As your data assets grow, a carefully considered SAN design can help close the gap between the sheer quantity of storage data and the amount that is adequately protected.
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OVERVIEW

Although storage networking technologies are commonly available to the entire market, each enterprise or institution is unique. Customizing an implementation to meet your specific needs therefore requires an understanding of your organization’s primary business requirements. Business requirements drive the guiding principles of what a solution should provide, and those principles establish the parameters of the final design. Characteristically, the first step is the hardest, and the process of defining business requirements can result in highlighting conflicting needs. For example, the requirement to centralize storage assets to reduce costs and management overhead can conflict with the requirement to accommodate a rapid proliferation of remote retail sites. Fortunately, harmonizing these requirements is facilitated by the broad array of technologies offered by the storage networking industry. In this dynamic environment, Brocade® provides a wide spectrum of solutions and product cost options to fulfill diverse business needs.

Ideally, a data center Storage Area Network (SAN) design should be flexible enough to accommodate both current and anticipated future needs, typically looking out three years. Although business expansion is rarely linear, it is helpful to compare an organization’s current storage infrastructure to the one it had three years ago. For most companies, that historical reality check reveals a substantial increase in storage capacity, servers, tape backup loads, and complexity of the fabric. That growth may be due to natural business expansion or simply to the proliferation of compute resources to more parts of the organization. In either case, the steady growth of data assets increases the gap between the sheer quantity of storage data and the amount that is adequately protected. A carefully considered SAN design can help close this gap.

In addition, building a SAN infrastructure that accommodates growth in servers and storage capacity over time must take into account that power resources are not infinite. A properly architected SAN can increase the efficiency of power utilization in the data center to minimize power costs and reduce the carbon impact of IT services.

STORAGE-CENTRIC VS. NETWORK-CENTRIC SAN ARCHITECTURES

SAN architecture is characterized by the relationship between servers and storage that is enabled by the configuration of directors and switches that compose the fabric.

- A storage-centric SAN architecture places storage assets at the core of the SAN design, with all fabric connectivity devoted to facilitating access to storage Logical Unit Numbers (LUNs) by any attached server.

- A network-centric SAN architecture, by contrast, borrows from conventional Local Area Network (LAN) networking and promotes any-to-any peer connectivity.

The impact of each approach becomes clear in considering practical examples of SAN designs in flat, mesh, and core-edge variations.
Flat SAN Topologies

The flat SAN topology has been a popular starting point for SAN design, because it simplifies connectivity and can accommodate redundant pathing configurations for high availability. As illustrated in Figure 1, initiators (servers) and targets (storage arrays) are directly connected to fabric switches or directors, and there is no need for Inter-Switch Links (ISLs) for data paths.

![Figure 1. A simplified, flat SAN architecture with no ISLs](image)

This is a storage-centric design, in which storage connectivity is centralized to the fabric and servers (with proper zoning) can attach to any storage LUN. With redundant A and B pathing, storage transactions can survive the loss of any single HBA, link, switch port, switch element, or storage port. Because each switch element provides independent paths to each storage array, there is no need for ISLs to reroute traffic between switches.

Depending on the traffic load generated by each server, the fan-in ratio of servers to storage ports (also known as over-subscription) can be increased. Typically, for 1 Gbit/sec links, a fan-in ratio of 7:1 can be used, although that ratio can be increased to 12:1 at 2 Gbit/sec and 18:1 or higher at 4 Gbit/sec. In the example in Figure 1, the over-subscription would occur within the director or switch, with many more ports devoted to server attachment and fewer ports for storage connections. If the server fan-in ratio cannot accommodate the collective traffic load of each server group, however, congestion will occur at the switch storage port and lead to a loss of performance and transaction stability.
In practice, the flat SAN topology can be expanded by adding more switch elements, as shown in Figure 2.

**Figure 2.** Expanding a flat SAN architecture via addition of switch elements

Although this design is entirely adequate for moderate-size SANs, it becomes difficult to scale beyond 1000 ports. Three 256-port directors on each of the A and B sides, for example, would provide 768 ports for direct server and storage connections. Adding a fourth or fifth director to each side would increase costs, complicate the cable plant, and increase the complexity of the SAN and its management.

In addition, the flat SAN topology is perhaps too egalitarian in applying an equal cost to all server connectivity—regardless of the traffic requirements of different applications. Particularly for flat SANs based on Fibre Channel directors, high-usage servers may benefit from dedicated 4 Gbit/sec connections but the reality is that bandwidth and director real estate are squandered on low usage servers. Likewise, a flat SAN topology cannot accommodate variations in cost and performance attributes of different classes of storage devices, and so offers the same connectivity cost to high-end arrays and lower-cost JBODs alike. Consequently, even medium-sized SANs with varying server requirements and classes of storage are better served by a more hierarchical core-edge SAN design.
**Mesh SAN Topologies**

In conventional LAN and WAN networks, the network is composed of multiple switches and routers wired in a mesh topology. With multiple links connecting groups of switches and routers and routing protocols to determine optimum paths through the network, the network can withstand an outage of an individual link or switch and still deliver data from source to destination. This network-centric approach assumes that all connected end devices are peers and the role of the network is simply to provide any-to-any connectivity between peer devices.

![Mesh SAN Topology Diagram](image)

**Figure 3.** A mesh SAN topology with redundant pathing

In a SAN environment, a mesh topology provides any-to-any connectivity by using ISLs between each switch and director in the fabric, as shown in Figure 3. As more device ports are required, additional switches and their requisite ISLs are connected. Because each switch has a route to every other switch, the mesh configuration offers multiple data paths in the event of congestion or failure of a link, port or switch. The trade-off for achieving high availability in the fabric, however, is the consumption of switch ports for ISLs instead of end devices, and increased complexity of the fabric cable plant.

Mesh topologies are inherently difficult to scale and manage as the number of linked switches increases. A mesh topology with 8 switches, for example, would require 28 ISLs (56 if 2 links per ISL are used). As the switch count goes higher, a disproportionate number of ports must be devoted to building a more complex and expensive fabric. Consequently, as a best practice recommendation, mesh topologies for SANs should be limited to 4 switches.

A more fundamental problem with mesh topologies, though, is the assumption that storage networks need any-to-any connectivity between peers. Although this model may be valid for messaging networks, it does not map directly to storage relationships. SAN end devices can be divided into active participants (initiators) and passive participants (targets). Initiators do not typically communicate with one another as peers across the SAN, but with storage targets in an active/passive relationship. Storage arrays, for example, do not initiate sessions with servers, but passively wait for servers to
instigate transactions with them. So the placement of storage targets on the SAN should be to optimize accessibility of targets by initiators and not to provide any-to-any connectivity. This goal is more readily achieved with a core-edge design.

Core-Edge SAN Topologies

Core-edge SAN topologies enable a storage-centric, scalable infrastructure that avoids the complexities of mesh topologies and limited capacity of flat SAN designs. The core of the fabric is typically provided by one or more director-class switches, which provide centralized connectivity to storage. The edge of the fabric consists of fabric switches or directors with ISL connections to the core.

As shown in Figure 4, the heavy lifting of storage transactions is supported by the core director, while the edge switches provide fan-in for multiple servers to core resources. This design allows for connectivity of different classes of servers on paths that best meet the bandwidth requirements of different applications. Transaction-intensive servers, for example, can be connected as core hosts with dedicated 4 Gbit/sec links to the core director. Standard production servers can share bandwidth through edge switches via ISLs to the core, and second-tier servers can be aggregated through lower-cost edge switches or iSCSI gateways to the core.

Storage placement in a core-edge topology is a balance between manageability and application requirements. Placing all storage assets on the core, for example, simplifies management and assignment of LUNs to diverse application servers. Some departmental applications, however, would be better serviced by grouping servers and local storage on the same switch while still maintaining access to core assets. A design department, for example, may have sufficient data volume and high-performance requirements to justify local storage for departmental needs as well as a requirement to access centralized storage resources.

Figure 4. A core-edge SAN topology with classes of storage and servers
As shown in Figure 5, a three-tier core-edge design inserts a distribution layer between the core and edge. In this example, the core is used to connect departmental or application-centric distribution switch elements via high performance ISLs. Brocade, for example, offers 10 Gbit/sec ISLs as well as ISL Trunking to provide a very-high-performance backbone at the core. This tiered approach preserves the ability to assign storage LUNs to any server, while facilitating expansion of the fabric to support additional storage capacity and server connections.

**NOTE:** For simplicity, the figures shown above do not detail alternate or dual pathing between servers, switches and storage. The fabric illustrated in Figure 4, for example, could be the A side of a dual-path configuration.

**INTER-FABRIC ROUTING**

Fibre Channel is a link layer (Layer 2) protocol. When two or more FC switches are connected to form a fabric, the switches engage in a fabric-building process to ensure there are no duplicate addresses in the flat network space. The Fabric Shortest Path First (FSPF) protocol is used to define optimum paths between the fabric switches based on link speed, latency, or traffic load. In addition, the switches exchange Simple Name Server (SNS) data, so that targets on one switch can be identified by initiators attached to other switches. Zoning is used to enforce segregation of devices, so that only authorized initiators can access designated targets. Analogous to bridged Ethernet LANs, a fabric is a subnet with a single address space that grows in population as more switches and devices are added.

At some point, however, a single flat network may encounter problems with stability, performance and manageability if the network grows too large. When a fabric reaches an optimum size, it is typically time to begin building a separate fabric instead of pushing a single fabric to its limits. The concept of a manageable unit of SAN is a useful tool for determining the maximum number of switches and devices that will have predictable behavior and performance and can be reasonably maintained in a single fabric.

Enterprise data centers may have multiple large fabrics or SAN continents. Previously, it was not possible to provide connectivity between separate SANs without merging SANs into a single fabric via ISLs. With Inter-Fabric Routing (IFR), it is now possible to share assets between multiple manageable units of SANs without creating a very large fabric. As shown in Figure 6, IFR SAN routers provide both connectivity and fault isolation between separate SANs. In this example, a server on SAN A can access a storage array on SAN B via the SAN router. From the perspective of the server, the storage array is a local resource on SAN A. The SAN router performs Network Address Translation (NAT) to proxy the
appearance of the storage array and to conform to the address space of each SAN. Because each SAN is autonomous, fabric reconfigurations or RSCN broadcasts on one SAN will not impact the others.

**Figure 6. Using IFR to provide device connectivity between separate SANs**

Inter-Fabric Routing thus provides the ability to build very large data center storage infrastructures, while keeping each fabric within manageable bounds. For multi-vendor fabrics, IFR enables interoperability between different SANs, even when some fabrics are run in vendor proprietary mode. IFR can also be used to link test and production SANs, while ensuring the stability of the production environment.

In combination with Fibre Channel over IP (FCIP), IFR can be used to scale enterprise-wide storage transport across multiple geographies to further streamline storage operations. Routing between remote SANs provides connectivity for sharing storage data across the enterprise, with the added stability of fault isolation across WAN links. The Brocade FR4-18i Routing Blade and the Brocade 7500 SAN Router provide enterprise-class connectivity for non-disruptive resource sharing between autonomous SANs, with the ability to scale larger data center deployments using managed units of SAN.

**VIRTUAL FABRICS**

It is also possible to segregate departmental or business unit applications on a shared SAN infrastructure by dividing the physical SAN into multiple logical fabrics. Each Virtual Fabric appears to be a separate fabric entity with its own zoning database and RSCN broadcast domain, even if the Virtual Fabric spans multiple fabric switches.

Virtual Fabrics are a means to consolidate SAN assets while enforcing managed units of SAN. In the example shown in Figure 7, for example, each of the three Virtual Fabrics could be administered by a separate department with different storage, security, and bill-back policies. Although the total SAN configuration may be quite large, the division into separately managed Virtual Fabrics simplifies administration while leveraging the data center’s investment in SAN technology.
Virtual Fabrics are implemented using the Brocade Administrative Domain (AD) feature. An Administrative Domain includes a collection of ports and devices that are managed as a group by SAN administrators who can have varying levels of control. For example, an administrator could have full admin, zoning-only, or read-only rights for a particular Administrative Domain. Each AD has its own zoning database to ensure management and connectivity isolation between Virtual Fabrics. Administrative Domains are also useful when migrating from multi-switch fabrics to more centralized director-based SANs. Multiple small SANs running departmental applications, for example, can gain the advantages of high availability and centralized management provided by directors while segregating the departmental applications via ADs.

**ADDITIONAL SAN DESIGN CONSIDERATIONS**

Whether you are implementing a SAN for the first time or are expanding an existing SAN infrastructure, the one unavoidable constant in data storage is growth. The steady growth in storage capacity needs, in additional servers and applications, and in data protection requirements is so predictable that anticipated growth must be an integral part of a corporate SAN design and investment.

**Designing for Growth**

A current requirement for 50 attached servers and 4 storage arrays, for example, could be satisfied with two 32-port switches (4 for redundant pathing) or two 256-port director chassis populated with two 32-port line cards each. Which solution is better depends on the projected growth in both storage capacity and server attachment, as well as availability needs. Unfortunately, some customers have inherited complex meshed SAN topologies due to the ad hoc acquisition of switches to satisfy growing port requirements. At some point, fabric consolidation may be required to simplify cabling and management and to provide stability for storage operations. Without the solid foundation of a well-designed and managed unit of SAN, higher-level data protection solutions are always at risk.
Designing for Function

A managed unit of SAN can also be characterized by its intended functionality, and functionality in turn can drive a specific SAN topology. A high-availability SAN, for example, requires redundancy in switch elements and pathing, as well as management tools to monitor and enforce continuous operation. A SAN designed for second-tier applications, by contrast, may not justify full redundancy and may be adequately supported on a more streamlined topology. In addition, a SAN designed specifically for tape backup has very different requirements compared to a production SAN. Tape is characterized by large block, bandwidth-intensive transactions, while production disk access is typically distinguished by small block, I/O-intensive transactions. Because tape operations consume bandwidth for extended periods of time and are sensitive to fabric events, customers may implement two separate SANs or leverage Virtual Fabrics to isolate production disk access from backup operations. If you need a separate tape SAN, a flat SAN topology that avoids potential ISL oversubscription is recommended.

Streamlining Server Attachment

An optimized SAN topology can also be affected by the server technology used to host applications. Blade servers and blade SAN switches, in particular, can adversely impact the consumption of Domain IDs and limit the total number of switches allowable in a SAN unit. A new standard for N_Prot ID Virtualization (NPIV) has been created to address this problem. An NPIV-enabled gateway presents logical hosts to the SAN and so eliminates the addition of another switch element, Domain ID assignment, switch interoperability issues, and switch management. The Brocade Access Gateway feature, for example, leverages NPIV to bring blade servers into the SAN without requiring administrative overhead to monitor Domain ID usage and without limiting potential interoperability conflicts. Attaching through NPIV-enabled edge switches or directors, the 4 Gbit/sec Fabric OS® blade switches and the Brocade 200E Switch in Access Gateway mode can seamlessly connect servers to Brocade, M-EOS, Cisco, or other SAN fabrics with NPIV capability.

Designing for Manageability

Monitoring SAN health on a day-to-day basis it key to identifying and proactively dealing with potential issues. Brocade’s Advanced Performance Monitoring, for example, provides continuous status on traffic loads and can readily show the impact of fabric changes as new servers or storage assets are introduced. Likewise, the Brocade SAN Health analysis utility automatically inventories fabric components, captures historical performance data, and generates detailed reports for the entire SAN environment. These tools facilitate fine-tuning the SAN design over time to ensure optimum operation and asset utilization.

Designing for Energy Efficiency

Energy efficiency is another key SAN design element. The Brocade 48000 Director, for example, consumes one half to one third less power than a comparably configured competitor’s director. Because every SAN component contributes to the overall carbon footprint in the data center, selecting energy efficient directors has a cumulative benefit as the SAN infrastructure grows over time and the cost of power increases.

Designing for Security

Security is a key element for SAN design to ensure stability of the storage transport and to protect data assets. Brocade Fabric OS provides comprehensive security and policy administration to protect customer data from unauthorized access, inadvertent disruption of the fabric, and data corruption. Given the increasing pressure of regulatory compliance, Fabric OS helps customers customize SAN security to meet their own specific policies and requirements.
BROCADE SAN DESIGN PRINCIPLES

With the largest installed base of directors and switches and years of experience helping customers design and implement SANs, Brocade has evolved a comprehensive set of best practices to guide data center SAN design. These best practices begin with an understanding of the key customer business requirements, which in turn define the guiding principles that should be followed to create the best possible SAN design tailored to an individual customer.

The most common parameters for data center SAN designs include:

- **Availability**—Storage data must always be accessible to applications
- **Performance**—Acceptable, predictable, and consistent I/O response time
- **Efficiency**—No waste of resources (ports, bandwidth, storage, power)
- **Flexibility**—Optimize data paths to utilize capacity efficiently
- **Scalability**—Grow connectivity and capacity as required over time
- **Serviceability**— Expedite troubleshooting and problem resolution
- **Reliability**—Design redundancy and stability of operations into the SAN
- **Manageability**—Streamline transport and storage administration
- **Cost**—Design within budget and account for ongoing operational expenses

In practice, how these basic parameters are accommodated may vary from one customer to the next and from one functional SAN deployment to another. A carefully considered SAN design incorporates each of these elements, and following Brocade SAN design principles will help you harmonize disparate requirements. In addition, even large, complex data center SANs benefit from a fresh perspective. Analyzing an existing infrastructure in terms of these basic requirements can reveal gaps or weaknesses that can be resolved with a new SAN design—while still repurposing existing infrastructure components.

**Principle #1: Minimize the Number of Fabrics to be Managed**

This includes both physical fabrics and virtual fabrics, because each virtual fabric represents a management responsibility. It is a simple fact that fewer fabrics are easier to manage. In some cases, however, additional fabrics are required for functional, security, or physical constraint challenges. By defining managed units of SAN and providing resource sharing via SAN routing, it is possible to reduce the number of fabrics required while avoiding resource isolation.
Principle #2: Minimize the Number of Switches per Fabric

Using larger switch elements such as directors simplifies management and minimizes potential fabric disruption. With 8 to 12 domains in a single fabric, less inter-switch coordination is required during fabric events and thus more stability for ongoing storage transactions. The Brocade Access Gateway feature in Fabric OS, for example, dramatically reduces the number of Domain IDs to manage and streamlines server connectivity to the SAN.

Principle #3: Limit Fabric Size

Limit the fabric size to about 1,000 to about 2,000 node connections. Although some production data center SANs can support 4,000 or more usable ports, these exceptional cases are not the rule. Limiting the number of node connections helps minimize per-fabric risk. In addition, going beyond 2,000 nodes complicates management of zones, zone sets, and port aliases and risks exceeding the practical upper limits of management software tools. If additional ports are required, deploy additional managed units of SAN and link SAN-to-SAN resources through SAN routing.

Principle #4: Use Switches with a High Level of RAS

Even with redundant fabrics for failover, you do not want paths to be lost. High Reliability, Availability, and Serviceability (RAS) elements are the cornerstone of a high-availability storage environment. Shared storage ports should always connect to switches or directors with high RAS capability. Brocade engineers high RAS into both switches and directors, so that even core/edge SAN designs can benefit from the highest RAS experience.

Principle #5: Avoid Over-subscription that Causes Congestion or Degraded Performance

Over-subscription of server connections to storage ports is acceptable when workloads are well-understood but any oversubscription should be designed conservatively. The over-subscription ratio should be consistent along all relevant data paths through the fabric. If storage ports, for example, are oversubscribed at 7:1, then nothing between the hosts and the storage should be subscribed at a higher level. Trunking ISLs between switches or between switches and directors should thus accommodate the collective workload offered by the server sets. Brocade’s unique ISL Trunking enables multiple ISLs to be treated as a single link with high performance aggregate throughput, and trunk sets can be further combined to accommodate high volume switch-to-switch traffic. In addition, because different applications offer different workloads, hosts should be classified into multiple categories of connectivity to isolate high bandwidth servers with lower subscription ratios from moderate- or low-bandwidth servers with higher subscription ratios.

Principle #6: Use the Core-Edge Model for Large Environments

A core-edge design model enables much larger fabrics to be built and can be aggregated with SAN routing to provide resource sharing for up to 4,000 ports. With two-tier device attachment, a core-edge SAN design offers a stable location for all storage ports, and prevents high bandwidth servers from consuming ISL bandwidth. Compared to mesh designs, a core-edge strategy helps simplify day-to-day management tasks and facilitates troubleshooting fabric issues.
**Principle #7: Design for Storage Traffic**

In SAN environments, transaction response time is measured in milliseconds, not hundreds of milliseconds as is common in LAN infrastructures. Because SAN traffic cannot tolerate unpredictable delivery or outages, a solid SAN design must provide reliable and consistent I/O response. Switch elements in the data path should be at least one order of magnitude faster than the fastest disk response time. In addition, latency through the fabric increases with each ISL and additional hop between initiator and target. To prevent the aggregate fabric latency from reaching the same magnitude as disk access times, high-performance switching with cut-through routing of frames is required. Brocade switches and directors are optimized to minimize switch latency and to provide localized switching within port groups to expedite delivery. For critical applications, localizing traffic to the switch, blade, or port group by co-locating servers and storage can maximize throughput while still providing access to other resources throughout the fabric.

**Principle #8: Keep It Simple**

By designing managed units of SAN, administration is simplified, the opportunity for mistakes is reduced, and availability is therefore increased. A carefully conceived and executed SAN design facilitates the addition of new servers and storage targets over time, without having to decipher complex fabric paths. Large data center storage networks designed around multiple managed units of SAN and SAN routing are far easier to scale, and enable administrators to accommodate their growing business requirements within a stable and consistent SAN design strategy.

**SUMMARY**

SANs are the most critical networks for every large institution and enterprise worldwide today. Without SANs, there is no storage access and no application support, and, business functions cannot be fulfilled. Without business functions, there is no productivity; without productivity, there is no enterprise. Designing SANs to meet key business requirements is therefore a strategic component for maintaining the viability of the enterprise itself. By using Brocade SAN design principles and products, customers can build manageable storage infrastructures that satisfy their current and their future business requirements—while keeping deployment costs under control.