput. To fully leverage the advantages of Flash drives, their special properties must be taken into consideration in matching them to the workload that best demonstrates them.

Flash drives are a FLARE revision-dependent feature. Flash drive support requires FLARE revision 28.0 or later.

Flash drives offer the best performance with highly concurrent, small-block, read-intensive, random I/O workloads. Their capacity and provisioning restrictions of the Flash drives in comparison to conventional hard disks may restrict their usage to modest-capacity LUNs. Generally, Flash drives provide their greatest performance advantages compared to mechanical hard drives when LUNs have:

- A drive utilization greater than 70 percent
- A queue length (ABQL) greater than 12
- Average response times greater than 10 ms
- An I/O read-to-write ratio of 60 percent or greater
- An I/O block-size of 16 KB or less

An in-depth discussion of Flash drives can be found in the *An Introduction to EMC CLARiiON and Celerra Unified Storage Platform Storage Device Technology* white paper available on Powerlink.

Configuration requirements

There are some differences in Flash drive configuration requirements over hard disks. Their usage requires the following provisioning restrictions:

- Flash drives cannot be installed in a DAE with SATA hard drives. They may share a DAE with Fibre Channel hard drives.
- Flash drives require their own hot spares. Other drive types cannot be used as hot spares for Flash drives. In addition, Flash drives cannot hot spare for hard drives. It is important that at least one Flash drive hot spare be available while maintaining a minimum ratio of 1:30 hot spares to all hard drive types for optimum availability.
- Flash drives can only be included in metaLUNs composed of LUNs with Flash drive-based RAID groups.

Currently, Flash drives are available from EMC on CLARiiON storage systems in the following unit count ordering limitations. Larger numbers are supported. Consult with an EMC Performance Professional on the resource utilization requirements of larger Flash drive installations.

Table 22 CLARiiON Flash drive configurations

CLARiiON model	Minimum Flash drives	Maximum Flash drives
CX4-120 and CX4-240	2	60
CX4-480 and CX4-960 (all configurations)	2	120

Capacity considerations

The following table lists the Flash drive per device capacities. Note that bound capacity is slightly less than the formatted capacity due to storage system metadata.

Table 23 Flash drive capacity

Nominal Capacity (GB)	Bound Capacity (GB)
73	66.60
100	91.69
200	183.41
400	366.76

All available CLARiiON RAID levels are supported by hard drives are available with Flash drives. Each RAID level and RAID group size have a different amount of user data capacity. However, RAID 5 groups offer the highest ratio of user data capacity with data protection to Flash drives.

The capacity of any Flash drive-based LUN can be extended through the use of extended RAID groups sometimes called wide RAID groups or metaLUNs to the maximum number of Flash drives permitted on the CLARiiON model. Note the maximum number of either Flash drives or hard disks in any CLARiiON RAID group is 16.

I/O considerations

Knowledge of the required capacity, I/O type, block size, and access type is needed to determine how suitable Flash drives are for the workload. In addition, the application threading model needs to be thoroughly understood to better take advantage of the Flash drive storage devices unique capabilities.

Flash drives can provide very high IOPS and low response time. In particular, they have exceptional small-block, random read performance and are particularly suited to highly concurrent workloads. Small-block is 4 KB or small multiples of 4 KB. “Highly concurrent” means 32 or more threads per Flash drive-based RAID group.

Be aware, that as with many semiconductor-based storage devices, that Flash drive uncached write performance is slower than their read performance. To most fully leverage Flash drive performance, they are recommended for use with workloads having a large majority of read I/Os to writes.

The following I/O type recommendations should be considered in using Flash drives with parity RAID 5 groups using the default settings:

- For *sequential reads*: When four or greater threads can be guaranteed, Flash drives have up to twice the bandwidth of Fibre Channel hard drives with large-block, sequential reads. This is because the Flash drive does not have a mechanical drive’s seek time.
- For *random reads*: Flash drives have the best random read performance of any CLARiiON storage device. Throughput is particularly high with the ideal block size of 4 KB or less. Throughput decreases as the block size increases from the maximum.
- For *sequential writes*: Flash drives are somewhat slower than Fibre Channel hard drives with single threaded write bandwidth. They are somewhat higher in bandwidth to Fibre Channel when high concurrency is guaranteed.
- For *random writes*: Flash drives have superior random write performance over Fibre Channel hard drives. Throughput is particularly high with highly concurrent access using a 4 KB block size. Throughput decreases with increasing block size.

To achieve the highest throughput, a highly concurrent workload is required. Note, this may require partitioning Flash drive RAID groups into two or more LUNs, or sharing RAID groups between SPs. Note that sharing RAID groups between SPs is contrary to hard disk-based best practices. Its use requires an in-depth understanding of the I/O.

Cache considerations

By default, Flash drive-based LUNs have both their read and write cache set to *off*. Note the performance described in the previous sections applies to the default cache-off configuration for Flash drive-based LUNs. However, certain well-behaved workloads may benefit from cache-on operation. Well-behaved workloads do not risk saturating the cache.

In particular, small-block sequential I/O-based workloads can benefit from cache-on operation. For example, sequential write performance can be improved by write-cache coalescing to achieve full-stripe writes.

Some applications performing random writes may be affected by the cached versus uncached performance of Flash drives. With write-cache on, Flash drive write performance as seen by the host will be identical to hard drive-based write performance. However, back-end throughput, if properly provisioned for, will be higher than available with hard drives. A likely candidate for cached-operation is small-block, sequential database log writes.

RAID group considerations

The performance and storage system resource utilization profile of Flash drives differs from the traditional rules for RAID group provisioning.

There is a model-dependent maximum number of allowed Flash drive per storage system. This is a total Flash drive limit. It includes drives used as either FAST Cache or for storage. The following table shows the limits:

Table 24 Maximum Flash drives per CLARiiON model, FLARE Rev. 30

	CX4-120	CX4-240	CX4-480	CX4-960
Maximum Flash drives	60	60	120	120

Due to their high performance and high availability, RAID 5 is the optimal RAID level for Flash drives. It is also the most economical in its ratio of available user data capacity to nominal capacity.

There is no limitation on the RAID group size for groups with Flash drives, other than a maximum of 16 per RAID group. Other factors, such as front-end port, SP CPU, and back-end bus utilization particular to the individual workload's I/O, are the important considerations when configuring Flash drives for the CLARiiON.

Generally, for small-block, random I/O workloads, add Flash drives to the RAID group until the needed number of IOPS or the required capacity is reached. For large-block random and sequential I/O there is a small operational preference for (4+1) and (8+1), since the stripe size is even and un-cached I/O may leverage full stripe writes.

Balancing of the back-end bus resource utilization becomes important with the high bandwidth of Flash drives. Bus bandwidth utilization will affect all storage devices on the same storage system back-end bus.

As bus utilization climbs due to heavily utilized Flash drives, there is less bandwidth available for the I/O requests of other storage devices.

The best practices for RAID group-bus balancing with conventional hard drives also apply to Flash drives. (See the “RAID group bus balancing” section.) The maximum number of Flash drives per back-end bus is dependent on how the Flash-drive-based RAID group's LUNs are configured, and on the application's requirement for bandwidth or IOPS.

If aFlash-drive-based RAID group's LUN(s) are accessed by a single SP, available bandwidth is about 360 MB/s. Otherwise, if a partitioned RAID group's LUNs are owned by both SPs, available bandwidth is 720 MB/s. (This bandwidth distribution is the same as with Fibre Channel drives.)

When provisioning Flash drive RAID groups with more than four drives and high bandwidth (> 300 MB/s) workloads, distribute the drives across two or more storage system buses. For example, with a five-drive (4+1) Flash RAID 5 group, and assuming standard racking (DAEs are installed on alternating buses), position two drives in one DAE, and three drives in an adjacent DAE.

When 16 or more Flash drives are installed on a storage system servicing a high IOPS workload, further precautions are required. High IOPS is > 50K back-end IOPS. Evenly distribute the RAID group's LUNs across the storage processors to further distribute the back-end I/O. With high IOPS, do not provision more than eight Flash drives per storage processor per bus (a bus loop). That is a 15 Flash drive maximum per bus. In some cases with many Flash drives provisioned on multiple-bus CLARiiONs, dedicating a bus exclusively to Flash drives should be considered.

Flash drive rebuilds

Flash drive RAID group rebuilds are primarily affected by available back-end bus bandwidth.

When all of the RAID group’s Flash drives are on the same back-end bus, the rebuild rate is the same as Fibre Channel rates. (See the “Rebuilds” section.) When a parity RAID group’s Flash drives are distributed across the available back-end buses as evenly as possible, the Rebuild rate is as shown in Table 25.

Table 25 Flash drive rebuild rates for RAID 5

Priority	Parity RAID rate (MB/s)
Low	2
Medium	6
High	13
ASAP	250

Please note that a large percentage of the available bus bandwidth may be consumed by a Flash drive ASAP rebuild. If bandwidth-sensitive applications are executing elsewhere on the storage system, the economical High (the default), Medium, or Low priorities should be chosen for rebuilds.

Flash drive performance over time

Flash drives do not maintain the same performance over the life of the drive. The IOPS rates of a Flash drive are better when the drive is new than when it has been in service for a period of time. The reduction in Flash drive performance over time is a side effect of the way they reuse capacity released by file system deletes. It is due to the effect of fragmentation of the drive’s mass storage, *not* individual locations "wearing out." Drives can be re-initialized to restore their original performance. However, re-initialization is destructive to stored data. The performance metrics used as a rule-of-thumb in this document are a conservative per-drive IOPS number that is achievable in the long run, with a broad range of I/O profiles for Flash drives that have been in service over a long period.

Additional information

Further general information on Flash drives can be found in the *Unified Flash Drive Technology Technical Notes* available on Powerlink.

FAST Cache

Storage systems with FLARE revision 30 or later support an optional performance-enhancing FAST Cache. The FAST Cache is a storage pool of Flash drives configured to function as a secondary I/O cache. Frequently accessed data is copied to the FAST Cache Flash drives; subsequent accesses to this data experience Flash drive response times. This cache automatically provides low-latency and high-I/O performance for the most-used data, without requiring the larger number of Flash drives to provision an entire LUN. The increase in performance provided by the FAST Cache varies with the workload and the configured cache capacity. Workloads with high locality, small block size, and random I/O benefit the most. Workloads made up of sequential I/Os benefit the least. In addition, the larger the FAST Cache capacity, the higher the performance is. FAST Cache supports both pool-based and FLARE LUNs. Finally, FAST Cache should not be used on systems that have very high storage processor utilization (> 90%).

Factors affecting FAST Cache performance

Locality is based on the data set requested locality of reference. Locality of reference means storage locations being frequently accessed. There are two types of locality, "when written" and "where written."

In the real world an application is more likely to access today's data than access data created three years ago. When data is written, temporal locality refers to the reuse of storage locations within a short period of time. A short duration is considered to be within a couple of seconds to within several hours. This is locality based on *when* data is being used.

Today's data is likely residing on mechanical hard drive LBAs that are near each other, because they hold new data that has only recently been written. This is locality based on *where* data is located on its host storage device. "Where written" refers to the use of data stored physically relatively closely on the storage system's mass storage. Physical closeness means being stored in nearby sectors or sectors on nearby tracks of a mechanical hard drive.

Note that physical closeness of data is not a factor when data is stored on FLARE LUNs implemented from Flash drives.

A data set with high locality of reference gets the best FAST Cache performance.

The extent of the data set is also important to understand. The extent of the working data set varies from application to application. A 3 to 5 percent extent is common, but a 20 percent extent is easily possible. For example, a 1.2 TB database with a 20 percent working data set has about 250 GB of frequently accessed capacity. Storage architects and administrators should confer with their application's architects and analysts to determine ahead of time the size of the working data set.

The size of the I/O can affect performance. FAST Cache performs best with small and medium-sized I/O. Medium block size is from 8 KB to 32 KB in capacity. Ideally the size of the I/O would equal the page size of the Flash drive for the best performance. The typical Flash drive page size is 4 KB.

The type (random or sequential) can affect the performance. FAST Cache is designed for optimizing random I/O that has a degree of locality. Workloads with significant sequential I/O are not good candidates for FAST Cache. The effectiveness of the storage system's primary cache in reading ahead already accounts for high performance of sequential reads. Likewise sequential writes are typically handled with very efficient direct-to-disk processing. Note that a truly random I/O workload would have low locality.

Larger caches hold more data, which increases the chance of a *cache hit*. Hits are when a read or write request can be serviced by the FAST Cache's Flash drives. A miss is a request serviced by the CLARiiON's mechanical hard drives. Cache hits within the FAST Cache have a very low response time compared to typical storage access.

FAST Cache and LUNs

When FAST Cache is enabled, it is enabled by default for *all* LUNs and pools provisioned on the storage system. Some LUNs will not benefit from the use of FAST Cache, or the FAST Cache may not have the provisioned capacity to optimally service every LUN and pool on the storage system. It may be necessary to manually disable FAST Caching on selected LUNs and pools to improve overall caching effectiveness.

FAST Cache can be applied to any LUN in a storage system. It is not recommended to use FAST Cache with LUNs made up of Flash drive-based RAID groups. If a LUN (or component LUNs of a metaLUN) is created in a RAID group, FAST Cache is enabled or disabled at the individual LUN (or component LUN) level. If a LUN is created in a storage pool, FAST Cache must be configured at the pool level.

FAST Cache is disabled for all LUNs and storage pools that were created before the FAST Cache enabler was installed (through an NDU process). After installing the FAST Cache enabler, the existing LUNs and storage pools will have FAST Cache disabled, but FAST Cache will be enabled (by default) on new LUNs and storage pools.

Note that not all LUNs will not benefit from FAST Cache, for example, transaction logs. These types of LUNs should be excluded from the FAST Cache.

FAST Cache warm-up

Warm-up is the filling of the FAST Cache with candidate data. FAST Cache needs to be completely warmed up for optimal performance. The efficient operation of the FAST Cache depends on that locality; the higher the locality the higher the caching efficiency. Likewise, the time it takes for the cache to warm up depends on locality in the workload.

Host response time is determined by the "hit rate" in the FAST Cache. In the FAST Cache, chunks of data are temporarily copied from the specified LUNs located on mechanical drives to the private LUNs on the Flash drives that make up the FAST Cache. Chunks of data are "promoted" to the FAST Cache when it detects that a range of addresses has been referenced several times. That range of address is then copied to FAST Cache. Once they are copied to the FAST Cache's Flash drives, reads and writes to any addresses in the transferred chunks of data are taken care of from the cache's Flash drives. These reads and writes result in FAST Cache hits. Any reads or writes to addresses not in the FAST Cache are serviced from the LUNs on the mechanical drives as usual. They are the misses.

The lowest response time for a given workload will occur when the maximum number of active addresses has been copied to the FAST Cache's Flash drives. That will result in the highest hit rate in FAST Cache.

A newly created or empty FAST Cache will have no hits. Assuming the workload reads or writes the same addresses with a range of addresses with required frequency, promotions will be made in the CLARiiON's background processing. The hit rate increases as more blocks are promoted. This is the cache "warm-up."

The FAST Cache does not have to be "full" to generate a low host response time. However, for optimal performance, a large percentage of the application's active working set needs to have been promoted to the FAST Cache. If the working set is smaller than the FAST Cache, a wide range of warm-up times are possible. Warm-up may take several minutes to several hours; it all depends on the pattern of the read and write requests. If the working set is larger than the FAST Cache, there may be very few hits or reuses of addresses in the FAST Cache. This is because they may not be hit before they are pushed out of the cache by the promotions of other address ranges.

FAST Cache provisioning

Flash drives are provisioned as a FAST Cache to improve the performance of FLARE LUNs or the LUNs in one or more pools. Within the available maximum FAST Cache size for the storage system, the FAST Cache should be large enough in capacity to contain an application's working data set.

FAST Cache consists of a RAID level 1 provisioning of multiple Flash drives. It provides both read and write caching. In addition, this type of provisioning has data protection.

In addition, the capacity of the FAST Cache and the number of Flash drives used to provision the cache are storage system-dependent. Table 26 shows the supported FAST Cache configurations, the maximum number of number of Flash drives per configuration, and the FAST Cache capacity that results.

Note that *only* the Flash drive configurations shown in the table are supported. Each FAST Cache size (capacity) requires a corresponding sizing of SP memory pages that will be dedicated to the Flash Cache metadata. This changes the memory allocations of other CLARiiON features. Only the drive configurations shown in the table are qualified.

Table 26 FAST Cache Maximum Flash drives per Storage System by Drive Capacity, FLARE Rev. 30.0

FLASH DRIVE CAPACITY	CX4-120	CX4-240	CX4-480	CX4-960	FAST CACHE RAW CAPACITY (GB)
200 GB				20	2000
				10	1000
			8		800
100 GB				8	400
		4	4		200
	2	2			100
73 GB				8	292
		4	4		146
	2				73

See the "Hot sparing" section for the implications of hot spares with FAST Cache.

FAST Cache Actual Capacity

The capacity of the FAST Cache will be less than the raw capacity of its drives. This occurs because FAST Caches are implemented on Flash drives as LUNs. They have the same metadata overhead as FLARE LUNs. For example, creating a read/write FAST Cache from a pair of 73 GB Flash drives results in a 66 GB FAST Cache. It creates a RAID 1, where a 66 GB LUN is allocated for SPA and a 66 GB LUN is allocated for SPB. Note these LUNs are a mirrored pair. That is a total 66 GB of FAST Cache results from two 73 GB Flash drives.

See the "LUN provisioning" section for a discussion of usable versus raw capacity in LUN provisioning.

Reserved LUNs: MirrorView, SAN Copy, and SnapView

Layered applications such as MirrorView, SAN Copy, and SnapView create reserved LUNs that may end up promoted into the FAST Cache. These reserved LUNs already have optimizations for priority in the storage system's primary write cache. Disabling FAST Cache on the MirrorView write intent log (WIL) and the SnapView clone reserved LUNs (CPL) is recommended. This will avoid their unnecessary promotion into the FAST Cache.

Disabling FAST Caching of all reserved LUNs is recommended. In general, FAST Cache does not provide a performance benefit to reserved (sometimes called "private") LUNs. However, promoting the contents of reserved LUNs into the FAST Cache also does not adversely affect overall system performance.

Additional FAST Cache information

Further information is available in the *EMC CLARiiON and Celerra Unified FAST Cache* white paper on Powerlink.

Availability

Availability refers to the storage system's ability to provide user access to their applications and data in the case of a hardware or software fault (sometimes called a *degraded* state or mode). Midrange systems like the CLARiiON CX4 series are classified as *highly available* because they provide access to data with a single fault. Often, the performance in degraded mode is lower than during normal operation. The following optimizations to the CLARiiON's configuration can improve performance under degraded mode scenarios.

RAID group provisioning

Single DAE and Multiple DAE Provisioning

Single DAE Provisioning is the practice of restricting the placement of a RAID group within a single DAE. This is sometimes called *horizontal* provisioning. Single DAE provisioning is the Unisphere default method of provisioning RAID groups. Owing to its convenience and HA attributes, Single DAE provisioning is used for most CLARiiON RAID groups. Storage administrators who follow this standard need not be concerned with the following section.

In *Multiple DAE Provisioning*, two or more DAEs are used. This is sometimes called *vertical* provisioning. One reason for multiple DAE provisioning is to satisfy *topology requirements*. If there are not enough drives remaining in one DAE to configure a desired RAID topology, they are selected from one or more other DAEs. The resulting configuration may or may not span buses depending on the array model and drive placement.

Multiple DAE provisioning can also be used to satisfy *performance requirements* specifically related to bus behavior. The RAID group is intentionally configured across multiple DAEs in order to gain parallel access to multiple buses on the storage system models that have more than one bus. These cases arise when:

- There are well-defined bandwidth goals that require careful load distribution
- Bursting host activity is known to cause bus bottlenecks
- Heavy write cache destage operations on a RAID group interfere with host reads
- Heavy large block I/O requests on a bus interfere with small block I/O response time

In previous CLARiiON implementations, some designers improved LUN availability in the event of a link controller card (LCC) failure through multiple DAE provisioning. The LCC is the device that connects a tray of drives to an SP's bus. Different revisions of FLARE handle an LCC failure in different ways. Beginning with release 26, there is a new mechanism for ensuring availability while at the same time maintaining data protection and decreasing the performance impact of the failure. In release 30, the LCC failure mechanism was revised again.

Prior to release 26, multiple DAE provisioning was relevant to improved availability when LCC failure meant loss of connectivity in configurations lacking automatic LUN failover (by PowerPath trespass, for instance).   Loss of connectivity was considered to be a greater problem than the resulting degraded performance or loss of RAID data protection. Failover was avoided with multiple DAE provisioning by ensuring that sufficient drives survived an LCC outage to maintain data accessibility *without a host trespass*. For RAID 5, "sufficient drives" required that no more than one drive was lost to the failure, and for RAID 10, no more than one drive per each mirrored pair was lost. However, the affected RAID groups were exposed to potentially significant performance degradation due to rebuild operations to hot spare(s) or to the original drive(s) upon LCC repair. And although failover was avoided, full protection was not restored until the rebuild operations were complete. If insufficient hot spares were available, full data protection was not achieved until well after the LCC fault was repaired. This trade-off favored availability over data protection.

In the case of LCC failure, multiple DAE RAID groups without sufficient drives and all single DAE RAID groups required a host trespass (either manually or by automatic failover) to continue operation. Since the peer SP still had complete access to the drives, rebuilds were avoided. This strategy favored data protection over availability where the risk was a loss of LUN connectivity at sites without host failover capability.

Starting with FLARE release 26, an SP with an LCC failure maintains ownership, availability, *and* data protection for both single DAE RAID groups and multiple DAE RAID groups with insufficient surviving drives. This is accomplished through a new internal SP request forwarding facility that diverts traffic to the peer SP *without* host trespass or front-end path modification. For these cases, data redundancy is maintained via background verify (BV) rather than rebuild and all drives remain online. However, a multiple DAE RAID group that has sufficient drives after the failure continues to maintain data redundancy via rebuild to hot spare(s) and/or the original drives upon LCC repair. The various cases are summarized:

Table 27 LCC failure and provisioning

Type	FLARE revision	Recovery operation
Single DAE	Pre-26	Background Verify (BV) (SP trespass)
Multiple DAE	Pre-26	Rebuild (sufficient drives, no trespass) -or- BV (insufficient drives, SP trespass)
Single DAE	26+	BV (request forwarding)
Multiple DAE	26+	Rebuild (sufficient drives, no trespass) -or- BV (request forwarding)

Given the advantages of data protection and availability afforded by request forwarding, we generally recommend provisioning single DAE RAID groups. If multiple DAE RAID groups are provisioned for performance reasons, we recommend configuring them to still take advantage of request forwarding in the event of an LCC fault. This is accomplished by grouping drives together:

- ♦ RAID 5 should have at least two drives per bus
- ♦ RAID 6 should have three drives per bus
- ♦ RAID 1/0 should have each mirrored pair on the same bus.

In the event of an LCC failure, it can be expected that BV and request forwarding will affect host response time, and that the peer SP utilization will increase during the outage in proportion to the deflected application load. For RAID 5 cases where BV is invoked at the default Medium setting, the performance degradation is almost exclusively due to the small cost of deflecting the I/O (about 0.5 ms for a typical read) if the peer SP is not overloaded. If RAID 10 LUNs incur noticeable increased read response times during the BV, the rate may need to be temporarily increased to High or ASAP in order to reduce its duration. Upon repair of the LCC, the request forwarding automatically reverts to normal operation and the BV continues if necessary without deflection.

Starting with FLARE revision 30, rebuild avoidance has been incorporated. In the event of an LCC failure, LUNs that span more than one DAE are not rebuilt. Instead, FLARE automatically uses its lower director to re-route around the failed LCC until it is replaced. The peer SP experiences an increase in its bus loading while this redirection is in use. The storage system is in a degraded state until the failed LCC is replaced.

Disk power saving (disk-drive Spin Down)

Disk-drive Spin Down conserves power by *spinning down* drives in a RAID group when the RAID group is not accessed for 30 minutes, and allowing the drives to enter an **idle** state. In the idle state, the drives do not rotate and thus use less power. (A RAID group that is idle for 30 minutes or longer uses 60 percent less electricity.) When an I/O request is made to a LUN whose drives are in spin down (idle) mode, the drives must *spin up* before the I/O request can be executed. A RAID group can be on idle state for any length of time. The storage system periodically verifies that idle RAID groups are ready for full-powered operation. RAID groups failing the verification are rebuilt.

To use the Spin Down feature, you must provision a RAID group from within Unisphere or the Navisphere CLI, and select drives that have been qualified by EMC for this feature. For example, all SATA drives 1 TB and larger in capacity are qualified for Spin Down. Spin Down can be configured at either the storage system or the individual RAID group level. We recommend the storage system level. Storage-system level Spin Down will automatically put unbound drives and hot spares into idle.

EMC recommends Spin Down for storage systems that support development, test, and training because these hosts tend to be idle at night. We also recommend Spin Down for storage systems that back up hosts.

A host application will see an increased response time for the first I/O request to a LUN with RAID group(s) in standby. It takes less then two minutes for the drives to spin up. The storage system administrator must consider this and the ability of the application to wait when deciding to enable the disk-drive Spin Down feature a RAID group.

Spin Down is not supported for a RAID group if any LUN in the RAID group is provisioned for use with MirrorView/A, MirrorView/S, SnapView, or SAN Copy sessions. In addition, the Spin Down feature is not available for drives that are part of pool-based LUNs.

Details on the disk-drive Spin Down feature can be found in the *An Introduction to EMC CLARiiON CX4 Disk-Drive Spin Down Technology* white paper available on Powerlink.

LUN provisioning

Availability of LUNs is based on the underlying availability provided by the LUN’s RAID groups, as well as the availability of caches and SPs. (The section on “RAID groups” will help you understand the availability implications of creating different types and capacity RAID groups.) However, the distribution of the workload’s recovery data across LUNs on more than one RAID group can increase the overall system availability. In addition, it can increase performance by reducing the time required to execute a rebuild.

When possible, place recovery data, such as clones and log files, on LUNs supported by RAID groups that do not also support the application’s LUNs. When more than one instance of an application exists, separate log LUNs from their instance’s application and application data. Placing an application’s recovery data on LUNs that are not on the same RAID group as the application’s LUNs speeds up the application recovery process. This is because the recovery data is immediately available and not affected by the delay of, for example, a drive rebuild.

Drive operation and planning

The CLARiiON performs several services that, although they benefit the user, can take significant drive and SP resources to execute.

There is a tradeoff between the amount of time it takes to do a LUN migration or rebuild and the effect of these operations on system resources and host access response time. Planning beforehand can reduce an adverse performance effect on the host or decrease the amount of time needed to migrate or rebuild; in a production environment, these goals can be mutually exclusive.

LUN management

There are three resources on a CLARiiON that affect overall system performance: storage processor (SP) CPUs, back-end buses, and RAID group drives. The duration of LUN migrations and rebuilds needs to be balanced with these resources.

The main factors affecting the duration of a drive operation are:

- Priority: Low, Medium, High, and ASAP (As Soon As Possible)
- Background workload: Storage system utilization

- Underlying LUN RAID group type: mirror or parity.
- RAID group hard drive type: Drive rpm speed and interface (for example, Fibre Channel or SATA).

Priority has the largest effect on an operation's duration and hence system performance. There are four priorities (Low, Medium, High, and ASAP) for LUN migration and rebuild

The Low, Medium, and High priorities economically use the system's resources, but have the longest duration. The ASAP priority accomplishes the operation in the shortest period of time. However, it also causes a high load to be placed on the drives, and additional SP CPU load. This will adversely affect host I/O performance to those drives.

EMC encourages users to use the High, Medium, and Low settings. In circumstances where concurrent access to host data has a higher priority than the time to recover, High should be used, and not ASAP.

LUN migration

The LUN migration facility is used to change a LUN's RAID group topology, move a hot LUN to a RAID group with lower utilization, and change a LUN's capacity.

The LUN migration rate is FLARE revision-dependent. Beginning with FLARE revision 29.0, the speed for migration performed at Medium and High increased dramatically, while the ASAP rate decreased. The ASAP decrease provides more resources for background workload. By default a FLARE 29.0 LUN migration bypasses write cache. You can achieve even higher bandwidth by increasing the value for the destination LUN write-aside parameter. This enables write cache. LUN migration with write cache enabled is not recommended for production environments with an active workload.

Low, Medium, High LUN migrations

Low, Medium, and High priorities have little effect on the performance of production workloads. These economical priorities implement the transfer as very large block, timed, sequential transfers.

The following table shows the rule-of-thumb migration rate for 15k rpm Fibre Channel drives:

Table 28 Low, Medium, and High migration rates for FLARE 29

Priority	Rate (MB/s)
Low	1
Medium	13
High	35

The economical transfer rates are throttled by design to allow production workloads to continue executing without adverse performance effects during the migration process.

ASAP migrations

ASAP LUN migrations with default cache settings should be used with caution. They may have an adverse effect on system performance. EMC recommends that you execute at the High priority, unless migration time is critical.

The ASAP setting executes the migration I/O with a minimum of delay between I/Os. Working on the SP itself, the inter-I/O latency is very low. The result is akin to a high-performance host running a heavy workload against the source and destination hard drives. The workload has the characteristics of a large block sequential copy from the source LUN to the destination LUN.

With FLARE 29.0 and later, the I/O write size for LUN migration is larger than the default value for LUN write-aside (1088 KB). *If you change the write-aside value for the destination LUN to 3072 or greater, you can make the migration up to four times faster.* The write-aside value of a destination LUN can be changed through the Navisphere CLI. It cannot be changed on the destination LUN once LUN migration has been initiated.

If you perform an ASAP migration through the write cache while the storage system is processing a workload, this may cause a forced cache flushing. Forced cache flushing has an adverse effect on overall storage system performance. The default ASAP migration settings avoid cache congestion. Up to two simultaneous ASAP migrations per SP are now possible. However, care should be taken to monitor system resources such as SP utilization and bus bandwidth when attempting this.

The configuration of the underlying RAID groups that support the source and destination LUNs also affects migration rate. The RAID types, drive types, number of drives, and speeds of hard disks effect on the migration rate. The largest and simplest factor affecting the ASAP migration rate is whether the underlying RAID groups are mirror or parity RAID groups, and the number of drives in the groups.

The following table shows the ASAP “rule-of-thumb” migration rate for 15k rpm Fibre Channel and 15k rpm SAS drives with RAID 1/0 (3+3) groups and RAID 5 (4+1) and default write cache off settings.

Table 29 ASAP migration rate default settings for FLARE 29

	Mirrored RAID rate (MB/s)	**Parity RAID rate (MB/s)**
Migration	92	55

A LUN migration going from a smaller source LUN to a larger destination LUN is done internally in two steps. First, the existing capacity is migrated to the new destination. Then, the system initializes the new capacity by using its standard bind algorithm. Note that LUNs sharing the RAID group of the destination LUN are adversely affected by both the migration and the initialization.

Use the following formula to estimate the time required to complete a LUN migration.

- Time: Duration of LUN migration
- Source LUN Capacity: Size of source LUN in GB
- Migration Rate: Rate of copy from source LUN to destination LUN from Table 29 or Table 30 depending on the selected migration priority
- Destination LUN Capacity: Size of destination LUN in GB
- Initialization Rate: Speed at which new additional storage is initialized in MB/s (Table 30 for ASAP, or else omit)

$$\text{Time} = (\text{Source LUN Capacity} * \text{Migration Rate})$$

Rebuilds

A rebuild can replace the failed drive of a LUN's RAID group with an operational drive created from a hot spare. Note that one or more LUNs may be bound to the RAID group with the failed drive. For this replacement to occur, there must be a hot spare available that is the correct type and size.

If an appropriate hot spare is not available, the RAID group remains in a degraded state until the failed drive is replaced. Then the failed drive's RAID group rebuilds from parity or its mirror drive, depending on the RAID level.

When a hot spare is used, a rebuild is a two-step process: rebuild and equalize. They occur after the failed drive is replaced by the hot spare. During the rebuild step, all LUNs on the RAID group are rebuilt to the hot spare either from parity or their peer. The LUNs are in a degraded state during the rebuild. A LUN rebuild is a prioritized operation. The available priorities are: ASAP, High, Medium, and Low. Rebuild times depend on a number of factors, including the rebuild priority, presence and location of an appropriate hot spare, drive type, drive size, workload, and RAID group type. Once the rebuild is complete, the LUNs operate normally and are not in a degraded state. During the equalize step, which occurs after the faulty drive is replaced, the hot spare is copied to the replacement drive.

Low, Medium, and High priorities have little effect on the performance of production workloads Table 30 shows the rule-of-thumb rebuild rate for 15k rpm Fibre Channel drives with RAID 5 (4+1) and RAID 1/0 (3+3) groups.

Table 30 Economical mirrored and parity RAID Fibre Channel hard drive rebuild rates

Priority	Parity RAID rate (MB/s)
Low	2
Medium	6
High	13

The economical transfer rates are throttled by design to allow production workloads to continue executing without adverse performance effects during the rebuild process.

The ASAP priority completes a rebuild in the least amount of time. ASAP rebuilds may have an adverse effect on the performance of other I/Os to its RAID group. Large RAID group rebuilds can also affect other I/O sharing the same bus(es). EMC recommends executing at the High priority, unless rebuild time is critical.

An ASAP rebuild has different rates depending on the RAID type, the hard drive type, and for parity RAID types, the number of drives in the RAID group. It also depends on the location of the drives – a rebuild of a Parity group at ASAP engages all the drives in the group at a high rate, and the aggregate bandwidth can approach or even hit the maximum bandwidth of a FC bus. If all drives are on one bus, then the rebuild rate may be limited by bus bandwidth.

Table 31 shows RAID type dependent rates.

Table 31 ASAP mirrored and parity RAID Fibre Channel hard drive rebuild rates with no load

	Mirrored RAID rate (MB/s)	Parity RAID 5 rate (MB/s)
Rebuild	83	73

The following table shows the hard drive type speed adjustment.

Table 32 ASAP hard drive rebuild speed adjustment

Hard drive type	Rebuild speed multiplier
15k rpm Fibre Channel	1.0
15k rpm SAS	1.0
10k rpm Fibre Channel	1.33
7.5k rpm SATA	1.54
5.4k rpm SATA	1.60
Flash drive	0.7

Parity type RAID 6 groups require more time to rebuild than parity type RAID 5 groups with the same number of drives. This difference in time decreases as the number of drives in the RAID group increases, due to the bus limitation discussed above. Generally, unless they are distributed across multiple back-end buses, larger parity RAID groups build more slowly than smaller groups. Use the following table to calculate the effects of RAID group size on rebuild rate when all drives are located on a single back-end bus. Substitute the value in this table for the rebuild rate in Table 33.

Table 33 Parity RAID rebuild rate for RAID group size

RAID group size (drives)	RAID 5 MB/s	RAID 6 MB/s
6	66.0	62.0
≤ 9	40.0	50.0
≤ 12	32.0	30.0
≥ 15	25.0	23.0

Note the values given in the table are an average number. A greater or lesser rebuild rate will be observed depending on the provisioning of the RAID group underlying the LUN. For example, a LUN with drives on multiple back-end buses has a higher rebuild rate than a LUN with drives on a single bus.

When a hot spare is used for the rebuild, an additional equalize operation occurs when the faulty drive is replaced and the hot spare is copied to it. The equalization rate for all rebuild priorities with 15k rpm Fibre Channel hard drives is shown in the following table. This rate is independent of other factors.

Table 34 Mirrored and parity RAID Fibre Channel equalization rebuild rates

	Mirrored RAID rate (MB/s)	Parity RAID rate (MB/s)
Equalization	82	82

Basic rebuild time calculation

Use the following formula to estimate the time required to complete a rebuild.

- Time: Duration of rebuild
- Failed hard drive capacity: RAID group capacity utilization * hard drive size in GB
- Rebuild rate: If priority is ASAP, use the time listed in Table 32. Otherwise, use the value from Table 34.
- Hard drive type and speed adjustment: Speed adjustment is found in Table 33.
- Equalization Rate: Speed at which the hot spare is copied to replacement for a failed drive.

Time = ((Failed hard drive capacity * Rebuild rate) * Drive type and Speed adjustment) + ((Failed hard drive capacity * Equalization rate) * Drive type and Speed adjustment))

Note the rebuild has two parts: rebuild and the equalization. Manual replacement of the failed hard drive must occur before equalization. After the rebuild the RAID group is running at full capability. The RAID group is no longer in a degraded status. The secondary equalization is an automated background process starting with the replacement of the failed drive.

ASAP rebuild example calculation

How many hours will it take to rebuild a 400 GB, 10k rpm, seven-drive (6+1) RAID 5 Fibre Channel group drive that is fully bound and utilized, at the ASAP priority? Assume a quick replacement of the failed hard drive allowing a seamless equalization. Assuming the LUN is bound with all the drives on the same bus and enclosure, the rebuild time is calculated using this equation:

Time = ((Failed hard drive capacity * Rebuild rate) + ((Failed hard drive capacity * Equalization rate)) * (Drive Type and Speed adjustment)

Where the parameters are:

- Time: Duration of rebuild in hours
- Failed Hard Drive Capacity: 400 GB
- Rebuild Rate: 66.0 MB/s (From Table 34, if this were a five-drive RAID 5 (4+1) the Rebuild Rate would come from Table 32)
- Drive Type and Speed Adjustment: 1.33 for 10k rpm Fibre Channel (from Table 33)
- Equalization Rate: 82.0 MB/s (from Table 35)

In this example the equation is: 9.9 Hrs = ((400 GB * (1/66.0) MB/s) + (400 GB * ((1/82.0) MB/s)) * (1024 MB/GB * (1/3600) sec/Hrs)) * 1.33).

Maintaining performance during an ASAP rebuild

The effect of an ASAP rebuild on application performance depends on the workload mix. There are three effects to consider:

- Rebuilding drive utilization
- Bus bandwidth utilization
- Relative drive queue contention

All applications performing I/O with the rebuilding RAID group will be slower. The rebuild will be sending up to eight I/Os at a time to each drive in a parity group. If the group is a mirror, it will send eight I/Os to the remaining mirror. Longer service times for the large rebuild reads and the longer queue will increase response time.

Bus bandwidth utilization will affect all drives on the same bus. As bus utilization climbs, there is less bandwidth available for other processes. Please note that when all drives of a parity RAID group are on the same bus, depending on the RAID group size and drive type, a large percentage of the available bus bandwidth may be consumed by an ASAP rebuild. The rebuild of large RAID groups can consume all available bus bandwidth. If bandwidth-sensitive applications are executing elsewhere on the storage system, RAID groups should be distributed across buses.

The contention for the drives between production and rebuild can be seen in the relative queues. Rebuild and equalize operations do not use the read or write cache subsystems, but they do send multiple, large I/O at the same time. Host I/O behavior may depend on the source pattern or on cache usage. Sequential writes destage from cache with multiple threads per drive with large coalesced block sizes competing with the rebuild operation. Concurrent sequential writes and a rebuild slow each other about the same amount. Sequential reads do not generally generate a similar parallel thread load per drive. Furthermore, there is a reduction of sequentiality at the drive due to contending workloads. So, sequential read operations like LUN backups run much slower during ASAP rebuilds than when an ASAP rebuild is not executing.

If you have an active sequential read workload on the rebuilding RAID group, the ASAP rebuild rate will be lower than the rates described in this section’s tables, due to contention. Storage system performance during an ASAP rebuild can be maintained by increasing the prefetch variables to favor the host read. One option is to change **prefetch multiplier** to 32 and **segment multiplier** to 4. For example, a 64 KB sequential read stream will prefetch 2 MB at a time in 256 KB chunks, substantially increasing the read rate during rebuild. Of course, if other processes are accessing those drives in normal operation, they also will be affected by the bias towards sequential reads.

If the adverse performance effects of an ASAP rebuild cannot be tolerated by the workload, rebuild priority should be set to High, Medium, or Low. These rebuild rates are slower than ASAP, but even at the High setting production workloads are only competing with the rebuild for 10 percent of the time.

LUN and Virtual Provisioning pool initialization

Newly bound LUNs and new Virtual Provisioning pools have their drives zeroed. This is called *background zeroing*. Background zeroing erases any data previously written to the drive. It provides confidentiality, and pre-conditions the drives for background verification. The background zeroing only occurs on drives that have previously been used. The zeroing occurs in the background, allowing the LUN to immediately be available. The zeroing rate is between 20 MB/s and 50 MB/s, depending on the drive type. The 5.4k rpm SATA drives have a lower zeroing rate than Flash drives, which have the highest rate.

With FLARE 29.0 and later, LUNs use *Fast Bind*. Fast Bind immediately makes a LUN available for use, before it is completely initialized in a bind or the unused remainder of the new or the destination LUN is initialized in a migration. This differs from previous FLARE versions that performed a separate initialization.

The complete zeroing of large-capacity LUNs or disks in new Virtual Provisioning pools can take several hours. This process may adversely affect storage system performance, particularly when many LUNs or maximum-size storage pools are created at the same time. Creating large numbers of LUNs or large pools without pre-zeroing should be avoided while a production workload is in progress, if possible.

The zero-ing process can be accelerated in the following ways:

- Use new drives from EMC.
- If the drives have been previously used, manually pre-zero drives before binding or pool creation.

New drives from EMC are pre-zeroed. New drives are automatically detected as being pre-zeroed, and are not “re-zeroed.”

Manually zeroing drives ahead of binding decreases the length of time it takes for LUNs or pools to be completely available. Pre-zeroing is executed by the individual drives internally at a rate of about 100 MB/s. Pre-zeroing needs to be performed on the drives *before* they are assigned to RAID groups or pools, and requires use of the Navisphere CLI. The following commands can be used to pre-zero drives:

```
1. naviseccli zerodisk –messner <disk-id> <disk-id> <disk-id> start
2. naviseccli zerodisk –messner <disk-id> <disk-id> <disk-id> status
```

The first command “start” begins the drive zeroing. The second command “status” can be used to monitor the zeroing progress.

Note that a LUN or pool is not completely initialized until a Background Verify has been completed. The bind wizard provides a “no initial verify” option for FLARE LUNs; if you select this option the bind wizard does not execute the Background Verify. This option is not available under Virtual Provisioning.

Chapter 5 Storage System Sizing and Performance Planning

Storage sizing consists of calculating the right number of drives for capacity, and calculating the correct number of drives and the right storage system for performance. This chapter is included to illustrate the major considerations in configuring a storage system for a workload. This chapter is *not* a substitute for the software tools available to EMC Sales and Technical Professionals providing sales support.

Introduction

Workload is always the primary consideration for storage system configuration. The workload's requirements can broadly be defined as capacity and performance.   It is important to have enough storage capacity and I/O per second (IOPS) to satisfy the workload's peak requirements. In addition, performance sizing and planning should take into account planned and unplanned degraded capacity and performance scenarios.

Capacity

First determine the RAID type and drive-group size. This calculation affects capacity in parity RAID types. Once the number of drives is known, the performance calculation can be made. EMC personnel have tools to determine the exact usable capacity of a provisioned system. These tools take into account the numerous factors affecting final capacity, such as vault drives, the extended redundancy data stored with each sector on a CLARiiON storage system, hot spares, and so forth.

Vault drives

The first five drives in a CLARiiON contain the vault. Vault drives can be used just as any other drives on the system. However, vault drives have less usable capacity. When bound with other non-vault drives, all drives in the group are calculated to have the same capacity as the vault drives. Thus, it is more efficient for capacity utilization to bind the vault drives together as a group (or groups). For vault drive performance considerations, refer to the "Performance" section on page 96.

Actual drive capacity

Accessible capacity may vary because some operating systems use binary numbering systems for reported capacity. Drive manufacturers consider a gigabyte to be 1,000,000,000 bytes (base 10 gigabyte). A computer OS may use base 2 (binary) and a binary gigabyte is 1,073,741,824 bytes.

Also, CLARiiON uses eight additional bytes per 512 byte sector for storing redundancy information. This 520-byte sector reduces the usable capacity by a small margin.

For example, a 146 GB drive has a formatted data capacity of about 133 GB and a 400 GB drive has a formatted data capacity of about 367 GB.

Parity versus mirrored protection

The use of parity or mirroring to protect data from drive failure also reduces usable storage. Mirroring always requires that 50 percent of total storage capacity be used to ensure data protection. This is called *protection capacity overhead.*

For example, a 16-drive RAID 1/0 (8+8) has a protection capacity overhead of eight hard drives. Eight of the 16 drives are available for storage; the remaining eight are protection overhead. Assume this RAID 1/0 group is composed of formatted 146 GB (raw capacity) 15k rpm Fibre Channel drives. The usable capacity of this RAID group is about 1.04 TB. Note the difference between the actual usable capacity and the approximately 2.3 TB (16*146 GB) that might be assumed, if formatting and mirroring are not taken into account.

The percentage of parity RAID space given to protection capacity overhead is determined by the number of drives in the group and the type of parity RAID used. Parity RAID 3 and RAID 5 have a single drive capacity equivalent of overhead out of total drives. RAID 6 has a two-drive equivalent overhead.

For example, a five-drive RAID 5 (4+1) group has a 20 percent overhead. It has the equivalent of four drives available for storage and the overhead of one drive for parity. Assume this RAID 5 group is composed of formatted 400 GB (raw capacity) 15k rpm Fibre Channel drives. Taking into account formatting and parity, this would result in a total usable capacity for this RAID group of about 1.4 TB.

Performance

Performance planning or forecasting is a science requiring considerable knowledge. The threading model of the workload, the type of I/O (random or sequential), the I/O size, and the type of drive all affect the performance observed. The *EMC CLARiiON Fibre Channel Storage Fundamentals* white paper contains detailed information on the factors affecting performance.

Rule-of-thumb approach

To begin a performance estimation, a rule of thumb is used for IOPS per drive and MB/s per drive. Use the guideline values provided in Table 36 or this estimate. This is a conservative and intentionally simplistic measure. Estimates of RAID group response time (for each drive), bandwidth, and throughput need to account for the I/O type (random, sequential, or mixed), the I/O size, and the threading model in use. It should be noted this is only the beginning of an accurate performance estimate; estimates based on the rule of thumb are for quickly sizing a design. More accurate methods are available to EMC personnel.

Random I/O

Small-block (16 KB or less per request) random I/O, like those used in database applications and office automation systems, typically require throughput with an average response time of 20 ms or better. At an average drive-queue depth of one or two, assume the following per drive throughput rates:

Table 35 Small block random I/O by drive type

Drive type	IOPS
Fibre Channel 15k rpm	180
SAS 15k rpm	180

Fibre Channel 10k rpm	140
SATA 7.2k rpm	80
SATA 5.4k rpm	40
Flash drive	2500

Most installations will have more than a single thread active, but want to keep response times below 20 ms. To create a more conservative estimate, these response time sensitive applications may want to perform calculations assuming one-third fewer IOPS per FC or SAS drive. In cases of random I/O sizes greater than 16 KB, there will be a steady reduction in the IOPS rate. In cases of well-behaved sequential access, the rate may be well double the listed IOPS for FC and SAS drives, even for large I/O sizes.

For example, a single threaded application has one outstanding I/O request to a drive at a time. If the application is doing 8 KB random reads from a 10k rpm drive, it will achieve 125 IOPS at 8 ms per I/O. The same application, reading a drive through 12 simultaneous threads of the same size, can achieve 240 IOPS at 50 ms per I/O.

When architecting for optimal response time, limit the drive throughput to about 70 percent of the throughput values shown in Table 36. Optimal throughput can be achieved by relaxing response time and queue depth ceilings. If a response time greater than 50 ms and a drive queue depth of eight or more is allowable, the table's drive throughput can be increased by 50 percent more IOPS per drive.

For random requests 64 KB to 512 KB, drive behavior is usually measured in bandwidth (MB/s) rather than IOPS. As the block size increases, so does the per-drive bandwidth. At a queue depth of one, assume the following per drive bandwidth rates:

Table 36 Large block random bandwidth by drive type

Drive type	64 KB (MB/s)	512 KB (MB/s)
Fibre Channel 15k rpm	8.0	32.0
SAS 15k rpm	8.0	32.0
Fibre Channel 10k rpm	6.0	24.0
SATA 7.2k rpm	4.0	16.0
SATA 5.4k rpm	2.5	12.0
Flash drive	100	100

Note the number of threads has a big effect on bandwidth. With a five-drive (4+1) RAID 5 LUN with a single thread continuously reading a random 64 KB pattern, the per-drive queue depth is only 0.2 and the 8 MB/s bandwidth applies to the sum of the spindle activity. In contrast, a 16-thread 64 KB random read pattern can achieve about 60 MB/s.

The number of drives that can be driven concurrently at the shown rates will be limited by the available back-end bandwidth of the storage system.

Sequential I/O

For 64 KB and greater block sizes running single thread sequential I/O, RAID group striping makes bandwidth independent of the drive type. Use 30 MB/s per drive as a conservative design estimate.

Depending upon your environment, drive bandwidth can be improved considerably though tuning. For instance, by using a 16 KB cache page size, a prefetch multiplier of 16, and a segment multiplier of 16, a five-drive RAID 5 (4+1) can achieve 50 MB/s per drive. If multiple threads are used, then these five drives can exceed the bandwidth of the back-end bus, which is about 360 MB/s. Note this may have an adverse effect on other applications sharing the bus.

Sending fewer, larger I/Os to the CLARiiON's "back end" improves sequential I/O performance. When more than one RAID group stripe is read or written, each drive in the group gets a single large I/O, which results in the most efficient use of the CLARiiON's back-end resources. This is particularly true if SATA drives are the destination of the I/O. The best sequential write I/O performance with any RAID stripe size occurs when the write cache page size is configured to be 16 KB and the RAID group's stripe size is evenly divisible by that 16 KB. This allows for up to 2 MB to be sent to the CLARiiON's drives from the cache in one operation of writing multiple RAID group stripes. For example, with a 16 KB cache page, a RAID 5 (4+1) with its 256 KB stripe size has eight stripes written in one operation. Similarly, a RAID 6 (8+2) with its 512 KB stripe has four stripes written in one operation.

Mixed random and sequential I/O

In mixed loads, the pure sequential bandwidth is significantly reduced due to the head movement of the random load, and the random IOPS are minimally reduced due to the additional sequential IOPS. The sequential stream bandwidth can be approximated using the values in Table 37and the random load can be approximated by using 50 percent ofTable 36's IOPS. Aggressive prefetch settings (prefetch multiplier 16, segment multiplier 16) improve the sequential bandwidth at the expense of the random IOPS. Increasing the random load queue depth increases its IOPS at the expense of the sequential stream bandwidth.

Performance estimate procedure

For a quick estimate:

- Determine the workload.
- Determine the drive load.
- Determine the number of drives required.
- Determine the number and type of storage systems.

Determining the workload

This is often the most difficult part of the estimation. Many people do not know what the existing loads are, let alone load for proposed systems. Yet it is crucial for you to make a forecast as accurately as possible. Some sort of estimate *must* be made.

The estimate must include not only the total IOPS, but also what percentage of the load is reads and what percentage is writes. Additionally, the predominant I/O size must be determined.

Determining the drive load

Note the IOPS values in Table 36 are *drive IOPS*. To determine the number of drive IOPS implied by a host

I/O load, adjust as follows for parity or mirroring operations:

- **Parity RAID 5 and 3:** Drive IOPS = Read IOPS + 4*Write IOPS
- **Parity RAID 6:** Drive IOPS = Read IOPS + 6*Write IOPS
- **Mirrored RAID:** Drive IOPS = Read IOPS + 2*Write IOPS

An example is if there is a four-drive RAID 1/0 (2+2) group, and the I/O mix is 50 percent random reads and 50 percent random writes with a total host IOPS of 10,000:

IOPS = 0.5 * 10,000 + 2 * (0.5 * 10,000)

IOPS = 15,000

For bandwidth calculations, when large or sequential I/O is expected to fill LUN stripes, use the following approaches, where the write load is increased by a RAID multiplier:

- **Parity RAID 5 and 3:** Drive MB/s = Read MB/s + Write MB/s * (1 + (1/ (number of user data drives in group)))
- **Parity RAID 6:** Drive MB/s = Read MB/s + Write MB/s * (1 + (2/ (number of user data drives in group)))
- **Mirrored RAID:** Drive MB/s = Read MB/s + Write MB/s * 2

For example, if a RAID 5 group size is 4+1 (four user data drives in group), the read load is 100 MB/s, and write load is 50 MB/s:

Drive MB/s = 100 MB/s + 40 MB/s * (1 + (1/4))

Drive MB/s = 150 MB/s

Calculate the number of drives required

Make both a performance calculation and storage capacity calculation to determine the number of drives in the storage system.

Performance capacity

Divide the total IOPS (or bandwidth) by the per-drive IOPS value provided in Table 36 for small-block random I/O and Table 37 for large-block random I/O. The result is the approximate number of drives needed to service the proposed I/O load. If performing random I/O with a predominant I/O size larger than 16 KB (up to 32 KB), but less than 64 KB, increase the drive count by 20 percent. Random I/O with a block size greater than 64 KB must address bandwidth limits as well. This is best done with the assistance of an EMC professional.

Storage capacity

Calculate the number of drives required to meet the storage capacity requirement. Ideally, the number of drives needed for the proposed I/O load is equal to the number of drives needed to satisfy the storage capacity requirement. Remember, the formatted capacity of a drive is smaller than its raw capacity. Use the *larger* number of drives from the performance capacity and storage capacity estimates.

Furthermore, the vault requires five drives, and it is prudent to add one hot spare drive per 30 drives (rounded to the nearest integer) to the drive count. To simplify the calculation do not include the vault and hot spare drives into the performance calculation when calculating the operational performance.

Total drives

Total Approximate Drives = RAID Group IOPS / (Hard Drive Type IOPS) + Large Random I/O adjustment + Hot Spares + Vault

For example, if an application was previously calculated to execute 4,000 IOPS, the I/O is 16 KB random requests, and the hard drives specified for the group are 7.2k rpm SATA drives (see Table 36):

Total Approximate Drives = 4,000 / 80 + 0 + ((4,000 / 80) / 30) + 5

Total Approximate Drives = 57

Calculate the number and type of storage systems

Once the number of drives is estimated, they must be matched to a storage system or set of systems supplying performance, capacity, and value to the client.

Select the storage system whose drive count best fits the client's requirement. Divide the number of drives by the maximum drive counts for CX4 from Table 8 on page 40 to determine the number of storage systems necessary to service the required drives effectively.

For best IOPS performance, the optimal Fibre Channel drive count for the storage system is shown in Table 38. Use the maximum drive count for the storage system (for example, 480 for a CX4-480) when considering entirely SATA drive installations. Divide the required number of drives by the drive counts in Table 38 to determine the type and number of storage systems to deploy. High-performance storage systems require a more complex analysis. They are not covered in this simple example. Consult with an EMC Professional for information regarding high-performance and high-availability storage system configuration.

Table 37 CX4 optimal drive counts

	CX4-120	CX4-240	CX4-480	CX4-960
Optimal Fibre Channel drive count	120	240	335	500

Storage systems

Storage Systems = Approximate Drives / Storage System Drive Maximum Count

For example, if a high-performance storage system requires approximately 135 drives:

Storage Systems = 135 / 240
Storage Systems = 1 (CLARiiON CX4-240 solution)
Resolving performance and capacity needs

The number of drives in a system is determined by the performance and capacity needs. The method described previously calculates the minimum number of drives needed to meet performance requirements.

A separate estimate is required using different drive sizes to calculate the number of drives needed to meet capacity requirements. The final number of drives used is determined by interpolating to determine the number of drives meeting both performance and capacity requirements.

Sizing example

The following example uses the procedure just described.

Step 1: Determine the workload

Having an accurate description of the workload is the first, most important step. Any error or ambiguity in the workload will adversely affect the sizing calculations and may result in a system unsuitable for the client's needs.

The following example includes the minimum workload requirements needed to perform a sizing estimate.

A client has a storage requirement for an object database. The application is expected to execute random I/Os. The profile is:

- 70 percent random reads
- 30 percent random writes
- Predominant I/O size is 16 KB
- Total host IOPS is 20,000
- Usable capacity required is 35 TB

The client is price-sensitive, so a large parity RAID is desired. However, the 30 percent write percentage is high enough for RAID 1/0 to be considered as well.

Step 2: Determine the required I/O drive load

Calculate the IOPS for the three RAID types being considered: RAID 5, RAID 6, and RAID 1/0.

The drive load is:

RAID 5 (8+1): 0.7 * 20,000 + 4 * 0.3*20,000 = 38,000 drive IOPS

RAID 6 (8+2): 0.7 * 20,000 + 6 * 0.3*20,000 = 50,000 drive IOPS

RAID 1/0 (8+8): 0.7 * 20,000 + 2 * 0.3*20,000 = 26,000 drive IOPS

From an IOPS perspective, RAID 1/0 would be the choice in this step.

Step 3: Determine the number of drives required

Calculate the number of hard drives for each RAID type needed assuming 15,000 rpm FC drives with hot spares and vault drives included in the total. The performance capacity is the IOPS divided by the drive IOPS.

RAID 5 (8+1): 38,000/180 + ((38,000/180)/30) +5 = 211 + 7+ 5 = 223 drive drives total

RAID 6 (8+2): 50,000/180 + ((50,000/180)/30) + 5 = 278 + 11 +5 = 292 drive drives total

RAID 1/0 (8+8): 28,000/180 + ((28,000/180)/30) + 5 = 156 + 5 +5 = 166 drive drives total

From a number of drives perspective, RAID 1/0 would be the choice in this case.

The number of drives needed to achieve performance needs to be resolved with the available hard number of drives needed to meet the storage requirement. This calculation is performed using data drives only. Do not include vault and hot spare drives in the calculation. Assume 300 GB FC drives with a formatted capacity of 268 GB.

RAID 5 (8+1): 8/9 * 211 * 268 = 50.3 TB

RAID 6 (8+2): 8/10 * 278 * 268 = 59.6 TB

RAID 1/0 (8+8): ½ * 156 * 268 = 20.9TB

From a capacity perspective, RAID 5 would be the choice in this substep.

Step 4: Determine the number and type of storage systems

The previous steps result in Table 38. This table is used to compare the RAID options toward making a storage system selection.

Table 38 Sizing estimate calculation results

RAID type	Drive load (IOPS)	Performance capacity (drives)	Storage capacity (TB)	Total drives
RAID 5	38,000	211	50.3	223
RAID 6	50,000	278	59.6	292
RAID 1/0	28,000	156	20.9	166

Determine which CLARiiON model most closely matches the calculated performance capacity, storage capacity, total drives, and stated requirements.

In this example, a CX4-240 with RAID 5 would be a good candidate. A reasonable RAID 5 solution would be 211 drives for data, seven hot spares, and five drives for the vault (and archive space). Adding a DAE containing 15 SATA drives for backup would make the final number of drives 238.

Note the RAID 5 solution would need to move to a larger CX4-480, if a requirement for clones, snaps, or mirrors is added.

Other considerations

A short discussion of why the RAID 1/0 and RAID 6 solutions were not chosen and how to make them successful candidates may be useful.

The RAID 1/0 solution has the needed IOPS for the client's system. However, it was not selected, because it does not meet the needed storage capacity. A RAID 1/0 would require more than 300 FC drives to meet the client's storage capacity requirement. This would require a CX4-480 to house them.

The RAID 6 solution more than meets the client's storage capacity requirement. In addition, it provides greater data security than the RAID 5 solution. It was not selected because the IOPS and total drive count would require the larger CLARiiON CX4-480 to house it. (The client is stated to be *price sensitive*.) However, if added requirements for growth, clones, snaps, and mirrors occur, the RAID 6 solution becomes competitive.

The final choice of a CLARiiON model involves weighing many factors. Capacity, performance, availability, growth, and cost objectives must all be considered. This example introduces the most important factors involved in the decision.

Appendix A Glossary

"When I use a word, it means just what I choose it to mean -- neither more nor less."

-- Humpty Dumpty, "Through the Looking Glass (And What Alice Found There)" (1871) by Lewis Carroll

10 GbE— 10 Gigabit per second Ethernet protocol.

ABQL — Average busy queue length (per drive).

Active data — Working data set being addressed by an application.

Active-active — Redundant components are active and operational.

Active-passive — Redundant components are ready and in a standby operational mode.

AFR — Annual failure rate.

ALUA — Asymmetric logical unit access protocol.

Allocated Capacity — Total physical capacity currently assigned to pool-based LUNs

American National Standards Institute — An internationally recognized standards organization.

ANSI — American National Standards Institute.

Application software — A program or related group of programs performing a function.

Array — Storage system.

Asymmetric Logical Unit Access — An industry-standard multipathing protocol.

Attachment — Drive hardware connector or interface protocol. On a CLARiiON it can be Fibre Channel, SAS, or SATA.

Authentication — Verifying the identity of a communication to ensure its stated origin.

Authorization — Determining if a request is authorized to access a resource.

Available capacity — Capacity in a thin LUN pool that is not allocated to thin LUNs.

Availability — Continued operation of a computer-based system after suffering a failure of fault.

Back-end — A logical division of the CLARiiON's architecture from SP to the back-end bus(es) and drives.

Back-end bus — The CLARiiON's Fibre Channel buses that connect the storage processors to the drives.

Back-end I/O — I/O between the storage processors and the drives over the back-end buses.

Background Verify — Automated reading of the LUN's parity sectors and verification of their contents by the CLARiiON for fault prevention.

Backup — Copying data to a second, typically lower performance, drive as a precaution against the original drive failing.

Bandwidth — A measure of storage-system performance, as measured in megabytes per second (MB/s).

Basic Input Output System — Firmware that sets the host to a known state, so the operating system software can be loaded and executed.

BIOS — Basic Input Output System.

Bind — To combine drives into a RAID group.

Bit — The smallest unit of data. It has a single binary value, either 0 or 1.

Block — The smallest addressable unit on a hard drive; it contains 512 bytes of data.

Bottleneck — A resource in a process that is operating at maximum capacity; the bottleneck causes the whole process to slow down.

Broadband — High-bandwidth networks and interfaces used for data and voice communications.

Buffering — Holding data in a temporary area until other devices or processes are ready to receive and process the data; this is done to optimize data flow.

BURA — Backup, Recovery, and Archiving data storage security domain.

Bursty — When, over time, the volume of I/O is highly variable, or regularly variable with well-defined peaks.

Bus — An internal channel in a computerized system that carries data between devices or components.

Busy hour — The hour of the day in which the most I/O occurs.

BV — Background Verify.

Byte — Eight computer bits.

Cache — Memory used by the storage system to buffer read and write data and to insulate the host from drive access times.

Cache hit — A cache hit occurs when data written from or requested by the host is found in the cache, avoiding a wait for a drive request.

Cache miss — Data requested by the host is not found in the cache so a drive request is required.

Cache page size — The capacity of a single cache page.

CAS — Content Addressable Storage object-based storage as implemented by EMC Centera®.

CBFS — Common Block File System.

CHAP — Challenge Handshake Authentication Protocol.

CIFS — Common Internet File System.

CLI — Command Line Interface.

Client — Part of the client/server architecture, the client is a user computer or application that communicates with a host.

Client/Server — A network architecture between consumers of services (Clients) and providers (Hosts).

Clone — An exact copy of a source LUN.

CMI — Configuration Management Interface.

Coalescing — Grouping smaller cached I/Os into a larger I/O before it is sent to the drives.

Command line interface — An interface that allows a user use text-based commands to communicate with an application or operating system.

Common Block File System — File system of CLARiiON pool-based LUNs.

Common Internet File System — Microsoft Windows file sharing protocol.

Concurrent I/O — When more than one I/O request is active at the same time on a shared resource.

Consumed capacity — Total of capacity in use or reserved by a pool-based LUNs in a pool.

Core — A processor unit co-resident on a CPU chip.

Core-switch — Large switch or director with hundreds of ports located in the middle of a SAN's architecture.

CPU — Central Processing Unit.

CRM — Customer Relationship Management.

Customer relationship management — Applications used to attract and retain customers.

DAE — Drive array enclosure.

DAS — Direct attached storage.

Data — Information processed or stored by a computer.

Data center — A facility used to house computer systems, storage systems, and associated components.

Data link — Digital communications connection of one location to another.

Data mining application — A database application that analyzes the contents of databases for the purpose of finding patterns, trends, and relationships within the data.

Data warehouse — A collection of related databases supporting the DSS function.

DBMS—Data Base Management System.

Decision support system — A database application, used in the “data mining” activity.

Degraded mode — When continuing an operation after a failure involves a possible loss of performance.

Departmental system — A storage system supporting the needs of a single department within a business organization.

Destage — Movement of data from cache to drives.

Dirty page — A cache page not yet written to storage.

Disk array enclosure — The rack-mounted enclosure containing a maximum of 15 CLARiiON drives.

Disk controller — The microprocessor-based electronics that control a hard drive.

Disk crossing — An I/O whose address and size cause it to access more than one stripe element in a disk, resulting in two back-end I/Os instead of one.

Disk processor enclosure — The cabinet that contains the CLARiiON storage processor and drives.

DPE — Disk processor enclosure.

DR — Disaster recovery.

Drive — A hardware component from which you can read and write data. Typically a hard drive, but also an Flash drive.

DSS — Decision support system.

Dump — Copying the contents of the cache to the vault.

Edge switch —A Fibre Channel switch located on the perimeter of a core-edge configured SAN.

EFD — Enterprise Flash Drive.

Enterprise Flash Drive — EMC term for SSD-type drive.

Enterprise resource planning — Applications that manage inventory and integrate business processes for an organization.

Enterprise system — A storage system supporting the needs of an entire business organization.

Environment — A computer's hardware platform, system software, and applications.

Equalization — Copying data from a hot spare to drive that is replacing a failed RAID group's drive.

ERP — Enterprise Resource Planning.

ESM — EMC Support Matrix.

ESX — VMware enterprise-level server virtualization product.

Ethernet — A technology for high-speed bandwidth connectivity over local area networks. The IEEE 802.3 standard.

Failure — A malfunction of hardware component(s) in a system.

Fail back — Restoring the original data path after correcting a failure.

Fail over — Using an alternate path because the original path fails.

Failure mode — The cause of a failure, or the event that starts a process that results in a failure.

Fan-in — Attaching numerous hosts to a few storage-system ports.

Fan-out — Attaching a few storage-system ports to many hosts.

FAQ — Frequently Asked Question.

FAST — Fully Automated Storage Tiering.

FAST Cache — Secondary I/O cache composed of Flash drives.

Fault — An error in the operation of a software program.

Fault tolerance — The ability of a system to continue operating after a hardware or software failure.

FC — Fibre Channel.

FCoE — Fibre Channel traffic over Ethernet.

FCP — SCSI Fibre Channel Protocol.

Fibre Channel — A serial data transfer protocol: ANSI X3T11 Fibre Channel standard.

File — A collection of data.

File system — The system an OS uses to organize and manage computer files.

Filer — NAS fileserver accessing shared storage using a file-sharing protocol.

FLARE — Fibre Logic Array Runtime Environment. CLARiiON's operating system.

Flash drive — Solid state disk storage device.

Flush — Writing the data in the write cache to the drives.

Forced flush — The high priority writing of data to drives to clear a full write cache.

Front end — A logical division of the CLARiiON's architecture, including the communications ports from hosts to the SP.

GB — Gigabyte.

GB/s — Gigabytes per second.

Gb/s — Gigabits per second.

GbE— Gigabit Ethernet (1 Gb/s Ethernet).

GHz — Gigahertz.

Gigabit — One thousand million bits.

Gigabyte — One billion bytes or one thousand megabytes.

Gigahertz — One billion times per second (1,000,000,000 Hz).

GigE — 1 Gb/s Ethernet.

GMT — Greenwich Mean Time.

Graphical user interface — Interface that allows you to communicate with a software program using visual objects on a monitor.

GUI — Graphical user Interface.

HA — High Availability or Highly Available.

HBA — Host Bus Adapter; A Fibre Channel network interface adapter.

Head crash — A catastrophic hard drive failure where a read/write head makes physical contact with a platter.

Hertz — Once per second.

Highly available — A system able to provide access to data when the system has a single fault.

Host — A server accessing a storage system over a network.

Hot spare — A spare drive that the storage system can use to automatically replace a failed drive.

HP-UX — A proprietary Hewlett-Packard Corporation version of the UNIX OS.

HVAC — Heating, Ventilation, and Air Conditioning.

Hz — Hertz.

IEEE — Institute of Electrical and Electronics Engineers.

IETF — Internet Engineering Task Force

iFCP — Protocol allowing FC devices to use an IP network as a fabric switching infrastructure.

ICA — Image Copy Application.

IETF — Internet Engineering Task Force.

IEEE — Institute of Electrical and Electronics Engineers.

iFCP — Protocol allowing FC devices usage of an IP network as a fabric switching infrastructure.

IHAC — I Have A Customer.

Initiators — iSCSI clients.

Institute of Electrical and Electronics Engineers — An international standards organization.

International Organization for Standardization — International organization that maintain standards.

Internet Engineering Task Force — International organization standardizing the TCP/IP suite of protocols.

Internet Protocol — A protocol used with TCP to transfer data over Ethernet networks.

IOPS — Input/Output operations Per Second.

IP — Internet Protocol.

IPSec — Internet Protocol Security.

IPv4 — Internet Protocol version 4.

IPv6 — Internet Protocol version 6.

iSCSI — Internet SCSI protocol. A standard for sending SCSI commands to drives on storage systems.

ISL — Interswitch Link. Connects two or more switches in a network.

ISO — International Organization for Standardization.

IT — Information Technology. Also, the department that manages a computer's computer systems.

JBOD — Just a Bunch Of Disks.

KB — Kilobyte.

Kb — Kilobit.

Kb/s — Kilobits per sec.

KB/s — Kilobytes per sec.

Kilobits — One thousand bits.

Kilobyte — One thousand bytes.

LAN — Local Area Network.

Large-block — I/O operations with capacities greater than 64 KB.

Layered Apps — Layered Applications.

Layered Applications — CLARiiON application software.

LBA — Logical Block Address.

LCC — Link Control Card.

Legacy system — An older storage system that does not have the latest hardware and software.

Linux — Any of several hardware independent open-systems operating system environments.

Load balancing — The even distribution of the data or processing across the available resources.

Local Area Network — A computer network extending over a small geographical area.

Locality — Proximity of LBAs being used by an application within mass storage.

Logical Block Address — A mapping of a drive sector into a SCSI block address.

Logical unit number— A SCSI protocol entity, to which I/O operations are addressed.

Logical volume manager — A host-based storage virtualization application such as Microsoft Logical Disk Manager.

Loop— SP A and SP B's shared connection to the same numbered back-end bus.

Lower director— SP A to SP B direct communications bus connection.

LUN — Logical Unit Number.

LVM — Logical Volume Manager.

Maximum Transmission Unit — The largest size packet or frame, specified in bytes, that can be sent in a packet- or frame-based network such as an iSCSI SAN.

MAN — Metropolitan Area Network.

MB — Megabyte.

MB/s — Megabytes per second.

Mb — Megabit.

Mb/s — Megabits per second.

Mean time between failure — The average amount of time that a device or system goes without experiencing a failure.

Mean time to data loss — A statistical estimate of when a failure will occur that causes a RAID group to lose data.

Mean time to repair— An estimate of the time required to repair a failure.

Media — The magnetic surface of a hard drive's platter used for storing data.

Megabit — One million bits.

Megabyte — One million bytes or one thousand kilobytes.

Megahertz — A million cycles per second (1,000,000 Hz).

Memory Model — Description of how threads interact through memory.

Metadata — Any data used to describe or characterize other data.

MetaLUN — A LUN object built by striping or concatenating multiple LUN objects.

MHz — Megahertz.

Mirror — A replica of existing data.

MirrorView — CLARiiON disaster recovery application

MPIO — Microsoft Multi-Path I/O

MR3 Write — The action the CLARiiON RAID engine performs when an entire RAID stripe is collected in the cache and written at one time.

MTBF — Mean Time Between Failures.

MTTDL — Mean Time To Data Loss.

MTTR — Mean Time To Repair.

MTU — Maximum transmission unit

Multipath — The provision for more than one host I/O paths between LUNs.

Multithread — Concurrent I/O threads.

Name-server — A process translating between symbolic and network addresses, including Fibre Channel and IP.

NAS — Network Attached Storage.

Native Command Queuing — A drive-based I/O execution optimization technique.

Navisphere — CLARiiON's resource management system software for FLARE revisions up to 29.0.

Navisphere Analyzer — CLARiiON's performance analysis system software.

NCQ — Native Command Queuing

Network — Two or more computers or computer-based systems linked together.

Network element — A device used in implementing a network. Typically refers to a switch or router.

Network file system — A UNIX/Linux file sharing protocol.

Network interface card — A host component that connects it to an Ethernet network.

NDU — Non-Disruptive Update

NFS—Network File System

NIC — Network Interface Card.

Nondisruptive update — Upgrading system software while applications are running with minimal effect on the applications' performance.

Non-optimal path — The ALUA failed-over I/O path from host to LUN

OS — Operating System.

OLTP — OnLine Transaction Processing system.

Online transaction processing — Multiuser systems supported by one or more databases handling many small read and write operations.

Operating environment — Operating System.

Operating system — The software on a computer that controls applications and resource management.

Optimal path — The normal operations I/O path from host to LUN

Oversubscribed Capacity — Thin LUN configured capacity exceeding provisioned pool capacity.

Ownership — SP management of LUN I/O.

Page — Cache unit of allocation.

Parallel ATA — Disk I/O protocol used on legacy CLARiiONs.

PATA — Parallel ATA disk I/O protocol.

Petabyte — One quadrillion bytes or one thousand terabytes.

PB — Petabyte.

PC — Personal Computer

PCI Express — A bus protocol used by computer-based systems.

PCIe— PCI Express.

PDU — Power Distribution Unit.

Percentage utilization — A measurement of how much of a resource is used.

Platform — The hardware, systems software, and applications software supporting a system, for example DSS or OLTP.

Platter — A component of a hard drive; it is the circular disk on which the magnetic data are stored.

Pool — A grouping of drives managed by the CLARiiON Virtual Provisioning feature.

Pool LUN — A LUN provisioned on a Virtual Provisioning pool.

Port — An interface device between a storage system and other computers and devices. Also, an interface between a drive and a bus.

Power distribution unit — A CLARiiON component connecting data center electrical power trunks to the storage system.

Powerlink — EMC's password-protected extranet for customers and partners.

PowerPath — EMC host-based multipathing application.

Prefetch — A caching method by which some number of blocks beyond the current read are read and cached in the expectation future use.

Private LUN — A LUN managed by FLARE and not addressable by a host.

Protocol — A specification for device communication.

PSM — Persistent Storage Manager.

PV Links —HP-UX Physical Volume Links

QA — Quality Assurance.

Quality Assurance — The department, or policies and procedures for verifying promised performance and availability.

QFULL — Queue Full.

QoR — Quality of Result.

QoS — Quality of Service.

Quality of result — A term used in evaluating technological processes or implementations.

Quality of service Agreement — A defined, promised level of performance in a system or network.

Queue full — An iSCSI protocol signal sent to hosts indicating a port or LUN queue cannot accept an entry.

RAID — Redundant Array of Independent Disks.

RAID group — A logical association of between two to 16 drives with the same RAID level.

RAID level — An organization of drives providing fault tolerance along with increases in capacity and performance.

Random I/O — I/O written to locations widely distributed across the file system or partition.

Raw drive — A hard drive without a file system.

RDBMS — Relational Database Management System.

Read Cache — Cache memory dedicated to improving read I/O.

Read/write head — Component of a hard drive that records information onto the platter or read information from it.

Read-ahead — See “prefetch.”

Rebuild — The reconstruction of a failed drives data from through either parity or mirroring.

Recovery time objective — The estimated amount of time to restore a system to full operation after a fault or failure.

Redundancy — The ability of the storage system to continue servicing data access after a failure through the use of a backup component or data protection mechanism.

Relational database management system — A database typically hosted on a storage system, for example, Oracle, DB2, Sybase and SQL Server.

Reliability — The ability of the storage system to run for long periods, and during stress, without suffering either hardware or software faults.

Request size — In a file system, the size of the block actually read from the drive.

Reserved Capacity — Virtual Provisioning pool capacity reserved for provisioned LUNs guaranteed available for allocation on demand.

Reserved LUN — See Private LUN.

Response time — A measure of performance including cumulative time for an I/O completion as measured from the host.

RFC — Request for comments.

RFP — Request for proposal.

Rich media — A workload that allows for active participation by the recipient. Sometimes called interactive media.

Rotational latency — The time required for a disk drive to rotate the desired sector under the read head.

Rpm — Revolutions per minute.

RPQ — Request for product qualifier.

RTO — Recovery time objective.

RV — Rotational vibration.

SAN — Storage area network.

SAN Copy — CLARiiON storage system to storage system copy application.

SAP — The enterprise resource planning application produced by the software company, SAP AG.

SAS—Serial attached SCSI.

SATA—Serial ATA disk I/O protocol.

Saturation — The condition in which a storage system resource is loaded to the point where adding more I/O dramatically increases the system response time but does not result in additional throughput.

SCSI — Small computer system interface.

Sector — The smallest addressable unit on a hard drive; a sector contains 512 bytes of data.

Sequential I/O — A set of I/O requests whose pattern of address and size result in serial access of a complete region of data in monotonically increasing addresses.

Serial ATA – A disk I/O attachment used on CLARiiONs.

Serial Attached SCSI - A point-to-point serial protocol for moving data to drives.

Service Time — The interval it takes a drive or resource to perform a single I/O.

Shelf — DAE.

Short stroking — A LUN performance optimization technique of only using a portion of a RAID group.

SLA — Service Level Agreement. A contract between a service provider and a customer providing a measurable level of service or access to a resource.

SLIC — Small I/O Card.

Small Computer System Interface — Set of standards for physically connecting and transferring data between hosts and drives.

Small block — I/O operations up to 16 KB.

Small I/O card — The generic name for the CX4 UltraFlex I/O modules, either Fibre Channel or iSCSI.

SnapView — CLARiiON point-in-time copy application.

Snapshot — Backup copy of how a LUN looks at a particular point in time.

Solid State Disk — A drive using non-volatile semiconductor memory for data storage.

SP — Storage processor.

SPE — Storage Processor Enclosure.

Spike — A sudden, sharp, and significant increase in load on the storage system.

Spin down —Setting inactive hard drives into a low-power “sleep” mode.

Spindle — A component of a hard drive; it is the axel platters are mounted on. Also, spindle sometimes refers to a hard drive.

SPS —Standby Power System.

SSD — Solid State Disk.

Stack — Layered protocols.

Storage area network — A network specifically designed and built for sharing drives.

Storage array — A storage system.

Storage object — A logical construct or physical device supporting both read and write data accesses.

Storage pool — A logical construct of drives supporting both read and write data accesses.

Storage processor — A logical division of the CLARiiONs architecture including the CPUs and memory.

Storage processor enclosure — Physical rack mounted cabinet containing CLARiiON Storage Processor. This enclosure contains no drives.

Storage system — A system containing multiple hard drives, cache and intelligence for the secure and economical storage of information and applications.

Stripe crossing — If a back-end I/O is not contained in an entire stripe, a stripe crossing occurs because the I/O takes more than one stripe

Stripe element — Capacity allocated to a single device of a stripe.

Stripe size — The usable capacity of a RAID group stripe.

Stripe width — The number of hard drives in a RAID group stripe.

Stripe — Distributing sequential chunks of storage across many drives in a RAID group.

Stroke — Movement of a hard drives' read/write head across the platter.

Subscribed Capacity — Total capacity configured for thin LUNs in the pool.

Switch — A Layer 2 device providing dedicated bandwidth between ports and switching functions between storage network devices.

System software — Operating system and applications used for a computer's management.

TB — Terabyte.

TCP — Transmission Control Protocol: a protocol used with IP to transmit and receive data on Ethernet networks.

TCP/IP — The pair of communications protocols used for the Internet and other similar networks

TCP/IP offload engine — A coprocessor-based host component that connects it to an Ethernet network.

Terabyte — One trillion bytes or one thousand gigabytes.

Thin friendly — Applications and file systems that do not pre-allocated capacity during installation or initiation.

Thin LUN — Logical storage unit whose capacity may be less than host's viewable capacity.

Thread — An independent I/O request that may execute in parallel with other requests.

Throughput — A measure of performance of I/Os over time; usually measured as I/Os per second (IOPS).

TLU — Thin Provisioning LUN.

TOE —TCP/IP Offload Engine.

Topology — How parts of a system component, subsystem, or system are arranged and internally related.

Track — A ring-like region of a hard drive platter on which data is organized and stored.

Tray — DAE.

Trespass — A multipathing initiated change in SP LUN ownership as a result of a failure or command.

UER — Unrecoverable Error Rate

UNIX — Any of several open system operating system environments.

Unisphere — CLARiiON's resource management system software for FLARE revisions 30.0 and later.

Unrecoverable error rate — Bit error reliability metric for hard drives.

UPS — Uninterruptible Power Supply.

User — An individual who operates application software.

User Capacity — Total storage capacity of a physical or logical storage object available to a host.

Vault — Special area on drives of DAE0 for storage of CLARiiON system files and cache dumps.

Virtual machine — A software application emulating a server hardware environment.

Virtual Provisioning — Explicit mapping of logical address spaces to arbitrary physical addresses. For example, presenting an application with more capacity than is physically allocated (pool-based storage).

VLAN — Virtual Local Area Network.

VLAN Tagging — Mechanism for segregating VLANs.

VM — Virtual Machine.

VMware — EMC's family of virtual machine applications.

Volume — LUN.

WAN —Wide Area Network

Warm-up — Interval during which active data is promoted into FAST Cache.

Watermark — A cache utilization set point.

WCA —Write Cache Availability.

Wide area network — A computer network extending over a large, possibly global, geographical area.

Windows — Any of several proprietary Microsoft operating system environments.

Wintel — Industry term used to describe computers based on an Intel hardware architecture and a Microsoft Windows operating system.

Wire Rate — The maximum bandwidth for data transmission on the hardware without any protocol or software overhead. Also known as "Wire Speed."

Workload — The characteristics of a pattern of I/O requests presented to the storage system to perform a set of application tasks, including amount of I/O, address pattern, read-to-write ratio, concurrency, and burstiness.

World Wide Name — A unique identifier in a Fibre Channel or SAS storage network.

WORM — Write Once Read Many.

Write Cache — Cache memory dedicated to improving host write I/O response time by providing quick acknowledgement to the host while destaging data to disks later in the background.

Write-aside — Bypass of the write cache, where the RAID engine dispatches a write immediately to the disks.

Write-aside Size —The largest request size, in blocks, written to cached for a particular LUN.

WWN — World Wide Name.