An Overview of Storage Area Networking Technology
SANs versus channel technologies, SAN components, Fibre Channel, SAN alternatives, SAN solutions to industry problems and SAN management using eHealth

- Introduction to Storage Area Networking Technology

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# Table of Contents

I. Executive Summary ......................................................................................................................... 2  
II. Introduction .................................................................................................................................... 2  
III. SAN Components .......................................................................................................................... 4  
IV. Fibre Channel .................................................................................................................................. 4  
V. Fibre Channel Standards .................................................................................................................... 7  
VI. Alternatives to SANs ......................................................................................................................... 8  
VII. SAN Case Studies .......................................................................................................................... 8  
VIII. SAN Management with eHealth .................................................................................................... 10  
IX. References ......................................................................................................................................... 14  
X. Glossary............................................................................................................................................... 14

## I. Executive Summary

This document presents an overview of Storage Area Network (SAN) technology. Storage Area Networks are increasingly replacing channel-attached media for access to stored data. The document defines SANs; discusses their advantages over traditional channel-attached technologies; identifies and describes the components of a SAN; describes Fibre Channel, the premier SAN technology; discusses alternatives to SANs; explains how SANs can be used to solve industry problems; and shows how SANs can be managed with eHealth.

## II. Introduction

Storage Area Networks are LAN-like networks designed to facilitate communication between servers and storage media. SANs decouple servers from storage media, replacing traditional server-to-peripheral device channel communication with a high speed network alternative, and thereby removing a number of restrictions and limitations on communication between servers and storage devices. Figure 1 shows a SAN layout.

Prior to the advent of SANs, the dominant mode of communication between servers and storage was via peripheral channel technologies. Dominant among these were the Small Computer Systems Interface (SCSI, pronounced “scuzzy”) standards. Dating back to 1986, SCSI represents a method for transporting data a limited distance over a parallel I/O bus. Over the years, the standard experienced several upgrades with such names as SCSI-1, SCSI-2, Ultra SCSI and
Ultra2 SCSI, progressively increasing the number of peripheral devices that could be addressed, the supported data rates, and the allowable distances. However, SCSI remains a channel-oriented technology that treats storage media as peripheral devices.

By inserting a specialized high speed network between servers and storage, SANs offer a number of advantages over SCSI and other server-to-peripheral device mechanisms, including:

- sharing of storage media such as disks, tapes and RAID arrays among multiple servers
- partitioning of traffic between conventional LAN and WAN media, and SAN media, permitting a more precise matching of communication medium to traffic requirements
- removal of distance limitations between servers and storage
- direct and secure backup/recovery of stored information
- the ability to add storage capacity without having a significant impact on system performance or availability
- improved information availability in the event of server failure
- scalability of storage independently of any associated servers, permitting storage upgrades without server upgrades

Figure 1. Storage Area Network
III. SAN Components

The dominant Storage Area Networking medium is Fibre Channel, a LAN-like technology specifically designed for use in SANs, and which we discuss in more detail in the next section. SANs contain a variety of devices which communicate with each other using Fibre Channel, as illustrated in Figure 2. We divide SAN devices into three broad categories:

(1) SAN servers, which are effectively gateways between the traditional LAN/WAN world and the SAN domain

(2) SAN communication devices, which resemble their counterparts in LAN/WAN configurations and include SAN switches or fabrics, SAN hubs, and associated SAN interfaces.

(3) SAN storage devices, which include RAID arrays, tape libraries, CD-ROM libraries, and JBODs (just a bunch of disks). These devices usually evolved in one of two ways: from traditional storage devices which were upgraded to communicate over a SAN, or from multi-purpose servers which were simplified and specialized to support only storage.

IV. Fibre Channel

*Fibre Channel Technology*

Fundamental to storage area networking is the use of network technology for communication between servers and storage devices, a task historically handled by peripheral device channels.
To satisfy the requirements of storage area networking, Fibre Channel technology was designed to be a transport medium somewhere between a channel and a network. Channels are dedicated point-to-point connections specifically designed to transport data between a server and locally attached storage. Networks, on the other hand, are more complex communication media with a multitude of functions. Fibre channel combines the desirable features of both.

Its channel-like features include

- dedicated point-to-point rather than shared connections
- implementation primarily in hardware
- communication with a limited number of device addresses, every one of which is known to the server operating system, and
- decoupling of data encoding from the physical medium.

Among its network characteristics are

- bi-directional communication of up to 100 megabytes/sec in each direction simultaneously
- implementation of control in a networking protocol, obviating the need for a channel control bus
- a layered architecture, corresponding to OSI layers 1 and 2, with support for higher level protocols, including ATM, FDDI, SCSI, IP, IEEE 802.2, and
- the ability to connect to other networking technologies via switches and routers.

Fibre Channel SANs are not restricted to a single medium; they support copper wire, coaxial cable, and multi-mode and single-mode optical fiber.

Fibre Channel networks can be configured in three basic topologies, illustrated in Figure 3:

- Point-to-point: bi-directional links, interconnecting two stations, which might be used, for example, to connect a server directly to a dedicated storage device
- Arbitrated loop: a loop topology, with up to 126 devices, used to connect devices within a localized area
- Fabric: a more general switching topology, providing connectivity among devices, involving a switch or a configuration of switches

The Fibre Channel protocol stack consists of five layers which correspond collectively to OSI layers 1 and 2, as shown in Figure 4:

- FC-0 is the physical layer, providing the electrical and optical parameters that define the digital signals and supporting data rates of 100, 200, 400 and 800 megabits/second.
- FC-1 provides encoding and decoding, coding 8 bits at a time into a 10-bit transmission character, with two extra bits for error detection and correction.
• FC-2 provides framing and signaling. This layer constructs frames, similar to Ethernet frames, usually ranging in size from 36 bytes to 2000 bytes; provides flow control and error correction; supports connections between Fibre Channel ports, and supports four different service classes.

• FC-3 offers advanced features, including striping, the use of multiple ports in parallel to transmit data; hunt groups that permit multiple reports to respond to the same address; and multicast delivery.

• FC-4 represents the higher level protocols that can use the underlying services of Fibre Channel, including SCSI, IP, and IEEE 802.2.

As SANs grow in size and complexity, Fibre Channel fabric switches are becoming increasingly important as they offer flexible connectivity and scalability. Fabric switches provide Fibre Channel connectivity to servers, storage devices or other fabric switches and can be configured in a variety of topologies, including mesh and star. They come in different sizes, depending upon the size and purpose of the SAN. The Brocade Silkworm 3800, for example, is an Enterprise class fabric switch and supports 16 ports and up to 2 Gbps per port. The Brocade Silkworm 12000, on the other hand, is a high-end Director class switch, suitable for a network core, supporting 64 or 128 ports and offering support for IP as well as Fibre Channel.

**Figure 3. Fibre Channel Topologies**

**Fibre Channel Fabric Switches**

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The ANSI working group X3T11 was formed in 1988 to develop a transport technology appropriate for communication between servers and storage devices. This group is responsible for the Fibre Channel standards.

IBM, Hewlett-Packard and Sun formed the Fibre Channel Systems Initiative in 1991 to develop profiles, or refinements of the ANSI standards, to ensure interoperability.

Several other industry organizations have been active in defining Fibre Channel standards, among them the Fibre Channel Industry Association (FCIA), an international organization of vendors, manufacturers, users and others committed to developing Fibre Channel in support of a wide range of applications, and the Storage Networking Industry Association (SNIA), a nonprofit organization dedicated to “delivering architectures, education, and services that will propel storage networking solutions into the broader market.” [9] This latter organization has been particularly influential in network management and is responsible for two of the most widely used SNMP MIBs in the Fibre Channel arena: the Fabric element MIB (RFC 2837) and the Fibre Channel Management Framework Integration MIB or FibreAlliance MIB.

### V. Fibre Channel Standards

<table>
<thead>
<tr>
<th>Fibre Channel Layer</th>
<th>Layer Functions</th>
<th>Equivalent OSI Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC-0</td>
<td>electrical parameters</td>
<td>1</td>
</tr>
<tr>
<td>FC-1</td>
<td>transmission encode/decode</td>
<td>2</td>
</tr>
<tr>
<td>FC-2</td>
<td>framing and signaling</td>
<td>2</td>
</tr>
<tr>
<td>FC-3</td>
<td>advanced features</td>
<td>3</td>
</tr>
<tr>
<td>FC-4</td>
<td>protocol mapping</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 4. Fibre Channel Layered Architecture
VI. Alternatives to SANs

Fibre Channel-based Storage Area Networks are not the only approach to solving some of the problems of server-to-peripheral-device storage. Two competing approaches have garnered some support in recent years.

Network Attached Storage

Network Attached Storage (NAS) is file-based storage that transfers files across an IP network, generally using the Network File Transfer (NFT) protocol. NAS utilizes the all-purpose Internet Protocol over whatever layer 2 technologies are available, with no special features designed to facilitate storage traffic. NAS is, in some fashion, intermediate between server-to-peripheral device channel communication and SAN communication, offering the advantages of transporting storage data over a network, but lacking those of a technology explicitly designed for storage traffic.

While SANs are designed to transfer data at the disk block level in a manner largely transparent to the application, NASs access data at the file level, typically using smaller network packet sizes and consequently requiring more processing to disassemble/assemble the data. They are most useful in file-sharing environments where multiple clients are involved and the amount of data actually transferred is relatively small.

Internet SCSI or iSCSI

Internet SCSI or iSCSI is the transport of SCSI over TCP/IP, often over gigabit Ethernet. It features transparency to applications designed to access peripheral devices via SCSI and has many of the advantages of a NAS, including use of familiar technologies and lower installation costs than implementation of a SAN.

iSCSI can be used in conjunction with SANs in a data center environment. iSCSI is used to transport the storage data to and from the data center via IP, and Fibre Channel is used to transport data within the data center to and from the actual storage devices. [4]

VII. SAN Case Studies

The following case studies illustrate some of the storage problems that can be solved with Fibre Channel technology.

SCSI Replacement

In a very common scenario [5] an IT manager might be responsible for a number of servers, each accessing its own set of peripheral disks over a SCSI bus. With the perennial demand for more disk space and faster disk access, the IT manager is faced with several problems:
• SCSI throughput is some tens of megabytes per second, whereas system requirements may easily be in the hundreds.

• SCSI can support a limited number of devices on same bus, and this translates into a limitation on the number of storage devices that a server can support. For more storage, an additional server might be needed.

• The distance limits on SCSI are a few or perhaps tens of meters, making it difficult to move the storage out of the same room as the server, let alone out of the building and into a dedicated storage facility.

• Storage directly attached to a server presents availability problems: if the server fails, the storage is inaccessible.

The solution is to tie all the servers and all the storage together with Fibre Channel and an associated SAN switch, effectively replacing the SCSI buses with a SAN, and providing

• throughputs up to hundreds of megabytes per second

• decoupling of storage from an individual server, removing the scalability limitation and permitting sharing of storage resources among multiple servers

• distances of the order of tens of kilometers

• enhanced storage availability because the failure of a server now has no impact on the ability of other servers to access storage

Avoiding Costly and Unnecessary Data Transfer

An animation design studio offers an interesting example of the advantages of Storage Area Networks. [6] Animation design requires large amounts of memory and storage. In this scenario, a number of artists with extremely aggressive deadlines worked at individual workstations and each workstation had a large amount of dedicated storage. Problems arose if an artist was required to move from one workstation to another, as the time required merely to move the data was extremely prohibitive. The data volume was huge and the Ethernet connection used to transport it was just not sufficient. Indeed, it took longer to copy over the data than to complete the entire project. The solution here was to share storage by installing RAID arrays and connecting all workstations and all storage to the same SAN switch, making access to storage independent of workstation.

Expertise and Security

Sometimes Fibre Channel works best in conjunction with other storage transport technologies. Storage Service Providers (SSPs) are in the business of managing SAN-based storage for their customers. This is often a cost-effective solution for the customers for a variety of reasons, among them the availability of SAN expertise on the part of the SSPs and the sharing of storage and networking resources among multiple customers.
The SSPs tend to use a physically separate storage networking infrastructure for each customer to ensure security. This requires extending the SSP SAN onto each customer site, presenting at least two problems:

- The customers are required to support Fibre Channel technology with which they may not be familiar.
- Direct customer access to the SAN tends to compromise the very security they are trying to safeguard.

The solution here is to use a router with both IP and Fibre Channel interfaces, such as the Cisco SN 5420 Storage Router. Multiple customers can communicate with their storage via the same router by using iSCSI from the customer sites to the router and Fibre Channel from the router to the actual storage devices. In this way they avoid having any Fibre Channel at the customer site.

A comprehensive look at SANs requires several eHealth products:

- System Health for two purposes: (1) reporting on the SAN servers that effectively divide the traditional LAN/WAN network from the SAN and (2) reporting on the various SAN storage devices, many or most of which contain a subset of the allowable server elements. These different categories of systems would be grouped and reported on separately.
- Router/Switch Health for reporting on the SAN fabric switches and hubs.
- LAN/WAN Health to report on the various Fibre Channel interfaces. There is, in particular, an At-a-Glance report designed specifically for Fibre Channel interfaces, shown in Figure 5.
- Response Health to report on response time and availability associated with communication between a SAN server and a storage device over a SAN.
- Live Health with suitable profiles to report on live exceptions associated with SANs
- Fault management to report on traps based on the various server, storage, switch and interface MIBs.

In the case of SAN storage, we are interested in reporting on both logical and physical storage variables. Logical storage variables are those perceived by the user or application (such as response time, logical volume utilization) and are generally associated with a SAN server. Physical storage variables are associated with the physical devices upon which information is stored (such as controller utilization, physical volume utilization) and may be resident on a SAN server or on a remote storage device.

One problem that might arise in some cases is the lack of an IP path to the storage devices. The storage devices are generally at the far end of the SAN from the servers and may be reachable only via layer 2 Fibre Channel media. If IP is not being used within the SAN, there might not be
an IP path from eHealth to the storage devices and hence no SNMP connectivity. Some configurations make use of an “out-of-band” IP over Ethernet path to the storage devices for this purpose, but such an accommodation is not universal.

**Product Use**

SANs are commonly employed by both enterprises and storage service providers. Enterprises employ SANs for mission critical, high availability, data intensive applications. Storage service providers use SANs to offer storage services to their customers.

Personnel concerned with SAN management include:

- Systems personnel at an enterprise or SSP who will use the fault, live and historical aspects of eHealth to troubleshoot real-time and day-to-day problems with the SAN
- Storage service provider SLA managers (and their customers) who will ensure the SAN is performing as agreed in the customer contract
- Enterprise or SSP capacity planning personnel who will use eHealth to determine if the SAN configuration is performing effectively, or if an equipment upgrade is required.

The SAN features of eHealth are expected to solve at least four common SAN management problems:

*Timely detection of faults and performance degradation from SAN devices*

A SAN operator needs to know immediately if a hub, fabric or disk array is degrading in order to make appropriate repairs before users are seriously affected. Even though SANs are typically deployed with built-in redundancy, faults and degradations need to be acted upon quickly to ensure reliability.

eHealth Fault Management alarms on a variety of conditions, including excessive Fibre Channel device environment faults (temperature, voltage and fan anomalies), or excessive LIP 8 protocol messages, the latter signifying that Fibre Channel device is having difficulty joining the SAN.

Live Health can be used to detect and isolate performance degradation problems such as excessive errors on a fabric port. In conjunction with Response Health, Live Heath is able to detect degradation in the time required to access a RAID drive.

Consider the following before/after scenario. A service provider operations center gets a call from users who are complaining that response is slow. The operations personnel manage to isolate the problem to a group of servers with an attached SAN; however, they have no visibility into how the Fibre Channel devices are performing. They look at the RAID Element Manager displays and everything appears OK. They swap out host bus adaptors and this doesn’t help. Then one by one, they swap out the cables between the Fibre Channel fabric switch and the RAID arrays. They finally find that the cable is bad on switch port 10.
With Fibre Channel support in eHealth Fault Management, the operations personnel would have received a trap from port 10 that the status had changed and gone off line. The SAN technician would go immediately to that port and replace the cable saving time, money and user convenience.

**Forecasting the need for additional capacity or redeployment**

Capacity planners need to know if servers, hubs, fabric switches and/or storage devices need to be added or upgraded. The At-a-Glance and Trend reports associated with the aforementioned products offer the appropriate tools.

Consider another before/after scenario. Every weekday night at approximately 4:30 PM, the enterprise operations center receives complaints that response times are slow. The operators know that there is heavy I/O at that time on a particular RAID array and add additional disks to the array to rebalance the data. Unfortunately, this does not solve the problem. They are using a managed hub with 100 attached disk devices. They finally realize that they are at capacity and need to go to a fabric switch. The problem is that it takes 30 days to get one.

With eHealth support for Fibre Channel, the capacity planners would have seen an increasingly worrying trend developing in their At-a-Glance and Trend reports. Bandwidth utilization, errors, and discards were increasing, and transmit credits were reaching zero all too frequently on one or more interfaces on the managed hub. Suitably configured, Live Exceptions might have alerted them to these problems even before they looked at the reports. The observed behavior would have indicated a developing bottleneck getting data into and out of the loop well before the problem became critical. The solution, as indicated above, was to replace the hub with a fabric switch. The new switch could have been ordered in plenty of time.

**Routine monitoring of SAN performance**

The eHealth products described above report a number of performance metrics. The various usage and volume statistics supported by System Health, Router/Switch Health and Response Health are applicable in a SAN environment. In addition, Top N, Trend and At-a-Glance reports explicitly for Fibre Channel interfaces provide associated metrics on utilization, errors, discards and various SAN-specific variables at each port of the SAN hubs and fabric switches.

**SLA compliance**

Storage service providers must meet their contractual commitments to their customers on SAN performance. Both the service provider and the customer have an interest in monitoring SLA compliance, the former to avoid problems and the latter to ensure that the service performs as advertised. Key SLA metrics include availability and response of the SAN. eHealth addresses this problem with the SAN traps and alarms built into Fault Detector and Live Health. Indeed, Live Health thresholds can be configured explicitly based on the parameters of the SLA.
Figure 5. SAN Fibre Channel Interface At-a-Glance Report
IX. References


X. Glossary

*Arbitrated loop.* A Fibre Channel topology where the communicating devices are connected in a loop or ring. An arbitrated loop can contain up to 126 devices.

*Fabric.* A Fibre Channel topology providing general connectivity among devices and typically involving a switch or a configuration of switches.

*FC-0.* The Fibre Channel physical layer, providing the electrical and optical parameters that define the digital signals. It supports data rates of 100, 200, 400 and 800 megabits/second.
FC-1. The Fibre Channel layer that provides encoding and decoding, coding 8 bits at a time into a 10-bit transmission character, with two extra bits for error detection and correction.

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FC-3. The Fibre Channel layer that offers advanced features, including striping (use of multiple ports in parallel) to transmit data; hunt groups that permit multiple reports to respond to the same address; and multicast delivery.

FC-4. The Fibre Channel layer that contains the higher level protocols that can use the underlying services of Fibre Channel. These protocols include SCSI, IP, and IEEE 802.2.

Fibre Channel. The most widely used Storage Area Network communication technology. Fibre Channel was designed to combine the desirable features of peripheral device channels and high speed networks.

Internet SCSI (iSCSI). Transport of storage data using SCSI over IP, often over gigabit Ethernet. It has the advantages of NAS, with the additional feature of transparency to applications designed to access peripheral devices using SCSI.

Network Attached Storage (NAS). File-based storage that transfers files across an IP network, generally using the Network File Transfer protocol. NAS utilizes the all-purpose Internet Protocol with no special technology designed to facilitate storage traffic.

Point-to-point. A Fibre Channel topology consisting of a bi-directional link interconnecting two stations. This is the simplest Fibre Channel topology and might be used, for example, to connect a server directly to a storage device.

Small Computer Systems Interface (SCSI). The dominant technology for server communication with storage devices, prior to the advent of Storage Area Networks. Dating back to 1986, SCSI is a peripheral channel technology for transporting data a limited distance over a parallel I/O bus. Over the years, the SCSI standard experienced several upgrades with such names as SCSI-1, SCSI-2, Ultra SCSI and Ultra2 SCSI, progressively increasing the number of peripheral devices that could be addressed, the data rates, and the allowable distances.
Storage Area Network (SAN). A LAN-like network designed to facilitate communication between servers and associated storage. SANs decouple storage media from the servers, replacing traditional server-to-peripheral device channel communication with a specialized high speed network alternative, removing a number of restrictions on communication between servers and storage devices.