

IBM FlashSystem A9000 Product Guide

| (Updated for Version 12.3.2)

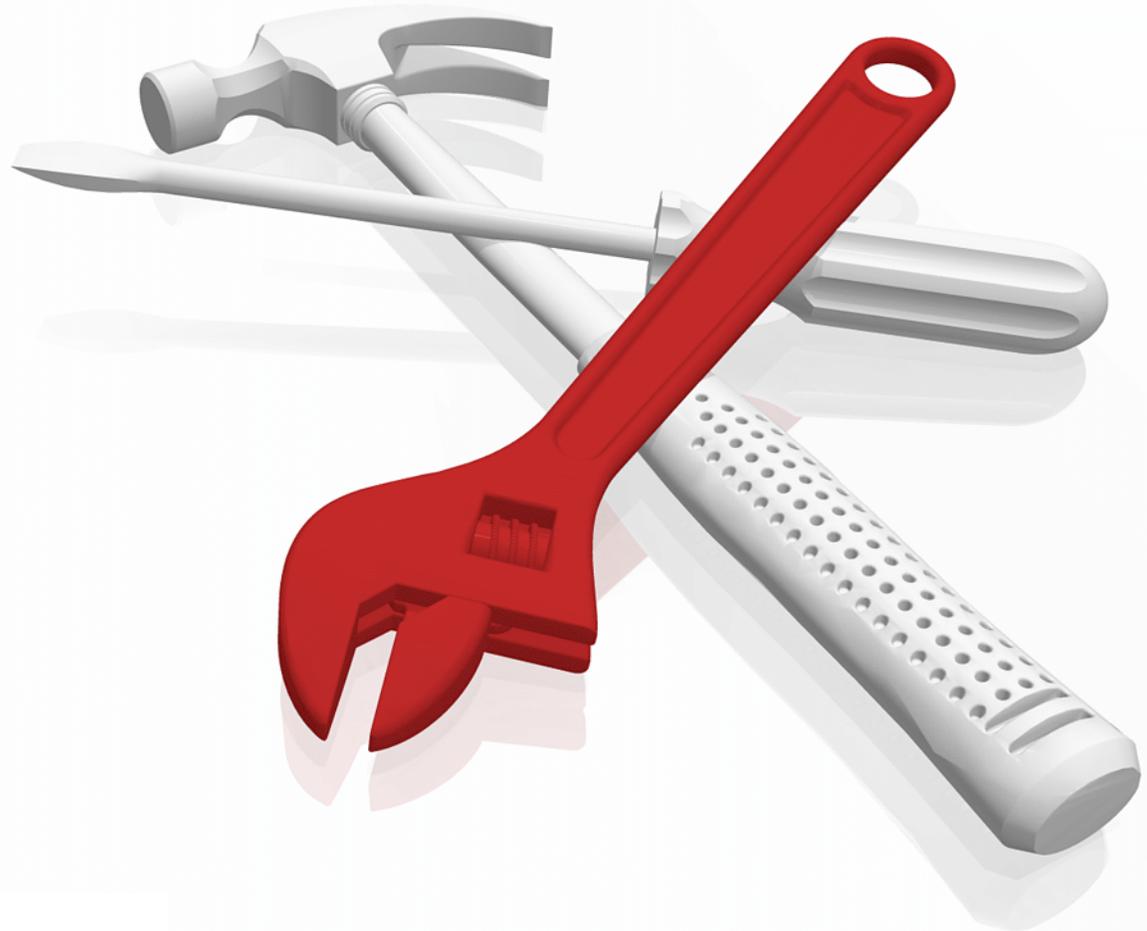
Bert Dufrasne

Stephen Solewin

Francesco Anderloni

Roger Eriksson

Lisa Martinez



IBM FlashSystem A9000 Product Guide

This IBM® Redbooks® Product Guide is an overview of the main characteristics, features, and technologies that are used in IBM FlashSystem® A9000 Models 425 and 25U, with IBM FlashSystem A9000 Software V12.3.2.

IBM FlashSystem A9000 storage system uses the IBM FlashCore® technology to help realize higher capacity and improved response times over disk-based systems and other competing flash and solid-state drive (SSD)-based storage. FlashSystem A9000 offers world-class software features that are built with IBM Spectrum™ Accelerate.

The extreme performance of IBM FlashCore technology with a grid architecture and comprehensive data reduction creates one powerful solution. Whether you are a service provider who requires highly efficient management or an enterprise that is implementing cloud on a budget, FlashSystem A9000 provides consistent and predictable microsecond response times and the simplicity that you need.

As a cloud optimized solution, FlashSystem A9000 suits the requirements of public and private cloud providers who require features, such as inline data deduplication, multi-tenancy, and quality of service. It also uses powerful software-defined storage capabilities from IBM Spectrum Accelerate, such as Hyper-Scale technology, VMware, and storage container integration.

FlashSystem A9000 is a modular system that consists of three grid controllers and a flash enclosure. An external view of the Model 425 is shown in Figure 1.



Figure 1 IBM FlashSystem A9000 Model 425

Key capabilities: FlashSystem A9000 includes the following key capabilities for an optimal solution in a cloud environment:

- ▶ FlashCore technology provides extreme IBM MicroLatency® performance.
- ▶ Grid Architecture ensures consistent and predictable microsecond response times.
- ▶ An enhanced management interface simplifies storage administration.
- ▶ Rich integrated data services provide peace of mind and includes data-at-rest encryption
- ▶ IBM Hyper-Scale provides simple scaling and management.
- ▶ Quality of service (QoS) and Multi-tenancy with network traffic isolation through VLAN support.
- ▶ Data reduction and intelligent capacity management for deduplication optimizes your infrastructure economics.
- ▶ High availability and disaster recovery features
- ▶ Key integration capabilities allow for systems to fit into and support your environment.

Storage Utility Offering

As of March 2018, along with software version 12.2.1 or later, IBM FlashSystem A9000 (9838-U25) storage utility model is available as part of the IBM Storage Utility Offering. Model U25 is otherwise identical to Model 425, except that the A9000 smallest flash enclosure configuration (eight 3.6-TB microlatency modules) is not available with the Storage Utility Offering.

The storage utility model provides a fixed total capacity, with a base and variable usage subscription of that total capacity. The variable capacity usage is billed on a quarterly basis.

IBM Storage Utility Offering enables clients to align their capacity costs to business initiatives. For details, see the IBM Storage Utility Offering home page:

<https://www.ibm.com/us-en/marketplace/storage-utility-offering>

Product highlights

FlashSystem A9000 provides an all-inclusive software license. All features, including replication, migration, encryption, and data reduction, are included at no extra charge with IBM FlashSystem A9000 Software V12 (5639-FS1), and apply to the entire storage system. The following features are also included:

- ▶ Data reduction: Pattern removal, data deduplication, and compression

FlashSystem A9000 uses the IBM industry-leading data reduction technology that combines inline, real-time pattern matching and removal, data deduplication, and compression. Compression also uses hardware cards inside each grid controller. Compression can easily provide a 2:1 data reduction saving rate on its own, which effectively doubles the system storage capacity. Combined with pattern removal and data deduplication services, FlashSystem A9000 can easily yield an effective data capacity of five times the original usable physical capacity.

Data reduction is implemented below the global cache to ensure rapid response times. This configuration provides a global scope for data reduction services, and allows other data services to be unaffected, including snapshots, replication, and host offload features, such as VMware vStorage API for Array Integration (VAAI).

- ▶ Intelligent capacity management for deduplication:

Starting with software version 12.3.1, FlashSystem A9000 and A9000R offers patented IBM Research technology that can analyze large amounts of data, without performance impact and provide effective estimates, per volume, for reclaimable capacity, attributed capacity, compression saving, de-duplication saving, and total capacity saving. That information is displayed in the Hyper-Scale Manager GUI (version 5.5.1 minimum is required).

- ▶ Multi-tenancy

FlashSystem A9000 enables a secure isolation of logical domains of storage resources among numerous tenants, with the ability to set different QoS levels for each domain. Multi-tenancy enables the division of storage system administration tasks into logical domains by using role-based permissions. It also enables rapid deployments while minimizing the need for extensive planning, tuning, or field upgrades.

- ▶ VLAN tagging and port trunking

Starting with software version 12.3.2, support for VLANs in iSCSI environments allows provisioning of private virtual network per tenant. FlashSystem A9000 VLAN support applies to the data iSCSI ports for hosts and replication, as well as management ports and other Ethernet ports. VLAN support capabilities include VLAN tagging and port trunking as defined by the IEEE 802.1Q specification. Hyper-Scale Manager GUI, version 5.6 or later is required. For more information, refer to Chapter 2 in *IBM FlashSystem A9000/R and IBM XIV Storage System Host Attachment and Interoperability*, SG24-8368.

- ▶ Host Rate Limiting: QoS

FlashSystem A9000 system resources, such as storage and cache, constitute a virtualized environment that is shared by all hosts and applications. This approach lends itself exceptionally well to accommodate high-performance requirements for multiple applications with similar performance objectives through fair resource allocation. QoS is available at the domain, pool, and volume levels.

In environments with applications that include various performance objectives, the QoS feature enables the client to restrict IOPs, bandwidth, or both to the appropriate object domain, pool, host group, or volume. QoS can be used to ensure that applications do not use too much of the storage system resources. This feature maximizes the resources that are available for applications that require the utmost performance.

- ▶ Fibre Channel and iSCSI

FlashSystem A9000 supports the Fibre Channel and iSCSI communications protocols for host attachment, migration, and remote mirroring. Newer systems have grid controllers equipped with FC-NVMe adapters. In these new controllers, the FC ports are dual-purpose and NVMe ready: a future software upgrade will enable these ports to connect with servers using FC, or using FC-NVMe, or both.

- ▶ Snapshots

The snapshot capabilities use a redirect on write design that allows snapshots to occur in a subsecond time frame with no effect on performance. The system supports multiple differential snapshots of a volume. Any of the snapshots can be made writable. Snapshots can then be taken of the newly writable snapshots (snapshots of snapshots). Volumes can even be restored from these writable snapshots. The built-in Snapshot Scheduler allows you to automate the snapshot creation and retention on volumes inside a specific pool.

- ▶ Synchronous remote mirroring to another FlashSystem A9000 or A9000R, and asynchronous remote mirroring to another FlashSystem A9000, A9000R, or IBM XIV® Gen3

Synchronous or asynchronous remote mirroring can be performed over Fibre Channel (FC) or IP (iSCSI) connections. Both protocols are also supported for two-way mirroring connectivity. Synchronous remote mirroring is used when a zero recovery point objective (RPO) is required. For practical reasons (latency), ensure that the distance is less than 100 km (62 miles). For longer distances, asynchronous replication is more appropriate.

Starting with FlashSystem A9000 Software V12.2.1, up to 3072 sync mirrors and up to 1024 async mirrors are supported. The maximum number of remote targets is 10.

- ▶ IBM HyperSwap®

HyperSwap, also referred to as *transparent failover*, delivers always-on, high availability (HA) service for storage volumes in a production environment. It is based on an active-active, cross-system, and cross-datacenter configuration, allowing volumes to autonomously and transparently switch between primary and secondary roles, based on the volume failover state. From a host perspective, the pair of mirrored volumes on the two FlashSystem A9000 or A9000R systems constitute *a single HyperSwap volume*, also referred to as *a stretched volume*, allowing the seamless failover.

- ▶ Multi-site HA/DR replication

Using three FlashSystem A9000 or A9000Rs, and combining HyperSwap and Asynchronous replication, creates a solution that entails both High Availability (HA) and Disaster Recovery (DR). One side of the HyperSwap pair has an active async link to the third system, and the other side has a standby link. For more information about Multi-site replication, see *IBM HyperSwap and Multi-site HA/DR for IBM FlashSystem A9000 and A9000R*, REDP-5434.

- ▶ Data Migration

FlashSystem A9000 also can act as a host and gain access to volumes on a storage system. The system is configured as a proxy to respond to requests between the current hosts and the storage while migrating all data in the background.

- ▶ Hyper-Scale Mobility

IBM Hyper-Scale Mobility allows a volume to be migrated non-disruptively from one FlashSystem A9000 to another FlashSystem A9000 or A9000R over synchronous WAN distances without any host disruption. This capability is in addition to the standard data migration that allows FlashSystem A9000 to proxy as a host and migrate volumes from other third-party storage arrays.

Starting with Software Version 12.2.1, Hyper-Scale Mobility is also supported from XIV Gen3 (with software level 11.6.2a) to FlashSystem A9000 or A9000R.

For more information about replication and migration, see the IBM Redbooks publication, *IBM FlashSystem A9000 and A9000R Business Continuity Solutions*, REDP-5401.

- ▶ Encryption

FlashSystem A9000 secures all written data with industry-standard AES-256 encryption for data-at-rest. It protects the grid controller SSDs and flash enclosure MicroLatency modules against exposure of sensitive data on discarded or stolen media by ensuring that the data cannot be read if the key used to encrypt the data is secured. Encryption is carried out at the hardware level to avoid any performance impact. Encryption key management can be carried out through an external or a local key scheme.

For more information, see the IBM Redbooks publication, *Data-at-rest Encryption for IBM FlashSystem A9000, IBM FlashSystem A9000R, and XIV Storage System*, REDP-5402.

- ▶ Authentication by using Lightweight Directory Access Protocol (LDAP)
LDAP can be used to provide user logon authentication, which allows FlashSystem A9000 to integrate with Microsoft Active Directory, Open LDAP, and Oracle Java Systems Directory Server. Multiple directory servers can be configured to provide redundancy if one server becomes unavailable.
- ▶ OpenStack and REST support
FlashSystem A9000 can use the well-established IBM code base for OpenStack and REST API support.
For more information, see the IBM Redbooks publication, *Using XIV in Open Stack environment*, REDP-5971.
- ▶ VMware synergy
IBM Spectrum Control™ Base V3.0 and above allow a simplified deployment and efficient integration of FlashSystem A9000 with the VMware vCloud suite.
See the IBM Redbooks publication, *Using the IBM Spectrum Accelerate Family in VMware Environments: IBM XIV, IBM FlashSystem A9000 and IBM FlashSystem A9000R, and IBM Spectrum Accelerate*, REDP-5425.
- ▶ Cloud integration
FlashSystem A9000 integrates easily into your existing data center infrastructure. It also integrates with a wide variety of cloud environments, including solutions for Kubernetes container environments, in addition to IBM Cloud™ Private, VMware, OpenStack, and Microsoft environments, at no additional cost.
- ▶ Container support
IBM Spectrum Connect enables the use of persistent storage for containers in Kubernetes environments. See the IBM Redbooks publication, *IBM Spectrum Connect and IBM Storage Enabler for Containers*, REDP-5470.

Hardware architecture

FlashSystem A9000 consists of three grid controllers and one flash enclosure. Each component is a 2U unit, which sums up to a total of 8U required rack space.

FlashSystem A9000 must be installed by IBM authorized personnel and can be placed into a customer-provided standard 19-inch rack.

Communication between the grid controllers and the flash enclosure is over InfiniBand. All cabling between the grid controllers and the flash enclosure is made fully redundant by using two sets of cables. The cables use industry standard plugs.

Each component requires two independent power sources. For more information about the requirements that apply to your country, see *IBM FlashSystem A9000R Models 9835-415, 9837-415, 9835-425, 9837-425, and 9837-U25 Deployment Guide*, GC27-8564.

Figure 2 shows the components configuration and their position in the stack, next to the assembled system view.

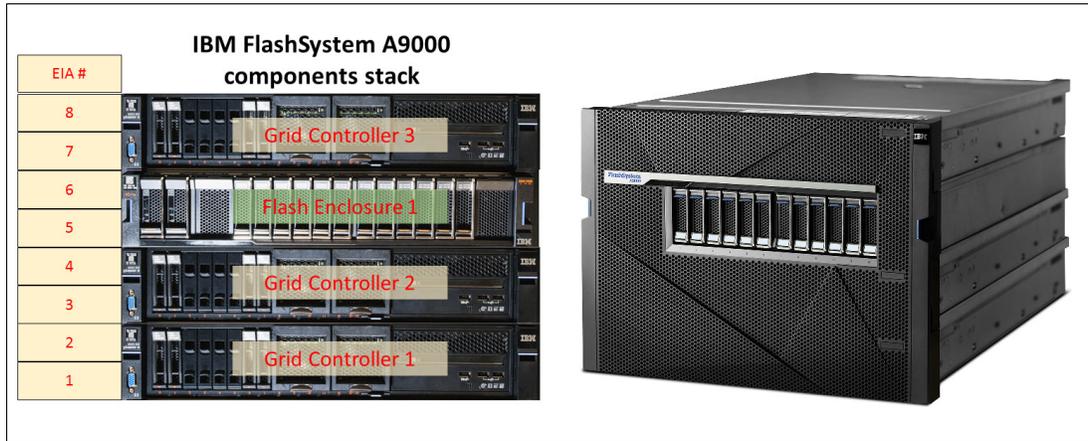


Figure 2 FlashSystem A9000 components stack and system view

Because the system is installed in a client-provided rack, its position in the rack can vary, and other customer servers or storage systems might be installed in the same rack.

Grid controller

The grid controller handles the compute-intensive portion of the workload and enforces data distribution to ensure that all of the resources of the system are being used. The grid controller also handles I/O from the attached hosts by providing 16 Gb FC ports and 10 Gb iSCSI ports.

FC-NVMe ready adapter: Model 425, shipping with Software Version 12.2.1 or later contain enhanced grid controllers equipped with FC-NVMe ready adapters. In these new controllers, the FC ports are dual-purpose and NVMe ready. IBM plans^a a future software upgrade that will enable these ports to connect with servers using FC, or using FC-NVMe, or both.

a. IBM's statements regarding its plans, directions, and intent are subject to change or withdrawal without notice at IBM's sole discretion. Information regarding potential future products is intended to outline our general product direction and it should not be relied on in making a purchasing decision. The information mentioned regarding potential future products is not a commitment or legal obligation to deliver any material, code, or functionality.

The grid controller is an Intel Xeon processor-based, reliable, high-end server. It offers two CPU sockets, 24 DDR4 ECC capable memory slots, and high-speed PCI Express 3.0 connectors to attach and serve all I/O ports that are required for FlashSystem A9000.

Table 1 lists the internal hardware components that are contained in the grid controller for FlashSystem A9000 Model 425.

Note: In June of 2018, IBM withdrew all four versions of the Model 415. They can no longer be ordered or purchased, but existing A9000 Model 415 systems can continue to be upgraded with additional grid elements.

Table 1 Grid controller components in FlashSystem A9000 Model 425

Component	Description
Processor	2 Intel E5-2650 v4 @ 2.20 GHz 12 cores with Hyper Threading
Memory	384 GB DDR4 RAM
InfiniBand adapter	2 Mellanox InfiniBand Connect Dual Port 56 Gbps FDR
16 Gb Fibre Channel adapter	0 or 2 QLogic QLE2962 Dual Ports (earlier machines might have QLE2662 instead)
10 Gb Ethernet adapter	1 or 2 Mellanox ConnectX-3 Pro Dual Port
Compression Accelerator	2 Intel Coletto Creek cards
Hard disk drive	2 hot-swap, RAID1 HDDs for system firmware and logging
Solid-state disks	2 hot-swap, 400 GB SSDs as vault devices
Battery Module	Dual internal redundant battery backup units

Figure 3 shows the front view of the grid controller. The drive cage contains two hard disks in a RAID 1 that are the grid controller boot devices, holding FlashSystem A9000 microcode and also various system logs and events. In the two rightmost slots of the drive cage are two SSDs that are used as vault devices for cache and metadata. In the middle of the controller are two battery backup units.

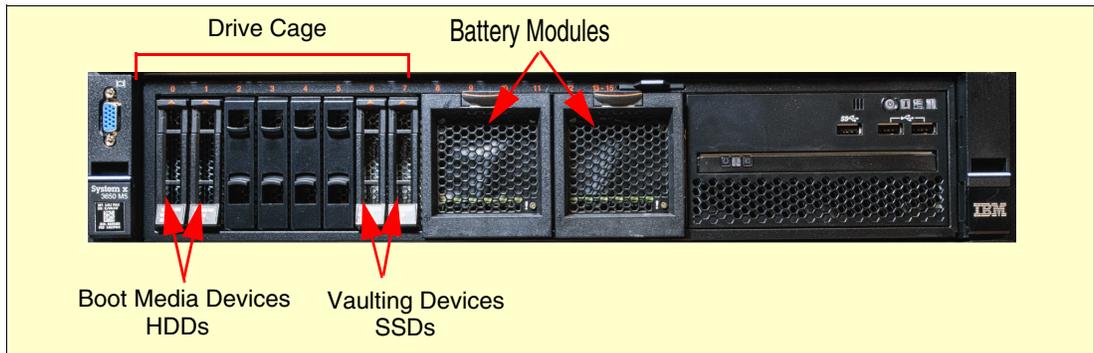


Figure 3 Grid controller front view

By design in FlashSystem A9000, the grid controller is an isolated failure domain. As such, any failure or maintenance action that requires shutting down one grid controller does not affect the overall system. Figure 4 shows the rear view of a grid controller.

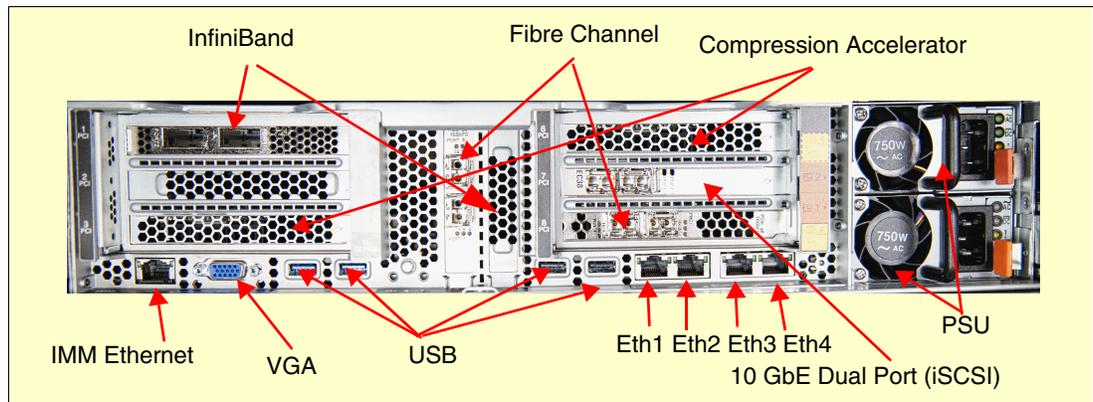


Figure 4 Grid controller rear view for FlashSystem A9000

The rear of the controller includes the following components:

- ▶ The PCI slots on the left side of the controller contain one dual port InfiniBand adapter in the top slot and one of the compression accelerators in the bottom slot.
- ▶ At the bottom of the controller is an Ethernet port that can access an integrated management module (IMM). This Ethernet port is not used in FlashSystem A9000.
- ▶ Next to the Ethernet port is a VGA connector and four USB ports. In some configurations, the USB ports are used for maintenance.
- ▶ The middle PCI slots contain another InfiniBand card and can contain an FC adapter.
- ▶ The top PCI slot on the right side of the controller contains the second compression accelerator card. In the middle slot is a 10 GbE dual port adapter. The bottom slot can contain an FC or FC-NVMe adapter, or an extra 10 GbE adapter.
- ▶ Below the PCI slots are four 1 GB Ethernet adapters that are used for the internal communication and as management ports.
- ▶ On the right side are two power supplies.

InfiniBand connection between the grid controllers is used for data transfer and internal management purposes. Management task uses IP over InfiniBand (IPoIB) for concurrent code upgrade, connectivity status checks, and so on.

Although two options are available for the grid controllers in FlashSystem A9000, all grid controllers in any single FlashSystem A9000 must be of the same option, as described next.

FC and iSCSI option

Figure 5 shows the FC option of the grid controller, which includes the following components:

- ▶ One dual port 10 GbE adapter in the middle right PCI slot (highlighted in green in Figure 5 on page 9) for iSCSI connectivity,
- ▶ One dual port FC-NVMe adapter in the middle and another FC-NVMe adapter at the lower right (highlighted in yellow in Figure 5 on page 9).

The blue rectangles in Figure 5 highlight the two InfiniBand adapters that are used for the internal backend communication only. The InfiniBand card cannot be used for host or mirroring access.

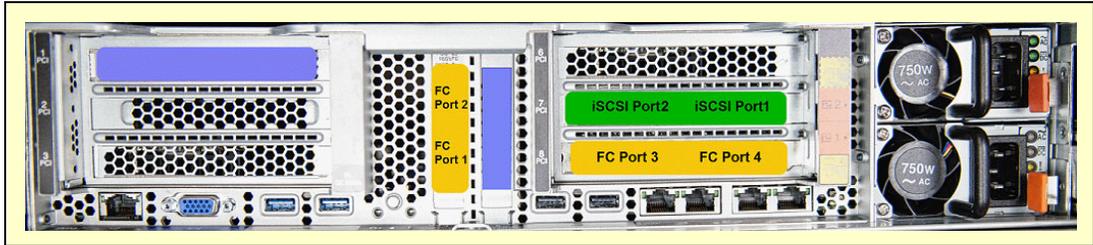


Figure 5 Fibre Channel with iSCSI option

iSCSI only option

Figure 6 shows the grid controller with the dual iSCSI connection option. It contains one 10 GbE dual port adapter in the middle right and a similar adapter on the lower right, both for iSCSI connectivity (highlighted in green in Figure 6).



Figure 6 iSCSI only option

Flash enclosure

Compared to Model 415, FlashSystem A9000 Model 425 includes an improved flash enclosure, with larger and more flexible capacity points, achieved by combining three-dimensional (3D) chip layout with triple-level cell (TLC) transistors. The new enclosure model also offers inline, always-on hardware compression that is done right on the MicroLatency modules without any performance impact.

FlashSystem A9000 continues to implement a full data reduction engine, including pattern removal, data deduplication, and compression in the grid controllers to achieve up to a 5x compression ratio. However, to reduce CPU workload and improve performance, internal metadata is not compressed by the grid controllers, allowing the underlying MicroLatency modules to do it instead.

There is only one flash enclosure in FlashSystem A9000. The flash enclosure includes MicroLatency modules, battery modules, power supplies, and two fully redundant canisters, as shown in Figure 7.

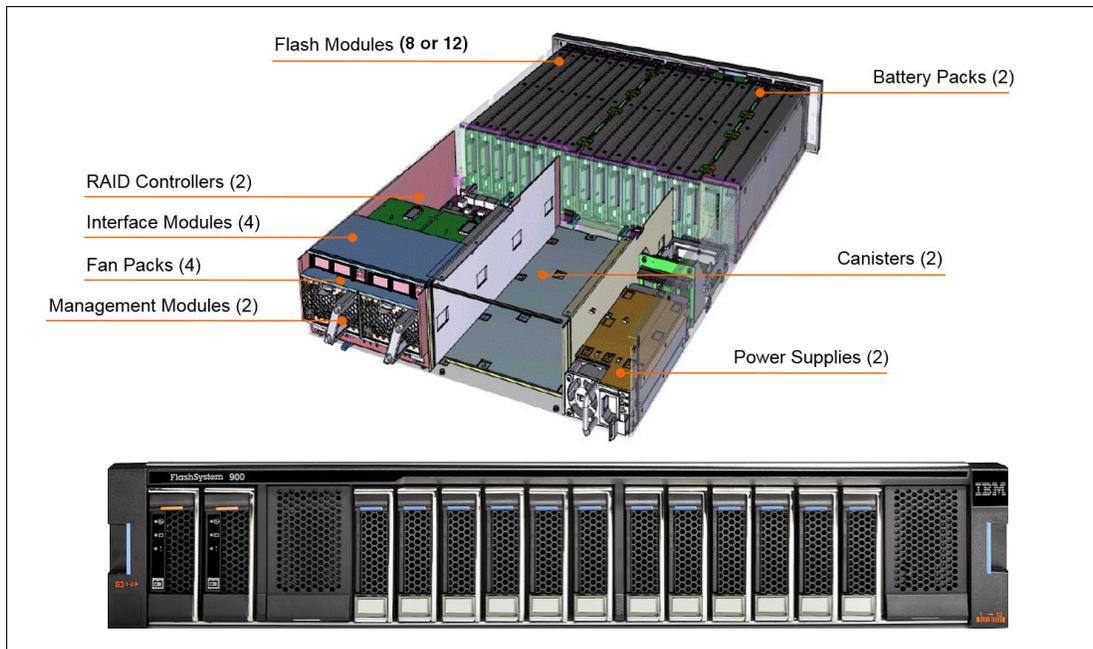


Figure 7 Flash enclosure inside view and front view (Model 425)

The flash enclosure canister contains the RAID controllers, interface modules, management module, two hot-swappable fan modules, two Ethernet ports, and two USB ports. The two interface controllers are at the top of the container and each has two 40 Gbps InfiniBand ports.

The models have these MicroLatency options:

- ▶ The flash enclosure in Model 425 contains 8 or 12 equally sized MicroLatency modules. There are three options for the MicroLatency Module capacity: 3.6 TB, 8.5 TB, and 18 TB. The 8-module enclosure is available only for the 3.6 TB capacity point. The data reduction technology enables each flash enclosure to offer effective capacities of 110 TB (with 8x 3.6 TB MicroLatency modules), 180 TB (with 12x 3.6 TB MicroLatency modules), 425 TB (with 12x 8.5 TB MicroLatency modules), and 900 TB (with 12x 18 TB MicroLatency modules), which assumes a data reduction saving ratio of 5:1.
- ▶ The flash enclosure in Model 415 contains 12 equally sized MicroLatency modules. There are three options for the MicroLatency Module capacity: 1.2 TB, 2.9 TB, and 5.7 TB. The data reduction technology enables each flash enclosure to offer effective capacities of 60 TB, 150 TB, and 300 TB, which assumes a data reduction saving ratio of 5:1.

Product physical specifications (Model 425/U25)

Two machine types are associated with FlashSystem A9000 Model 425. They are available with two standard warranty periods, as listed in Table 2 on page 11. Model U25 is only available with a three-year warranty.

Table 2 Machine types and models and warranty periods

Warranty period	IBM FlashSystem A9000 Model 425
One-year	9836-425
Three-year	9838-425 or 9838-U25

The FlashSystem A9000 Model 425 components and capacity information are listed in Table 3.

Table 3 .FlashSystem Model 425 components and capacity

Components	Capacity
Number of grid controllers	3
CPUs (cores)	6 (72)
Memory in GBs	1152
iSCSI (10 Gb) only ports	12
iSCSI (10 Gb) + FC (16 Gb) ports	6 + 12
Number of flash enclosures	1
MicroLatency modules	8 ^a or 12
MicroLatency module capacity in TBs (three options)	3.6/8.5/18
Usable physical capacity in TBs	21.6 ^b /36 ^c /85/180
Effective capacity in TBs ^d	110 ^b /180 ^c /425/900
Maximum effective capacity in TBs ^e	1200/1200/1200/1200

- a. The option is available only when using the 3.6 TB MicroLatency Modules and is not supported with Model 9838-U25
- b. Achieved in configuration with 8 MicroLatency Modules of 3.6 TB capacity.
- c. Achieved in configuration with 12 MicroLatency Modules of 3.6 TB capacity.
- d. Effective capacity assumes a data reduction that is calculated at about 5:1.
- e. Maximum effective capacity is the up-most provisioning limit that effective capacity can be stretched to by IBM.

Dimensions and weight

The rack dimensions and weight are listed in Table 4.

Table 4 Rack dimensions and weight

Dimensions and weight	Measurement
Height	356 mm (14 in.) - 8U
Width	483 mm (19 in.)
Depth	930 mm (36.6 in.)
Weight	125 kg (276 lb.)

Power consumption

Before starting the physical installation, ensure that an electrician is available who can fulfill the requirements for connecting IBM FlashSystem A9000.

The typical power consumption is 1.74 kW, with a maximum of 2.625 kW.

Thermal dissipation

The thermal dissipation with three grid controllers and one flash enclosure is approximately 6.7 kBTU per hour.

Scale out with IBM Hyper-Scale Mobility

Scaling from a FlashSystem A9000 to a FlashSystem A9000 or A9000R is possible by using the IBM Hyper-Scale Mobility function.

Hyper-Scale Mobility can move volumes from any FlashSystem A9000 to another FlashSystem A9000 or A9000R, enabling you to distribute application I/Os to more systems and move data from one system to another. Upon completion of the volume move, the host is transparently and automatically redirected to the new system.

Hyper-Scale Mobility addresses the following scenarios:

- ▶ Scaling between FlashSystem A9000 and A9000R systems
- ▶ Balancing workloads across systems without service downtime for better performance
- ▶ Retiring systems gracefully and upgrading to current technology
- ▶ Detaching storage and host maintenance cycles
- ▶ Managing storage growth

Starting with FlashSystem A9000R Software V12.2.1, Hyper-Scale Mobility is also supported from an XIV Gen3 with code level 11.6.2a to FlashSystem A9000R or A9000.

Reliability, availability, and serviceability

The unique modular design and logical topology of FlashSystem A9000 fundamentally differentiates it from traditional, monolithic systems. This architectural divergence extends to the exceptional reliability, availability, and serviceability (RAS) aspects of the system.

FlashSystem A9000 also incorporates autonomic and proactive monitoring and self-healing features. These features enable preventive measures to preserve data redundancy before a component malfunction occurs.

The system is automatically restored to full redundancy within minutes of a hardware failure. When a grid controller fails, its workload is directly taken over by another grid controller.

For more information about the reliability features of a flash enclosure, see “IBM FlashCore and 2D RAID technology” on page 15.

Reliability

Reliability is engineered at the following levels:

- ▶ The separation of grid controllers and flash enclosure protects against the effects of a failed grid controller. A grid controller can fail without any effect to the flash enclosure. The tasks of a failed grid controller are taken over by the other grid controllers. Correct host multipathing must be used to prevent host disconnection.
- ▶ Redundant hot-swappable components:
 - Each flash enclosure has two clustered, hot-swappable canisters that each contain two hot-swappable fan modules, two management controllers, four management Ethernet ports, and a USB port for service connectivity. The batteries, fans, and power supplies are all redundant and hot-swappable.
 - If a MicroLatency module failure occurs, critical customer applications can remain online while the defective module is replaced. Each flash enclosure is configured with a hot spare module for use during a MicroLatency module failure.
 - Each grid controller contains two redundant, hot swappable power supplies. The cooling system is resilient to keep the grid controller running, even with up to two fans in failed state. The microcode is stored on two RAID1 secured HDDs. The data and functions of each grid controller is mirrored in a three-way manner.
- ▶ The two-dimensional RAID protection (2D-RAID) of the flash enclosure protects against MicroLatency module, flash chip, and other flash system-related failures. 2D-RAID consists of IBM Variable Stripe RAID™ and flash enclosure-wide RAID 5. IBM Variable Stripe RAID is a patented IBM technology that provides an intra-module RAID stripe within each flash module and is described in “Flash enclosure 2D RAID” on page 16. Variable Stripe RAID technology helps reduce downtime and maintain performance and capacity during partial or full flash chip failures.

A MicroLatency module can fail without any effect on the flash enclosure. When a MicroLatency module fails, the RAID 5 configuration over the MicroLatency modules allows a rebuild by using the hot spare MicroLatency module in the flash enclosure.
- ▶ The flash enclosure runs an internal scrubbing process to verify the integrity of the data. It is a low-priority process to optimize performance. If an error is detected during the scrubbing process, the flash enclosure attempts to correct it. If the attempt was unsuccessful (unrecoverable error), an event is sent but the flash enclosure remains online.
- ▶ InfiniBand cabling is redundant and split onto two different InfiniBand adapters in each grid controller.
- ▶ All active components (grid controllers, flash enclosure) contain a redundant battery backup unit (BBU). During an accidental power loss on both main power sources, a loss in BBU redundancy, or in an overheating situation, FlashSystem A9000 automatically performs a shutdown to protect the data (cache and metadata). This process is known as *shutdown vaulting*. During normal system operation, the cache and metadata are also saved to the vaulting devices at regular intervals, approximately every 5 minutes (live vaulting). Shutdown vaulting does not overwrite live vaulting.

Vaulting: The role of the vaulting procedure is to write memory-resident data (which is volatile) onto non-volatile storage during system shutdown.

FlashSystem A9000 uses the SSDs in the grid controller as vault devices. The vaulting process design point is to save three copies of the data, preferably on SSDs in three different grid controllers. During a hardware failure, the system still saves at least two copies of the data. That is, the system does not remain online with less than two grid controllers.

The grid controller destages the following data during the shutdown:

- Data in write cache
- Metadata that changed since the last vault was run

The flash enclosure also has redundant BBUs to allow a graceful shutdown of the enclosure. It writes the following data during shutdown:

- Data in the flash enclosure write cache
- Recent data distribution table

After all of the data is secured, the components power off. If the utility power recovers after the automatic shutdown, FlashSystem A9000 should start automatically.

When the system restarts, it starts a *devaulting* procedure. The devaulting procedure retrieves the data from the vault devices back to memory upon system start as part of the system power-up process. Each vaulting device (SSD) reports to the system the piece of data that it holds. The system uses an internal vault distribution table to assign each piece of data to cache nodes.

If vaulting or devaulting fails during shutdown or startup (often because of a catastrophic hardware or software failure), the system moves to maintenance until IBM intervention.

Availability

Grid controllers feature automatic and seamless failover capabilities. The cache of a grid controller is triplicated. That is, one copy is local and two other copies are on two other grid controllers. If the system can still maintain at least one secondary cache, it remains operational. This behavior implies that a FlashSystem A9000, which is equipped with three grid controllers, can stand one grid controller outage. The loss of another grid controller (an unlikely event) triggers a graceful system shutdown.

System-wide performance monitoring ensures the availability of the needed software functions. For example, if a software process (such as caching or data reduction) is unresponsive, they are expelled from the degraded grid controller and their workload is taken over by other grid controllers.

FlashSystem A9000 includes an enhanced call home functionality. When configured for call home, each system reports events regularly and sends heartbeats with system health information to IBM. Based on the events and heartbeats, IBM support can automatically open support tickets and start service actions without the need for any manual customer action.

Statistical data, which is gathered by IBM based on the events and heartbeat information, helps IBM identify possible upcoming situations that might need proactive assistance.

Power is monitored and battery units are conditioned for longer lifespan.

The system temperature is monitored at the flash enclosure level and at the system level. When temperature gets out of range, a graceful shutdown is triggered.

Concurrent code load enables customer applications to remain online during firmware upgrades to all components, including the flash enclosures and MicroLatency modules.

Serviceability

High levels of serviceability are achieved by providing the following features and functions:

- ▶ Thorough testing of all components during the manufacturing process.
- ▶ Enhanced Call-home.
- ▶ Logs and statistics are collected and recorded by each interface and port that relate to the data path (Fibre Channel, iSCSI, InfiniBand, and Ethernet).
- ▶ Debug utilities, including XRAY data collection on FlashSystem A9000 and Host Attachment Kit (HAK) diagnostic collection on the host side.
- ▶ IBM SSR has access to service tools for guided repairs, pre-upgrade checks, concurrent upgrade, and so on.
- ▶ Remote support capabilities minimizing time to resolution.

IBM FlashCore and 2D RAID technology

The IBM FlashCore technology that is used in FlashSystem A9000 is based on patented mechanisms to deliver extreme performance, MicroLatency, macro efficiency, enterprise-grade reliability, and a wide range of operational and cost efficiencies.

The data path inside the flash enclosure is hardware-accelerated, which means that there is no CPU in the data path. This configuration ensures the lowest latency and highest throughput.

IBM FlashCore technology features

Figure 8 shows the following major areas within IBM FlashCore technology, and the unique IBM attributes of each technology.

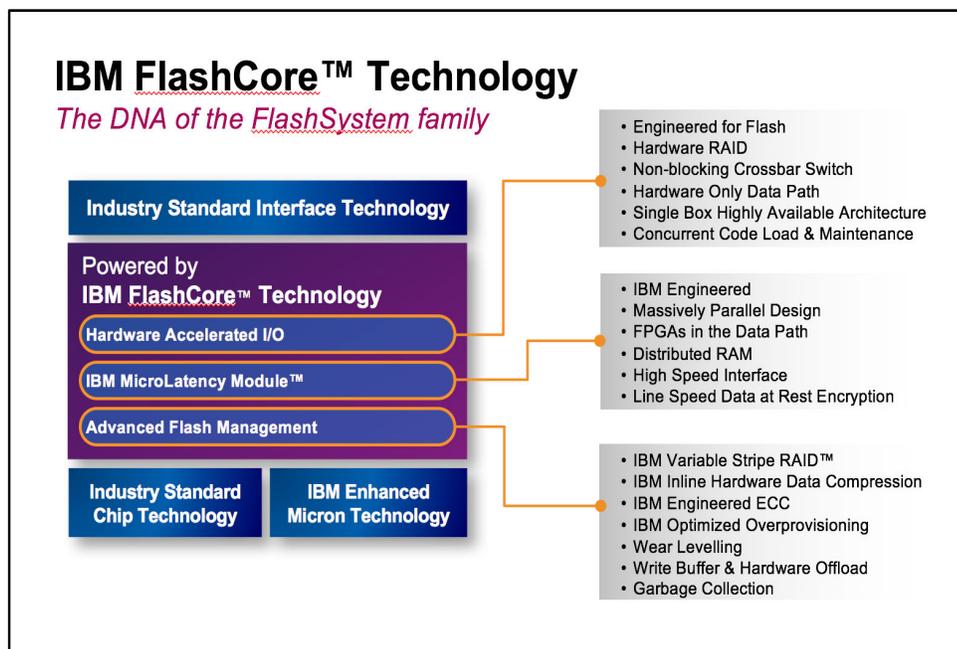


Figure 8 IBM FlashCore technology

- ▶ Hardware Accelerated I/O

The FlashSystem A9000 flash enclosure hardware design offers several unique IBM components. These components include Hardware RAID, Non-Blocking Crossbar Switch, Hardware-Only Data Path, Highly Available Architecture, Concurrent Code Load, and Concurrent Maintenance.

The use of an all-hardware data path design ensures the highest performance and lowest latency of the FlashSystem A9000 flash enclosure.

- ▶ IBM MicroLatency modules

FlashSystem A9000 Model 415 flash enclosure uses 20 nm IBM enhanced multi-level cell (MLC) flash card memory chips.

The FlashSystem A9000 Model 425 flash enclosure uses the new IBM enhanced 3D triple-level cell (3D-TLC) flash card memory chips.

FlashSystem A9000 design also uses IBM Engineered Massively Parallel Design, Field Programmable Gate Array (FPGA) modules in the Data Path, Distributed RAM, and High-Speed Interfaces plus hardware-based data-at-rest encryption.

- ▶ Advanced Flash Management

FlashSystem A9000 has unique patented designs to ensure maximum availability. These designs include IBM Variable Stripe RAID, IBM Inline Hardware Data Compression, IBM Engineered Error Correction Code (ECC), IBM Optimized Over-Provisioning, advanced wear leveling on IBM MicroLatency modules, Write Buffer and Hardware Offload, and IBM Garbage Collection.

The wear leveling algorithm ensures the even usage of all blocks. The garbage collection process collects the blocks (which are no longer used) so that they can be reused for writing.

Given that FlashSystem A9000 uses software data reduction, the data being sent to the flash enclosure is already compressed, and therefore is bypassing the inline hardware data compression.

Flash enclosure 2D RAID

The flash enclosure includes 8 or 12 MicroLatency modules. A RAID 5 is built over all the MicroLatency modules to protect the flash enclosure from a MicroLatency module failure.

The flash chips that are inside the MicroLatency module are protected by the IBM Variable Stripe-RAID (VSR). Variable Stripe-RAID protects the MicroLatency module against chip failures or if only a part of chip fails. It monitors the health of the flash media, efficiently detects and manages flash failures, and optimizes the use of all flash resources.

With Variable Stripe-RAID, a flash failure does not result in the need for a maintenance event. No flash module replacement is necessary, and the MicroLatency module is not degraded in any way.

Increased protection: Variable Stripe-RAID protects against expected and unexpected failures inside a flash chip.

The combination of the RAID 5 over the MicroLatency module and the VSR inside a MicroLatency module is called two-dimensional RAID protection (2D RAID).

Figure 9 shows the IBM FlashSystem 2D RAID technology.

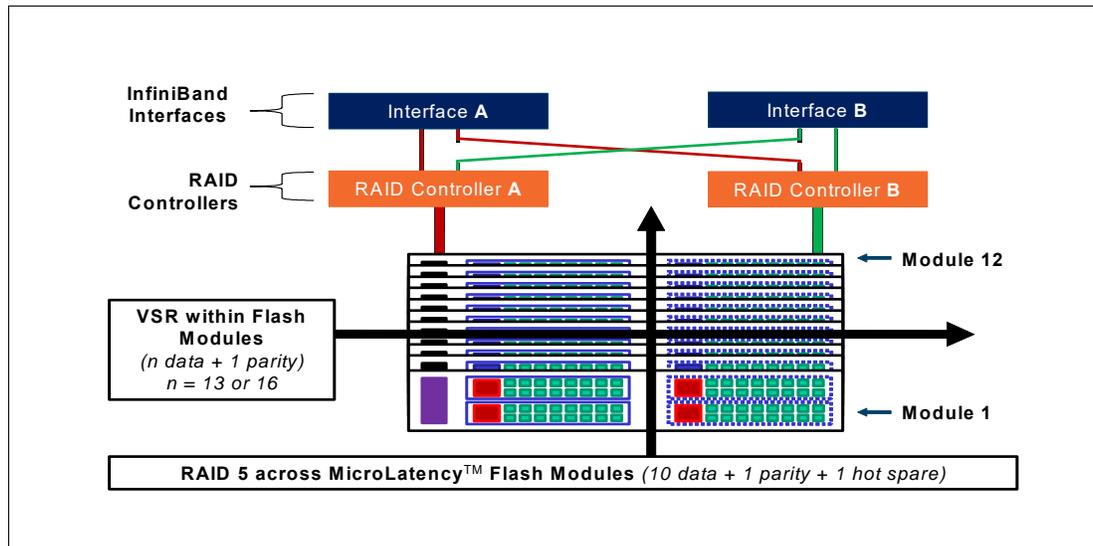


Figure 9 IBM FlashSystem 2D RAID protection

Logical architecture and functions

FlashSystem A9000 logical architecture is built on IBM Spectrum Accelerate™ software. The architecture features many added enhancements to optimize the software stack for use with flash storage.

Parallelism and grid architecture

The grid architecture plays an important role in ensuring that all components of FlashSystem A9000 have an active role in servicing host requests. Each grid controller performs the following roles, which are implemented by specific software functions and designated as nodes:

- ▶ **Interface:** The interface node processes host I/Os. From the physical standpoint, every grid controller has FC or iSCSI cards that can be connected to a network for attachment to application hosts.
- ▶ **Data reduction:** The data reduction node implements data deduplication and compression functions. Each grid controller dedicates some processing capacity and memory for the purposes of data reduction.
- ▶ **Data distribution:** The data distribution process ensures that the distribution information is kept up-to-date, which enables data placement across all flash enclosures by using 16 MB partitions.
- ▶ **Caching:** The cache node implements and manages caching functions. Data reduction is accomplished below cache in FlashSystem A9000, so each grid module has significant read and write cache to allow for consistent microsecond response times.

As shown in Figure 10, the various nodes are instantiated and run in parallel on each grid controller. This design enables multiple main threads for higher performance. Resiliency and system availability is also improved, because any failed node on a controller automatically fails over and can be redistributed to another similar node on a different grid controller.

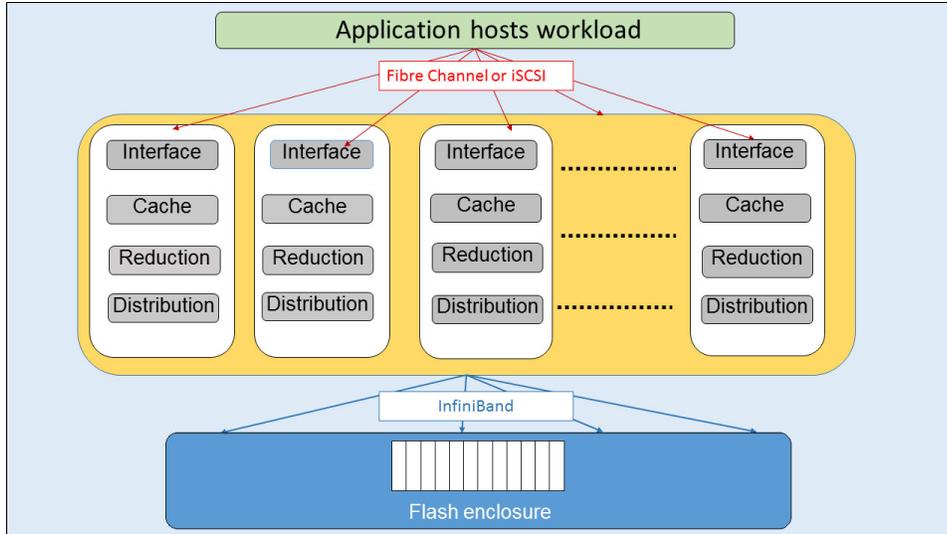


Figure 10 Parallelism and grid architecture

Cache resiliency

The cache and cache management design enables decoupling between computation functions (typically, caching, data reduction, and metadata management) and storage resources.

To ensure resiliency, the system is creating multiple copies of the data in cache. Each host data block has a primary cache in a grid controller that is assigned as the primary module, and two other backup caches in two different grid controllers, as shown in Figure 11 (data reduction nodes are not shown).

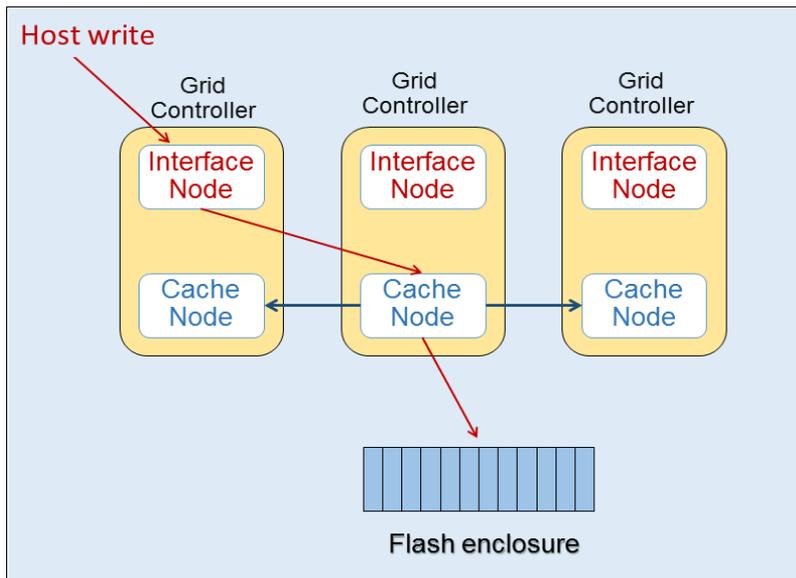


Figure 11 Cache resiliency design

When information is written to FlashSystem A9000, the primary module ensures that data is also written to both backup modules. The write is acknowledged to the host only when all three copies are in place.

Inline data reduction

FlashSystem A9000 performs always-on, inline global data reduction to provide application hosts with capability to provision virtual storage capacity that is an order of magnitude higher than actual physical capacity. It also delivers microsecond performance benefits of FlashSystem storage at a lower cost per gigabyte.

Data reduction in FlashSystem A9000 uses the following three-phase process:

1. Pattern matching and removal
2. Data deduplication
3. Compression

Below cache: Placement below cache means that there is no latency effect for cached I/Os. System functions, such as migration, snapshots, or VMware VAAI operations, are not affected.

Pattern matching and removal

This first layer of data reduction comes from pattern matching. Pattern matching mechanisms match incoming host writes with a pre-configured set of known patterns that is stored in the system.

When a write is processed, it is split into 8 KB blocks, as shown in Figure 12. Each block is then hashed and the hash value is compared to a table of well-known hashes. If a match is found, the corresponding pattern ID, which is only 2 bytes (highlighted by the green arrows in the Removal section of Figure 12) is stored. Any match that is found at that stage is replaced with internal markings (a hash) without doing data deduplication and compression yet.

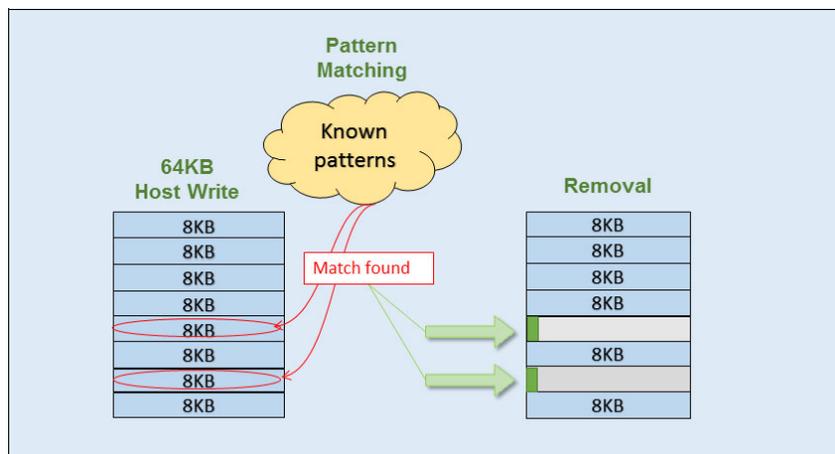


Figure 12 Pattern matching and removal

Data deduplication

Data deduplication is the ability to store data only once, although it can be written many times by various hosts or applications.

The data deduplication mechanism identifies identical blocks of data and stores only one copy of that data in the system. All other identical blocks are pointed to that copy.

In Figure 13, each color represents unique data. Every square represents an 8 KB block. The system can detect duplicates and stores only one copy of the duplicate 8 KB blocks. For duplicates, Figure 13 shows that only the pointers to the data are stored in the system.

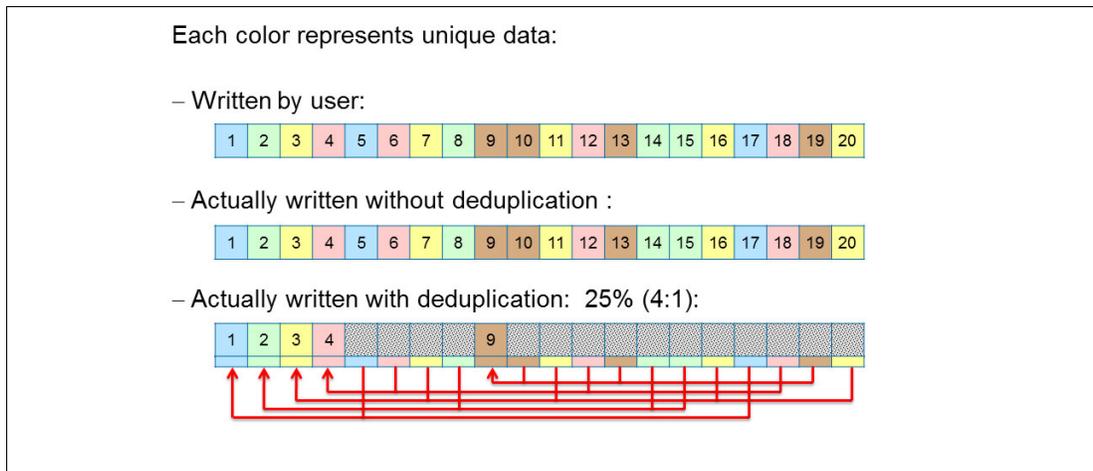


Figure 13 Data deduplication in FlashSystem A9000

Whenever a new unique block is found, a new hash is created and stored in a repository. The hash value of any subsequent 8 KB writes is checked against the repository for a match.

Data deduplication is done in sequences and the system stores hashes in a memory construct, which is known as a *segment*. Each hash (data) has an owning segment, and a specific segment can also contain references to a hash that it owns or references to a hash in another owning segment. As shown in Figure 14, the owning segment of a referenced hash is indicated by the corresponding background color.

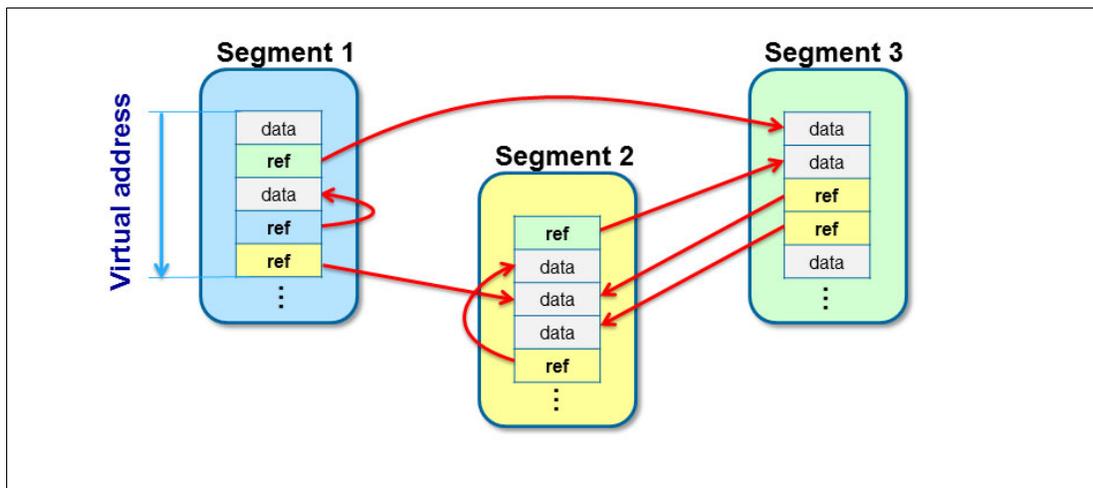


Figure 14 Hashes and references in segments

Segments maintain a list of other segments that they created references to recently. Therefore, the recent segments are checked first when looking for a match, which typically speeds up the matching process.

As shown in Figure 15, data deduplication of the 8 KB blocks is done over a 4 KB alignment. This process increases the probability of finding a match, and results in a higher data deduplication percentage.

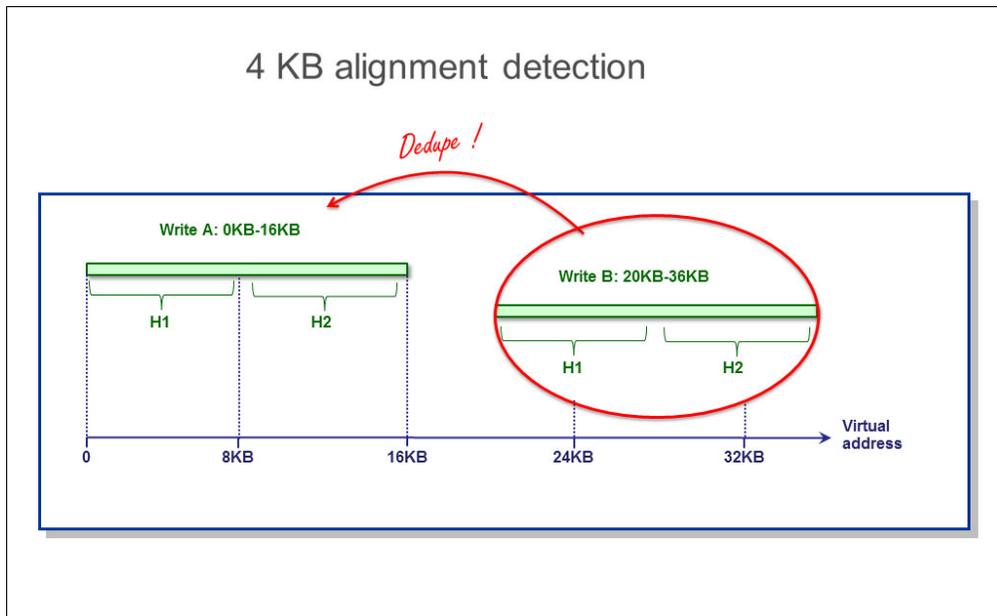


Figure 15 Dedupe: 4 KB alignment detection

Compression

Finally, data moves on to the compression step (see Figure 16) for more data reduction.

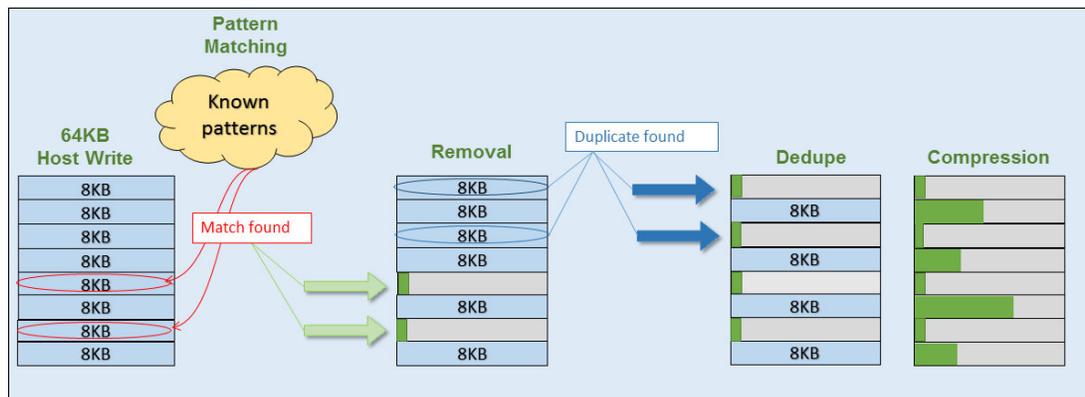


Figure 16 Compression

Compression in FlashSystem A9000 is hardware assisted. Two Intel Coletto Creek cards are included in each grid controller.

The IBM patented compression technology that is used by FlashSystem A9000 is based on a z1ib data compression algorithm that operates in a real-time method.

The compression engine alters the traditional approach to compression. It uses variable-size chunks for the input, and fixed-size, 32 KB chunks for the output. This difference is the basis of many of its benefits.

Fixed size writes: Traditional compression writes variable size chunks to the storage device, whereas FlashSystem A9000 compression writes fixed size output chunks.

In addition, FlashSystem A9000 uses *temporal locality*-based compression. As shown in Figure 17, temporal compression adds the time dimension that is not available to other compression algorithms. It offers a higher compression ratio because the compressed data in a block represents a more homogeneous input data.

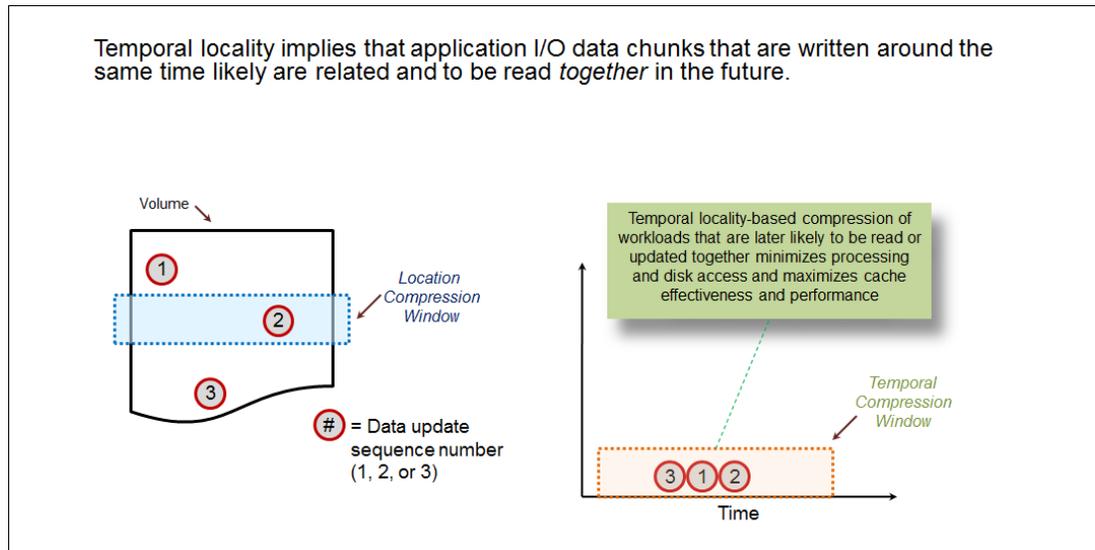


Figure 17 Temporal locality

Storage provisioning concepts

This section describes how the available physical storage is virtualized and effectively managed in FlashSystem A9000.

Storage pools

The available capacity in the system can be administratively portioned into separate and independent storage pools.

A pool must have an allocated size that is greater or equal to the total size of volumes and snapshots that it will contain. The minimum size of a pool is 103 GB.

Tip: With Version 12.3, a pool can be system-wide. In other words, a single pool can use the full system effective capacity, up to the system allocation limit of 1.2 PB.

Volumes

A *volume* is defined within the context of only one storage pool. Because storage pools are logical constructs, a volume and any snapshots that are associated with it can be moved to any other storage pool. As a benefit of the system virtualization, there are no limitations on the associations between logical volumes and storage pools.

FlashSystem A9000 uses the grid concept, and distributes volume data evenly across hardware resources. The data is distributed evenly across all flash modules by using partitions, and each partition is 16 MB.

The minimum volume size that can be created in FlashSystem A9000 is 1 GB, and the maximum size is 1 PB.

Snapshots

A snapshot is a point-in-time copy of a volume's data and is contained within the same storage pool as the source. As implemented in FlashSystem A9000, snapshots have minimal effect on system performance. When the original data is updated, the update is stored in a new partition and a pointer of the original volume points to the new partition. However, the snapshot volume still points to the original partition. This method is called *redirect-on-write*.

Consistency groups

A *consistency group* is a group of volumes of which a snapshot can be made at the same point, which ensures a consistent image of all volumes within the group at that time. This consistency between the volumes in the group is paramount to maintaining data integrity from the application perspective. By first grouping the application volumes into a consistency group, it is possible to later capture a consistent state of all volumes within that group at a specified point by using a special snapshot command for consistency groups.

Multi-tenancy and QoS

Multi-tenancy brings flexibility and simplicity to managing tenant data and storage resources across multiple FlashSystem A9000 systems by using the following methods:

- ▶ Secure division and isolation of storage pools, volumes, consistency groups, mirrors, data migrations, and QoS performance classes among numerous tenants
- ▶ Simple, quick delegation of administration tasks and role-based permissions
- ▶ Simple, rapid deployment without the need for extensive planning and tuning

Domains

Multi-tenancy is based on the concept of *domains*, in which FlashSystem A9000 is logically partitioned into one or more independent containers, each with its own assigned administrators. This configuration enables secure isolation from other domains of the logical entities that are contained within a domain.

A user who is associated with a single domain has no knowledge of the other domains that are on the system, or about the pools or volumes that are associated with those domains. Domains can be associated with the following entities:

- ▶ Users and user groups
- ▶ Storage pools (and inherently, the volumes and snapshots that they contain)
- ▶ Hosts and clusters
- ▶ Remote mirror targets

Note: Although a storage pool (and the volumes and snapshots that it contains) can be associated with only a *single* domain, users (and user groups), hosts (and host clusters), and remote mirror targets can be associated with *multiple* domains.

A domain restricts the resources that a user can manage. A user can manage only the parts of the system that are associated with the domains with which they are associated, as shown in Figure 18 on page 24.

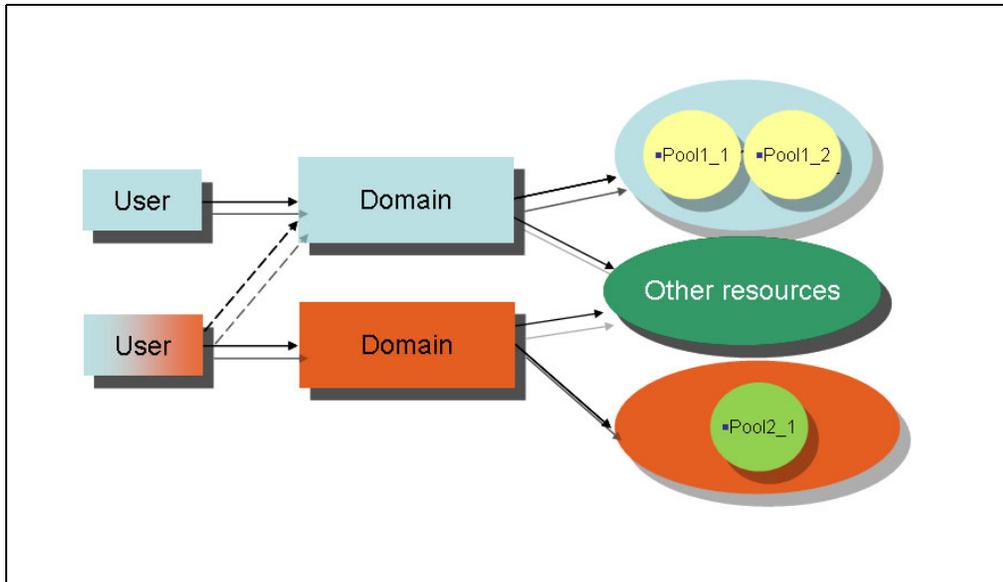


Figure 18 User view of domains and resources

Quality of service

The QoS feature allows FlashSystem A9000 to deliver different service levels to hosts that are connected to the same system.

The QoS feature favors performance of critical business applications that run concurrently with non-critical applications. Because FlashSystem A9000 resources are shared among all applications and all hosts are attached to the same resources, division of these resources among critical and non-critical applications might have an unintended adverse performance effect on critical applications.

QoS can address this issue by limiting the rate (based on bandwidth and IOPS) for non-critical applications. Limiting performance resources for non-critical applications means that the remaining resources are available without limitation for the business-critical applications.

The QoS feature is managed through the definition of performance classes and then associating hosts with a performance class. The feature can also be set by domains, storage pools, and volumes. Each performance class is implicitly 1 of 2 types: Host type or pool/volume/domain type.

Consider the following points about the QoS feature:

- ▶ Up to 500 performance classes are configurable.
- ▶ QoS is applicable to host, domain, pool, volume, and restricted combinations of these entities. For example, hosts cannot be specified for a performance class that contains a domain or pool.
- ▶ Limits can be defined as *Total*, meaning for FlashSystem A9000 as a whole, or *Per Interface*.
- ▶ Limits are specified as IOPS or bandwidth, as shown in Figure 19 on page 25.

Figure 19 Setting QoS limits

Security

Security is of utmost importance for mission-critical workloads. FlashSystem A9000 includes many features to ensure access and the data are secure.

Local security

To prevent unauthorized access to the configuration of the storage system and ultimately to the information stored on its volumes, FlashSystem A9000 uses password-based user authentication. By default, FlashSystem A9000 is configured to use native (locally managed) user authentication. Native user authentication uses the credential repository that is stored locally on FlashSystem A9000. The local credential repository maintains the following information:

- ▶ Domain memberships
- ▶ User name
- ▶ User password
- ▶ User role
- ▶ User group
- ▶ Optional account attributes

Native authentication mode implements user role mechanism as a form of role-based access control (RBAC). Each predefined user role determines the level of system access and associated functions that a user is allowed to use.

LDAP support

FlashSystem A9000 offers the capability to use LDAP server-based user authentication. When LDAP authentication is enabled, the system accesses a specified LDAP directory to authenticate users whose credentials are maintained in the LDAP directory.

The benefits of an LDAP-based centralized user management can be substantial when the size and complexity of the overall IT environment are considered. Maintaining local user credentials repositories is relatively straightforward and convenient when dealing with only a few users and storage systems. However, as the number of users and interconnected systems grows, the complexity of user account management rapidly increases. Managing such an environment becomes a time-consuming task.

Encryption for data-at-rest

FlashSystem A9000 provides optional encryption of data at rest. Encryption can be enabled during the installation of the system or at any time later. While encryption is not enabled, the system is unlikely to meet customers' or legal compliance standards, and the data is not protected against security issues.

Encryption is hardware-based AES-XTS 256 with centralized key management.

Data-at-rest encryption protects the data that is stored on the grid controller SSDs and flash enclosure MicroLatency modules against unauthorized access, use, disclosure, disruption, modification, perusal, inspection, recording, and destruction. Data-at-rest encryption protects the data if the SSDs or flash enclosure MicroLatency modules are stolen or improperly discarded.

FlashSystem A9000 allows a choice between an external key manager-based implementation and a local key-based encryption implementation.

To provide centralized and simplified key management and the separation of key storage from data storage, FlashSystem A9000 implements an external key management scheme. In this scheme, key management is accomplished by using external Key Management Interoperability Protocol (KMIP) compliant servers, such as IBM Security Key Lifecycle Manager or Gemalto SafeNet KeySecure server.

FlashSystem A9000 cache backup SSDs and flash enclosure MicroLatency modules feature self-encrypting capabilities that provide a local key management option. Local key management enables system support for key management services without requiring a dedicated, independent key management server. By avoiding a dedicated key server, the cost and complexity of managing keys can be reduced, potentially translating into a lower system total cost of ownership. The local key solution offers a simplified deployment of data-at-rest encryption, but clients must ensure that it is adequate for their data security requirements.

Concurrent conversion from external key management to internal key management is supported. However, the reverse operation of changing from local key to an external key server, first erases any data already on disk.

Physical access security

If someone gains physical access to the equipment, that person might manually shut off components by bypassing the preferred process. In this case, the storage system is likely to lose the contents of its volatile caches, which results in a data loss and system unavailability. To eliminate or greatly reduce this risk, FlashSystem A9000 can be installed in a rack that is equipped with lockable doors.

Storage management user interface

IBM Hyper-Scale Manager introduces a new web-based management graphical user interface (GUI) from which one or more supported FlashSystem A9000 systems can be managed and monitored in real time from a web browser.

The following functional highlights are included:

- ▶ All encompassing customizable dashboard
- ▶ Context-oriented user interface in a single-page, web-based application that enables viewing all relevant information for every object at a glance
- ▶ Smart view of object relationships and dependencies in a visual map (for example, view all volumes that are mapped to a host)
- ▶ Instant object-centered management and monitoring
- ▶ Advanced filters for focusing on the required object
- ▶ Quick tracing of objects and fast navigation between objects

- ▶ One-click selection and operation options (map, unmap, delete, and so on)
- ▶ Health score of all systems in the inventory
- ▶ Integrated statistics information

The main features are shown in Figure 20.

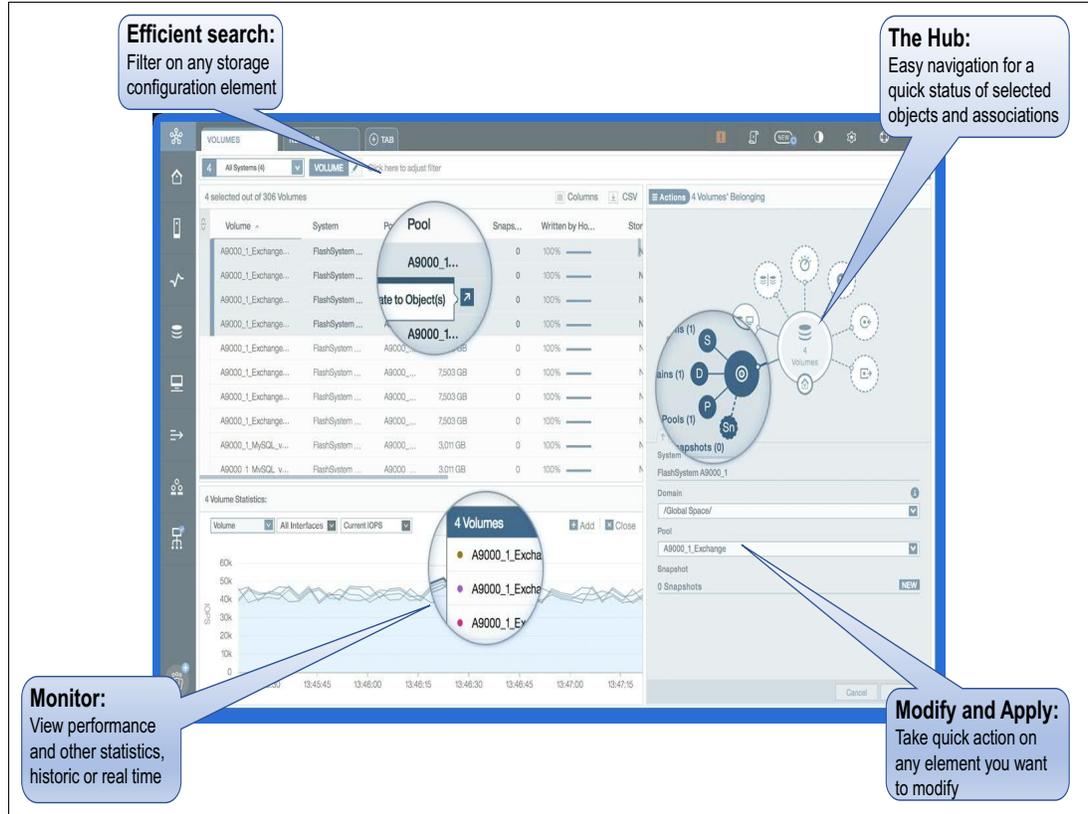


Figure 20 Hyper-Scale Manager GUI

Hyper-Scale Manager Server

The Hyper-Scale Manager is a server application that provides the GUI that is used to manage FlashSystem A9000. It is installed on a separate host or virtual machine, which runs RedHat Enterprise Linux or CentOS as the operating system. The system requirements are listed in Table 5.

Table 5 Hyper-Scale Manager minimum requirements

Component	Requirements
Environment	Physical host or a virtual machine
Operating System (OS)	RedHat Enterprise Linux (RHEL) x64 version 6.x or 7.x, 64-bit CentOS 6.8 or 7.2
CPU	At least two physical cores
Memory	Minimum of 4 GB
Disk Space	Minimum of 76 GB in the installation path and 1 GB in /tmp directory
Network	One 1 GbE (or faster) Ethernet connection

To access the management web interface and for the Hyper-Scale Manager server to communicate with FlashSystem A9000, some network ports must be opened. Table 6 lists the ports that must be opened in the OS firewall.

Table 6 Firewall ports for Hyper-Scale Manager

Open ports needed	Direction	Port number
Simple Mail Transfer Protocol (SMTP)	Outbound	25
Backend communication with the storage systems	Outbound and inbound	7778
Web User Interface (over HTTP)	Inbound	8080
Web User Interface (over HTTPS)	Inbound	8443
Cloud Integration	Inbound	8440

Related information

For more information, see the following resources:

- ▶ *IBM FlashSystem A9000 and IBM FlashSystem A9000R Architecture and Implementation*, SG24-8345
- ▶ *IBM HyperSwap and Multi-site HA/DR solution for IBM FlashSystem A9000 and A9000R*, REDP-5434
- ▶ *Data-at-rest Encryption for the IBM Spectrum Accelerate Family: IBM XIV and IBM FlashSystem A9000 and IBM FlashSystem A9000R*, REDP-5402:
- ▶ *IBM Hyper-Scale Manager for IBM Spectrum Accelerate Family: IBM XIV, IBM FlashSystem A9000 and A9000R, and IBM Spectrum Accelerate*, SG24-8376
- ▶ IBM FlashSystem A9000 on IBM Knowledge Center
<https://www.ibm.com/support/knowledgecenter/STJKMM>

The following publications are available:

- *IBM FlashSystem A9000 Command-Line Interface (CLI) Reference Guide*, SC27-8559
- *IBM FlashSystem A9000 Product Overview*, GC27-8583
- *Hyper-Scale Manager REST API Specification*, SC27-6440
- *Hyper-Scale Manager User Guide*, SC27-8560
- *IBM FlashSystem A9000R Models 9835-415, 9837-415, 9835-425, and 9837-425 Deployment Guide*, GC27-8564
- ▶ IBM Offering Information page (announcement letters and sales manuals)
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