Surveying Today's Most Popular Storage Interfaces

Backed by strong industry support, SCSI, Fibre Channel, IEEE 1394, Serial ATA, and iSCSI provide the technologies to meet IT's diverse storage interface needs.

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Storage interfaces have been a necessary component of computer systems since computing's inception. At a basic level, a storage interface functions like any generic interface, defining the boundary between two dissimilar surfaces or systems. In a computer system, a storage interface defines both the boundaries between storage devices—such as hard drives, tape drives, or similar media—and how those dissimilar computing resources engage one another to work as a coherent system.

Today's storage interface arena consists of diverse industry standards combined with R&D investments from major industry players who continue to aid in the evolution of these numerous technologies. Although SCSI—the Small Computer System Interface—is probably the most pivotal standard in use today, other crucial storage protocols include Fibre Channel, IEEE 1394, Serial ATA, and iSCSI.

SCSI: An Enterprise Foundation

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Originating as a general-purpose interface standard, SCSI debuted with rich capabilities, including multi-initiator support, sophisticated error management, out-of-box connectivity, and support for a wide variety of peripherals. SCSI's immediate popularity with Apple Macintosh users spawned a market for various peripheral devices connected outside the desktop box.

Early developments

Although the standard's founders knew SCSI must evolve to enjoy continued success, the enterprise-class capabilities they envisioned had yet to be exploited. Instead, a rather small enterprise market, and various retail and database applications, focused on enterprise-oriented companies like NCR, which sought to help multi-initiator applications flourish.

Fueled by low-cost controller devices, a maturing software base, and clear market value, SCSI commanded a substantial presence in both the desktop and server markets. Using SCSI allowed adding drives with faster spindle speeds to workstations, adding optical drives and scanners to PCs, and using tape to maintain streaming capabilities in servers.

SCSI made systems simpler. Functional upgrades to the volume PC market made SCSI an attractive, profitable option that encouraged a steady stream of ongoing market investments—ranging from silicon suppliers to cable, connector, and terminator sources.

Enterprise adoption

SCSI's low-cost mission-critical capabilities made it a perfect choice for the vast majority of enterprise-class systems. Manufacturers who followed

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the standard focused on improving enterprise capabilities across their product lines, from standard high-volume servers to the most sophisticated such as Symmetrix.

Eliminating the cabling between devices within a storage enclosure provides a key example of adapting to the market's demands. By establishing backplane standards for "hot plugging" devices and instituting a move to low-voltage differential signaling schemes, SCSI greatly improved system performance while maintaining the connection lengths required between devices.

Even with such significant changes, SCSI's unique shared distributed bus structure let older devices coexist with the latest generation of SCSI peripherals. The creation of SCSI Expander components further supported the use of legacy peripheral devices and their accompanying software.

Broadening SCSI's market appeal

Although SCSI adequately addressed system connectivity needs at the drive-interface level, the market demanded greater connectivity between systems and storage subsystems—especially in larger systems. Managing large volumes of storage as a unified resource required connections that allowed for increased distances between boxes, higher degrees of scalability, and failover and load-balancing schemes to govern these connections.

Fibre Channel effectively met the new demands of mission-critical application environments by using the SCSI protocol's enterprise-proven logical-connection capabilities. Carrying the logical command descriptor block structure of SCSI forward proved a critical step in serving enterprise-class environments. In effect, Fibre Channel expanded SCSI's influence into storage area networks, making the logical SCSI interface essential to Fibre Channel's market position.

Fibre Channel's success proved SCSI's value and marked its place as an essential foundation for subsequent enterprise storage initiatives, including Storage over IP, iSCSI, and InfiniBand.

Ultra 320 SCSI and beyond

With the current generation of Ultra 320 SCSI components, controllers, and drives, systems can sustain performance levels in excess of 100,000 I/Os per second while working smoothly with customers' existing hardware. New generations of SCSI devices can consistently coexist with previous generations, thus preserving 20-plus years of enterprise-proven SCSI software.

With the proven capabilities of Ultra 320 SCSI and Ultra 640 SCSI's greater promise, parallel SCSI will likely remain an essential factor in enterprise systems and device connection schemes for years to come. However, as with any parallel connection scheme, moving these interfaces forward becomes measurably more difficult with each generation. Supporting smaller, power-efficient form factors at a drive data rate doubling every 2.2 years—while maintaining signal integrity for such high-availability systems—presents a substantial challenge.

Table 1. Serial Attached SCSI features and benefits.

Feature	Benefits
Leverages industry standards	Fast time to market Improved interoperability Performance roadmap to 6.0 Gbps
Allows coexistence with SATA disk drives	Flexible price-performance points Single backplane design
Point-to-point architecture supports more than 128 devices	Ease of scalability Flexible topologies
Thinner cables and fewer signals	Improved cable routing, airflow, and cooling
Smaller connectors	Meets requirement for dual-port enterprise 2.5-inch hard disk drives

Serial Attached SCSI

With an eye to the future, and mindful of their collective enterprise legacy, several leading companies have embraced a new storage initiative—Serial Attached SCSI. Table 1 lists Serial Attached SCSI's features and benefits. Standardization on this new interface has the potential to bring together the best of parallel SCSI, Fibre Channel, and the emerging Serial ATA.

Just as parallel SCSI embraced the challenges of hot plugging and improved signaling, Serial Attached SCSI is now responding to the challenges of tomorrow's mission-critical application environments, which include

- smaller form factors,
- greater addressability with support for higher spindle counts,
- greater flexibility for in-box and near-box cabling schemes,
- increased reliability with dual-porting capabilities, and
- unprecedented customer choice.

Complementing the SATA interface development's efforts, Serial Attached SCSI lets the customer choose among SATA drives competitively priced for a cost-driven volume market. These drives deliver a connection scheme that accepts high-performance, robust storage devices capable of serving the most demanding enterprise applications. By employing SATA physical signaling and mating schemes, embracing Fibre Channel's packet-based approach to switched SCSI connections, and preserving the

SCSI's serial point-to-point connection scheme lets users choose how best to develop their storage application environment.

logical SCSI protocol itself, Serial Attached SCSI promises new interface capabilities for the enterprise.

Serial Attached SCSI serves the enterprise by leveraging a common mating scheme, enclosure, and infrastructure. This flexible connection scheme presents opportunities for building products that could ship as soon as 2004.

SCSI's bright future

SCSI has fundamentally influenced the enterprise market's evolution. Every new storage initiative demonstrates its significance in the enterprise. Serial Attached SCSI propels this influence well into the future by maintaining compatibility with SCSI's rich and successful legacy. This protocol offers a serial point-to-point connection scheme that lets OEMs, system integrators, and customers choose how best to develop their storage application environment.

The industry's commitment to furthering SCSI's interface capabilities has made it a lasting foundation for the enterprise. The ANSI-accredited T10 Technical Committee (http://www.t10.org) is at work on this industry-standard development initiative. Meanwhile, the SCSI Trade Association, STA (http://www.scsita.org), holds the responsibility for the interface's business development.

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Fibre Channel Delivers

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The problems IT managers face—the explosion of storage needs, proliferation of rich-content media, and Internet use—are quickly making older, direct-attached storage technology obsolete. A new paradigm in storage has arisen in the past few years to replace DAS: storage area networks (SANs). Fibre Channel, the enabling technology behind this SAN revolution, has blazed a trail for new developments that benefit the storage space.

The SCSI protocol provides the basis for most enterprise-level DAS. SCSI ensures that systems store data efficiently and correctly, operating at the block level and making access for both reading and writing data extremely efficient. This approach differs from file-level access to data by requiring significant overhead and operating-system interaction.

SCSI's benefits come at a price, however: Only 15 devices can be attached to a SCSI controller, and the distance between controller and storage cannot exceed a few meters. These limitations make adding storage to a system both difficult and disruptive.

Fulfilling the needs of enterprise-level companies thus required a new protocol that would meet several key requirements:

- *Allow SCSI use.* Fibre Channel's developers designed it to operate as a SCSI protocol superset, but also to let other, higher-level protocols access the underlying transport layer, including TCP/IP over Fibre Channel.
- *Increase device count per controller.* Fibre Channel introduces an arbitrated loop, increasing the number of devices available per controller to 126. Fibre Channel's fabric capabilities increase the total number of devices addressable in a Fibre Channel SAN to more than 16 million.
- *Increase distance between devices.* Fibre Channel allows copper connections out to several meters, basic optical connections to 500 meters, and long-wave connections to 10 kilometers. Some implementations allow direct connections to distances of 80 kilometers. These distances allow direct data center connections via native fiber channels. Fibre Channel also includes the FCIP protocol, which allows long-haul connections worldwide. Islands of SANs can thus be connected anywhere across the globe.
- *Allow both fiber and copper connections.* From its inception, Fibre Channel's developers designed it to work with both copper and optics. This dual capability allows inexpensive copper connections for intracabinet, intrachassis, and very-short-haul distances, while optical connections permit longer-haul distances in an EMI-safe context. An urban legend maintains that Fibre's spelling actually reflects the

conjugation of the words "fiber" and "wire," rather than the European spelling of "fiber."

- *Provide nondisruptive scaling*. The need to expand a storage system or SAN without having to reconfigure or power down a system led to the requirement for hot-plugging devices. This requirement manifested itself in hot-pluggable hard drives, gigabit interface converters, small-form-factor pluggable devices, and easily connected cables for both copper and optical connections. A drive shelf allows adding or removing and replacing SAN drives by simply plugging or unplugging them.

Fibre Channel roadmap

The Fibre Channel Industry Association (http://www.fibrechannel.org) works in conjunction with the T11 standards body to determine market needs and establish a roadmap for Fibre Channel's continued development. The FCIA's roadmap covers Fibre Channel's target markets, speeds, and feeds.

The current speeds-and-feeds roadmap calls for 1.0625 Gbaud per second, 2.125 Gbaud per second and 12.75 Gbaud per second for SAN infrastructures, and 4.25 Gbaud per second for intrachassis Fibre Channel. Current Fibre Channel implementations routinely achieve a performance of 2.125 Gbaud per second, providing excellent price per bandwidth.

Fibre Channel has already made inroads into the midrange storage market and is making progress in the entry-level SAN marketplace. As it migrates from the high-end enterprise-class SAN solutions to entry-level SAN systems, the technology continues to provide superior reliability, performance, and scalability.

Fibre Channel optimizes SANs while providing reliable performance and scalability.

Path of least resistance

Fibre Channel has become the incumbent protocol for implementing SANs. Current economic conditions and a heightened sense of the need for comprehensive disaster recovery and backup plans have led to a conservative approach that favors this technology.

The Fibre Channel protocol is relatively simple to learn. The real learning curve with SANs is understanding storage, which is protocol independent. This issue is important to the industry in general, especially now that an ever-growing number of trained, SAN-aware technicians are available to help create, install, and maintain SANs.

With years of experience, mature standards, and a comprehensive roadmap, Fibre Channel offers a solid alternative to SAN managers. Designed for high-reliability systems and the assurance of data protection and backup, Fibre Channel optimizes SANs while providing reliable performance and scalability.

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FireWire as a Mass-Storage Interface

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Based on work done largely at Apple Computer, in partnership with early adopters such as Sony and Texas Instruments, developers completed the IEEE 1394 Standard for a High Performance Serial Bus in 1995. Both Apple and the 1394 Trade Association refer to IEEE 1394 as FireWire (http://www.1394ta.org). Although the term has no official meaning, like Ethernet and Bluetooth it helps customers identify a technology whose official name consists of an abstract number.

In 1995, digital video camcorders became the first major products to incorporate FireWire, followed by computers in 1997 and mass storage products early in 1999. Today, a wide variety of additional products use FireWire—including consumer products such as cameras, scanners, printers, televisions, game consoles, and many kinds of storage devices.

In 2000, the IEEE released the 1394a update. Although it adds no major features, this update allows significant performance improvement and clarifies many previous ambiguities. Most computer and storage products using FireWire now support this updated version.

FireWire's feature set

A 1394 bus can simultaneously support packet transfer at 100, 200, and 400 Mbps. A single bus can freely mix up to 63 devices supporting any or all of these speeds. The bus transports each packet at the best possible speed depending on the source and destination nodes, so adding a digital video camera capable of only a 100-Mbps rate need not force

FireWire provides an easy and quick way to add, upgrade, and share computer storage devices.

computers and storage devices to slow down from the 400-Mbps rate they commonly support. Packets directed to or from the DV camera itself will require the slower rate.

FireWire devices can be connected or disconnected from the bus at any time. Self-describing and self-configuring, these devices free users from having to adjust ID selectors or assign drivers to devices individually. Electrically, a network of point-to-point serial links appears as a bus above the physical layer. Like a bus, all packets are visible to all nodes, with the exception that higher-speed packets cannot be sent to or through lower-speed devices.

FireWire provides up to 45 watts of electrical power for operating devices on the bus. This feature, absent from other common storage buses, ensures that devices with modest power requirements do not require an extra power connection. For example, Apple's iPod MP3 player uses FireWire as its only data and power connection. The player can recharge its built-in battery at the same time it downloads new music from a computer.

FireWire uses isochronous transport to provide real-time data delivery, reserving up to 80 percent of the bus bandwidth for one or more isochronous channels. The hardware then provides guaranteed transmit opportunities at defined intervals to ensure timely data transfer. DV cameras, among other devices, use the isochronous service, which is particularly efficient because it makes unused reserved bandwidth immediately available for asynchronous devices, such as storage devices.

A memory model defines FireWire's asynchronous transport. Asynchronous requests indicate a desire to read or write data at a 64-bit address on the bus. The high 16 bits of this address select a node—and, in the future, a bus—while the remaining 48 bits select a memory address within that node. Writes can be completed with an immediate acknowledgment that yields a unified transaction. A write that cannot obtain immediate confirmation can be completed as a split transaction. Although reads always use a split transaction, they can send the response packet immediately—without arbitration—if they can provide the requested data very quickly.

Memory-mapped I/O and DMA

In FireWire's open host controller interface specification, asynchronous packets addressed to the lower portion of a host node's 48-bit address space can directly address host memory. OHCI can service read and write requests by direct memory access to the specified memory address, without assistance from the local CPU or any interrupts. A packet sent to an address outside this physical-memory range in the computer can cause an interrupt, which host software interprets. With this architecture, each storage device added to a FireWire bus acts as an additional DMA controller and can move payload data to or from host memory at its own pace.

FireWire uses the serial bus protocol, version 2, to define this operation. SBP-2 specifies how the host can write storage commands in its own memory, then signal a storage device to read and execute those commands. SBP-2 provides options for the host to append additional commands during execution. It also lets the device optimally reorder the execution of commands, assuming the host allows it.

Once the device has completed a command, it can inform the host by sending a packet to a host address to cause an interrupt. The host then knows that data has been transferred to or from its memory and that the command structure it prepared is available for reuse. FireWire can execute the transfer of many megabytes with only a single host interrupt to signal completion.

Storage products using FireWire

FireWire hard disk drives are used as ordinary add-on storage. Drives powered solely by FireWire are also used as lightweight, high-capacity portable media. Several manufacturers offer FireWire CD and DVD drives for use with lightweight notebook computers that do not have an internal optical drive. FireWire DVD writing drives have recently increased in popularity because few computers have these drives built in. Drives for Zip, magneto-optical, tape, and other media can be ordered with FireWire interfaces.

In addition to providing an easy and quick way to add, upgrade, and share computer storage devices, FireWire also has been adopted for high-performance RAID applications. A single FireWire interface can deliver more than 40 Mbytes per second for RAID, while PCI cards can add more channels at a low cost. Further, FireWire has been used for high-end jukebox-type storage products that offer more than a terabyte of capacity.

FireWire is most powerful when it connects multiple devices. These devices may interoperate as peers to deliver greater capability as a system than each device offers by itself. Apple's Target Disk Mode demonstrates this potential: One computer emulates a FireWire disk drive that a second computer accesses. This role reversal by the first computer demonstrates FireWire's flexibility, but shows only a small part of FireWire's potential to enable further innovation.

FireWire is particularly useful for connecting multiple devices. Using peer-to-peer access, devices can cooperate to provide more services than they could alone or when connected to a central computer by a different interconnect.

To date, FireWire has been used only in limited applications, such as Apple's Target Disk Mode. More uses for the power it offers remain to be offered in future products.

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Serial ATA's point-to-point topology provides a direct path between the disk drive and the host.

Serial ATA

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A next-generation technology, the Serial Advanced Technology Attachment interface connects disk drives to the PC platform. SATA has its roots in the parallel ATA interface, which has been the most popular disk drive interface in terms of devices shipped. In 2001, more than 172 million disk drives shipped with the parallel ATA interface. Adding to this figure the volume of optical and removable storage devices and host interfaces with ATA suggests that an immense number of ATA ports are in use.

Parallel ATA's popularity stems in part from its relatively low cost and simplicity. However, it is a storage-centric bus with limited scope that addresses only two storage devices inside the box on an 18-inch cable, with a simple protocol and a single host.

Two factors are driving the transition from parallel ATA to SATA: signaling voltages and the number of signals the interface requires. Parallel ATA requires 33 signals on a host controller using an 80-conductor cable, as well as a 5-volt tolerance. Both of these requirements limit the future potential of parallel ATA because semiconductor technology advances have lowered operating voltages and die sizes.

Faced with the continued need to scale interface data rates to match disk drive data rates and the requirements of parallel ATA's physical plant, several companies formed a group to define the long-term, software-compatible replacement for parallel ATA. The Serial ATA Working Group introduced the first SATA specification, Serial ATA 1.0, in 2001 (http://www.serialata.org).

SATA's benefits

The Serial ATA Working Group seeks to develop a replacement for parallel ATA that maintains the characteristics that made parallel ATA popular: low cost, simplicity, and limited scope. SATA technology's acceptance and success in the desktop and mobile computing markets requires that it emulate these characteristics. Thus, key SATA features include the following:

- a 10-year technology roadmap that starts with data transfer rates of 150 Mbps, scales to 300 Mbps and, eventually, 600 Mbps;
- 100 percent device-driver compatibility between SATA and parallel ATA;
- 250-mVolt signaling levels;
- improved wireability, enabled by a seven-wire data interface with four data signals and a point-to-point star topology;
- blindmate connector with data and power bays, ideal for both cabled and backplane environments;
- hot-plug support;
- cable lengths that extend to 1 meter; and
- improved reliability with 32-bit cyclic redundancy checking for all transfers and improved signal integrity.

While addressing the needs of the desktop and mobile computing platforms, some enhancements that SATA defines—such as blindmate connector, point-to-point topology, and hot-plug support—make it attractive for other applications as well.

SATA applications

Device cost and cost per gigabyte drive the use of ATA-class disk drives in network storage applications. System integrators building cost-sensitive entry servers or devices that package the highest possible volumetric density have been turning to ATA-class disk drives. This trend is especially prevalent when performance, measured in I/Os per second, takes a back seat to cost and capacity.

Table 2. Potential Serial ATA roadmap.

Year	Event	Data transfer rate
2001	First-generation specification	150 Mbps
2002	First SATA products	
2003	Integrated SATA solutions	
2004	Second-generation specification	300 Mbps
2005-2006	Market continues to build and SATA feature set grows, enabling new applications	
2007	Third-generation specification	600 Mbps

SATA's point-to-point topology provides a direct path between the disk drive and the host, which lets engineers easily aggregate many disk drives in a single system. This topology offers additional benefits including

- dedicated bandwidth between a device and the host;
- the ability to more easily isolate device failures; and
- performance scalability based on the device data rate, not on speed-matching between devices.

As SATA matures, it will continue to replace parallel ATA disk drives, including applications outside traditional PC computing, such as personal video recorders, electronic gaming, and some network storage applications.

Making SATA a reality

The SATA 1.0 specification has already acquired more than 100 contributors, promoters, and adopters. Since 2001, many companies have produced SATA device samples and technology and product demonstrations. SATA is well on its way to becoming the most popular disk interface, replacing parallel ATA in a variety of applications. Table 2 shows SATA's anticipated future development path.

Work has already begun on Serial ATA II, whose goals include definition of 3-Gbps signaling (enabling 300-Mbps data-transfer rates), enhanced command queuing, and enhanced connectivity.

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iSCSI Protocol

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The Internet SCSI protocol has been developed to transport storage commands, status, and data over mainstream IP networks. Like Fibre Channel, iSCSI encapsulates SCSI command descriptor blocks in a serial stream. Serializing block I/O—storage area networking's enabling technology—allows the flexible deployment of shared storage resources such as servers, disk arrays, and tape subsystems. While Fibre Channel uses a dedicated gigabit network infrastructure separated from the corporate LAN, iSCSI uses mainstream Gigabit Ethernet switching that can be tightly integrated into the corporate LAN.

As Figure 1 shows, iSCSI carries SCSI data over TCP/IP. Routing packets across the network requires an IP layer, while the TCP layer ensures end-to-end session control and lost-packet recovery. With the widespread deployment of gigabit-switched-optical networks, bandwidth and congestion cause less concern.

Given minimal packet loss through the network, the upper-layer TCP recovery mechanism is rarely invoked. The TCP layer serves primarily as an insurance policy against infrequent network disruptions, its packet retransmission ensuring that while individual packets may be lost, data never will be.

The iSCSI protocol shares many features with Fibre Channel. Both use an underlying high-speed serial transport to carry SCSI read and write commands to storage targets. They both have a variable network address identity and a fixed unique worldwide name address. They both also rely on flow-control mechanisms to maintain stable conversations between pairs of communicating devices across the network.

An iSCSI SAN differs from a Fibre Channel SAN primarily in the plumbing that supports SCSI exchanges. Fibre Channel provides a layer 2 architecture, analogous to bridged LANs before the introduction of TCP/IP. iSCSI relies on a layer 3 architecture that includes network routing. Once SCSI commands, status, and data are put in an IP format, storage data can use conventional equipment to traverse any common IP network infra-

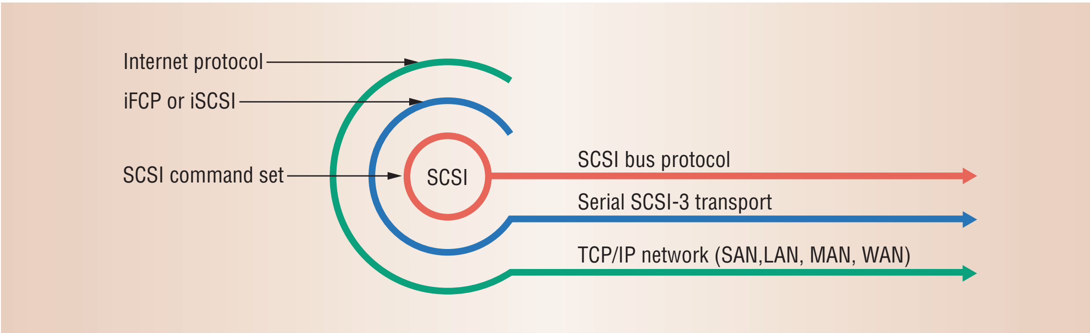

Figure 1. Internet SCSI protocol. iSCSI uses an IP layer to route SCSI data packets across the network, then uses the TCP layer to ensure end-to-end session control and lost-packet recovery.

structure—including Gigabit Ethernet, ATM, Sonet, or Frame Relay.

Figure 2 shows an iSCSI SAN that includes servers and storage systems with native IP interfaces to the network. The network itself can be composed of Gigabit Ethernet switches, IP routers, wide area links, and switched-optical network segments. However efficient the IP network may be, upper-layer storage applications can be sensitive to objective influences such as speed-of-light latency.

Streaming applications such as tape backup can typically tolerate more latency over distance than synchronous disk-mirroring applications that expect acknowledgment for every transaction. As with Fibre Channel SANs, basic network design should accommodate the iSCSI transactions' bandwidth requirements.

By integrating storage data into mainstream data communications infrastructures, iSCSI makes shared storage access ubiquitous. This creates new markets for SAN solutions and new engineering initiatives for iSCSI product development and SAN management.

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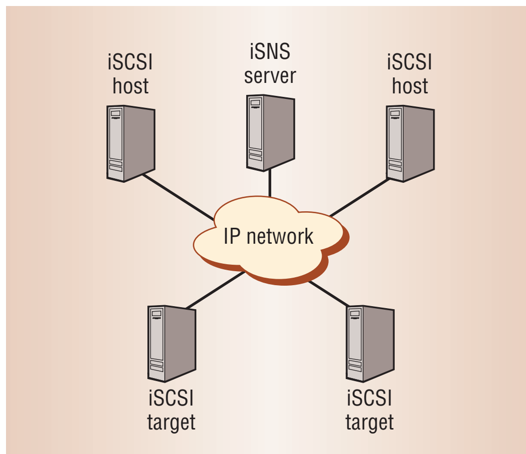

Figure 2. iSCSI storage area network. This pristine SAN includes servers and storage systems with native IP interfaces to the network.

Taken collectively, these new storage technologies offer customers a broad selection of solutions, from high-end, high-performance storage networks for enterprise applications to more flexible deployment of storage for workstation environments. Hybrid storage products may integrate different storage technologies to achieve greater economies and storage densities. Serial ATA, for example, can provide backend storage for RAID controllers whose network interfaces are Fibre Channel or iSCSI.

The convergence of storage architectures poses new challenges to developers who wish to optimize performance and interoperability without incurring additional design overhead. As compensation, the market for innovative storage solutions continues to expand and offers new opportunities for faster, higher-capacity, and lower-cost storage devices. ■

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