Gigabit Ethernet Over Copper

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Executive Summary

Network managers are turning to Gigabit Ethernet technology to relieve bottlenecks at server connections, switch stacks, and other points of aggregation from workgroups into the data center. Gigabit Ethernet has been standardized for fiber optic cable since 1998, but until recently was not standardized for Category 5 copper cable, the most widely used cabling medium within buildings. In the past, network managers wanting to go to Gigabit speeds were often faced with re-wiring their buildings with fiber cable.

Today, with approval of the 1000BASE-T standard for Gigabit Ethernet over copper, Gigabit speeds can be widely deployed at less expense using standard Category 5 cabling. This paper provides information about 1000BASE-T and gives a variety of deployment examples. At the end of this paper, you'll find additional resources for further investigation of Gigabit Ethernet over copper.

The Move Toward Gigabit LANs

Organizations have long used Local Area Networks (LANs) to share applications and equipment across workgroups. Ethernet, the networking standard pioneered by Intel, Digital and Xerox, has become the most commonly used LAN technology worldwide. More than 85 percent of all installed network connections are Ethernet, according to International Data Corporation (IDC).

In the past few years, high-bandwidth applications and high-speed communications between networked users have driven major increases in desktop computing power, first to Fast Ethernet and now to Gigabit Ethernet. This trend is expected to continue, spurred in part by the rapid growth of e-Business and the rapid adoption of Fast Ethernet in workgroups.

The Role of the Internet

Gartner Group estimates that by 2005, 25 percent of consumer spending and 70 percent of business-to-business commerce will be "Internet-involved." In addition, many companies are building intranets where employees can gather business information using Internet technology. These changes are fostering new, bandwidth-intensive multimedia applications encompassing voice, video and data – applications that are used all the way down to the desktop level. Other demanding applications range from scientific imaging to data warehousing.

With applications requiring greater bandwidth at the desktop, and with the number of users continuing to grow, more and more organizations have chosen to migrate to high speed networking technologies. Fast Ethernet, which runs at 10 times the rate of Ethernet, has become the most popular choice. By building on the original 10BASE-T Ethernet standard, Fast Ethernet provides an affordable, non-disruptive transition from 10Mbps to 100Mbps.

However, the growing use of Fast Ethernet connections to high performance desktops has created the need for an even more powerful technology higher up the network. A typical network is analogous to the plumbing in a house, where many smaller pipes connect to fewer medium-sized pipes, which in turn connect to one large pipe accessing the local water supply. By the same token, if many desktops all need to access a server through the same pipe, then that pipe should be large enough to carry several times the bandwidth of a desktop.

Accordingly, migration to Gigabit Ethernet is beginning to grow even as the pace of Fast Ethernet adoption continues to accelerate.

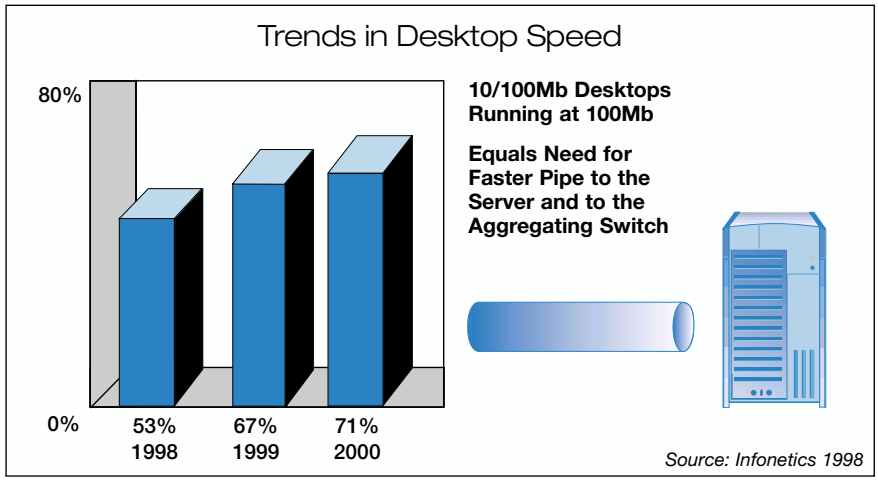

Figure 1

Setting the Stage

Several factors contribute to setting the stage for Gigabit Ethernet:

- Many of today's PCs are "future-proofed" with 10/100 connections. The number of 10/100 PC users running Fast Ethernet is growing rapidly (Figure 1). And with 100Mbps bandwidth at the desktop, even greater bandwidth is required at the server and backbone levels. According to Infonetics, an estimated 71 percent of desktops will be running at 100Mbps by the end of 2000.
- A majority of high performance LAN purchases are driven by server bottlenecks and the addition of new servers to the network (Infonetics, '99). Today's servers can process larger files and move more data faster than ever before, but the network and its server connections must support this performance.
- Thanks to Internet technologies and applications, as well as today's centralized data center model, about half of all network traffic now travels across IP or IPX subnets. This traffic must be aggregated at the backbone levels before it is moved out across subnets and eventually out onto the WAN. This has increased the need for high performance, bandwidth-intensive switches that are capable of Layer 3 routing.

The most appropriate solution to these challenges is 1000Mbps Gigabit Ethernet, which offers a natural upgrade path for current Ethernet and Fast Ethernet installations. Gigabit network adapters are needed to prevent bottlenecks from developing at high-demand servers, and Gigabit uplinks and switches are needed to aggregate Fast Ethernet traffic at switch stacks and the network backbone.

In the future, Gigabit LANs are expected to be the norm. In the meantime, LAN managers are looking for ways to future-proof their networks for 1000Mbps and move critical segments to Gigabit now. The recent adoption of the 1000BASE-T standard, which allows deployment of Gigabit Ethernet over Category 5 (CAT 5) copper cabling, has helped facilitate these efforts.

Industry Standards

As networking has progressed, so have industry standards. Gigabit Ethernet has evolved from the original 10Mbps Ethernet standard, 10BASE-T, and the 100Mbps Fast Ethernet standards, 100BASE-TX and 100BASE-FX. A 10 Gigabit Ethernet standard is already planned.

In June of 1998, the IEEE approved Gigabit Ethernet over fiber optic cable as IEEE 802.3z, and its implementation was widely supported by networking vendors.

With adoption of 802.3z, companies could rely on a well-known, standards-based approach to improve traffic flow in congested areas.

A year later, in June of 1999, the IEEE further standardized IEEE 802.3ab Gigabit Ethernet over copper as 1000BASE-T, allowing Gigabit speeds to be transmitted over Category 5 cable (Figure 2).

Importance of Gigabit Over Copper

When a company chooses its cabling infrastructure, it is making a long-term investment that can last as long as ten to fifteen years. On average, almost half of the cabling infrastructure is in place for more than five years, according to Sage Research. Most of the cabling already installed in buildings today is Category 5.

Not surprisingly, organizations have been reluctant to tear out their existing Category 5 cabling and lose this investment in order to deploy high-speed networking. Prior to approval of 1000BASE-T, deployment of Gigabit Ethernet tended to be limited to areas where fiber cabling was required or desired. With the adoption of 1000BASE-T, however, widespread deployment of Gigabit is possible over the existing copper infrastructure.

The Cost-effective Choice

1000BASE-T is ideal when budgets are tight, because it increases performance by building on a company's current investment. Technicians are familiar with the technology, so re-training is not needed. Costly protocol, hardware and cabling changes can be avoided, and any disruption to the network is usually minimal. What's more, Gigabit over copper is the most economical cabling choice in terms of cost per Mbps, even more economical than Gigabit over fiber.

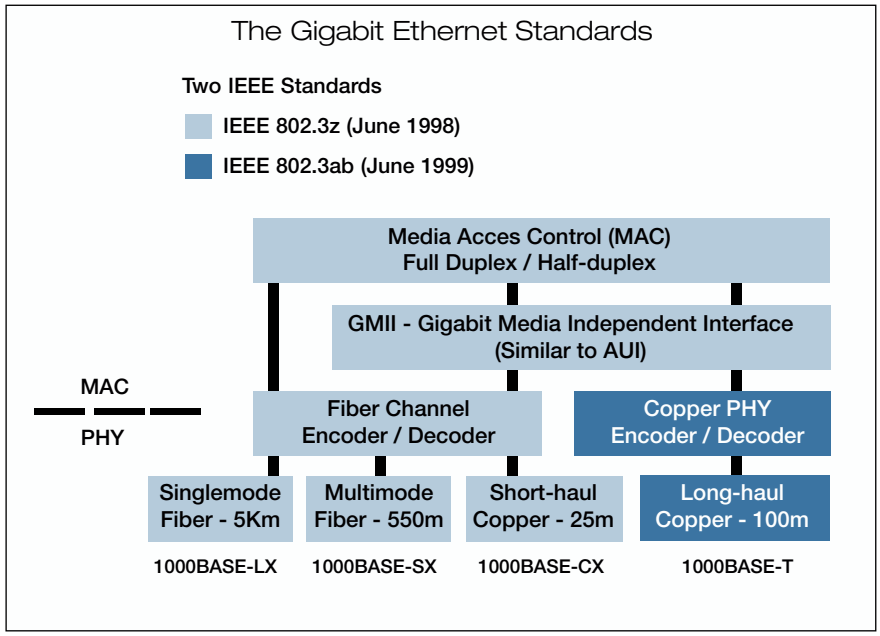

Figure 2

Another advantage is that Gigabit Ethernet employs all the same specifications defined by the original Ethernet standard, including the same Ethernet frame format and size. This is not true of other high-speed network technologies available. For example, ATM has a fixed-length data cell, while Ethernet frame lengths can vary greatly (64 to 1514 bytes) depending on the size of the protocol header, data and pad. As a result, connecting ATM to existing Ethernet or Fast Ethernet segments would require translating each ATM cell to an Ethernet frame.

Since it uses the same specs, 1000BASE-T is fully compatible with the large installed base of Ethernet and Fast Ethernet nodes, as well as V.90 modems. This backward compatibility makes it easy to scale. A variety of 10/100/1000 connectivity devices allow managers to turn up network speed to selected workgroups or segments now, while pre-enabling others for future migration to Gigabit. The migration path is consistent with the familiar path from 10Mbps to 100Mbps. A path from Gigabit to 10 Gigabit Ethernet is expected to be available soon.

Quality of Service

Gigabit Ethernet is also a good choice because it supports Quality of Service (QoS), which will be increasingly important for avoiding latency problems as voice, video and data share the network wire. Like Fast Ethernet, Gigabit Ethernet supports existing traffic management techniques that deliver Quality of Service over Ethernet, such as IEEE 802.1p traffic prioritization and Resource Reservation Protocol (RSVP).

RSVP is gaining industry acceptance as a preferred way to request and provide quality of network connections. 802.1p provides a means for priority "tagging" of Ethernet packets in a way that can be communicated to network devices. In intelligent L3/L4 switches, a network administrator can profile traffic by specific IP type (such as HTTP or FTP) and guarantee predictable delivery of this traffic.

Important Specifications

Cable Configuration

The 1000BASE-T physical layer standard provides 1Gbps Ethernet signal transmission over four pairs of Category 5 UTP cable. It transmits at 125 Mbaud, the same symbol rate as Fast Ethernet. But by using more sophisticated five-level (PAM-5) coding along with four wire pairs, it is able to transmit much more data. To simplify, each wire pair sends and transmits simultaneously, for 250Mbps per pair (125 Mbaud x 2 bits). Multiplying 250Mbps by four pairs yields the nominal rate of 1000Mbps.

Distances

The standard covers cabling distances of up to 100 meters, or networks with a diameter of 200 meters. The 100-meter cabling distance is the safe limit for reliable transmission, and the diameter assumes 100 meters in two directions from a switch.

Half-duplex and CSMA/CD

1000BASE-T supports full duplex and/or half-duplex operation. However, few if any products offered to date support half-duplex – presumably there is little demand, since the principal benefit of Gigabit Ethernet is to maximize performance. Full duplex offers virtually twice the bandwidth.

When running in half-duplex mode, Gigabit Ethernet uses the CSMA/CD protocol. Half-duplex collision domains should be the same as for 100BASE-TX, although each domain can support only one half-duplex repeater. In order to make CSMA/CD work for Gigabit Ethernet, it was necessary to alter the normal timing within a collision domain. At Gigabit speeds, smaller sized data packets could literally reach their destinations before the sending station could detect a collision signal. To overcome this problem, minimum-sized packets are padded with an extension field.

Full Duplex and Flow Control

In full duplex, Gigabit Ethernet relies on the same flow control method as full duplex Fast Ethernet. Nodes on a full duplex channel simultaneously send and receive packets. This makes CSMA/CD collision detection impractical. Instead, flow control methodology is used to avoid congestion and overloading. In simplified terms, each node periodically sends out a packet to indicate that it is transmitting and needs the other node to be in receive mode.

Reliability

Third-party tests have shown that nearly complete efficiency can be achieved in transmitting data with Gigabit Ethernet, and the bit error rate (less than one in ten billion) is the same as for Fast Ethernet. 1000BASE-T makes use of DSP signal equalization techniques to manage problems of noise, echo and other interferences, and to ensure the low bit error rate. It is a highly reliable technology, which can be deployed with confidence in mission-critical networks.

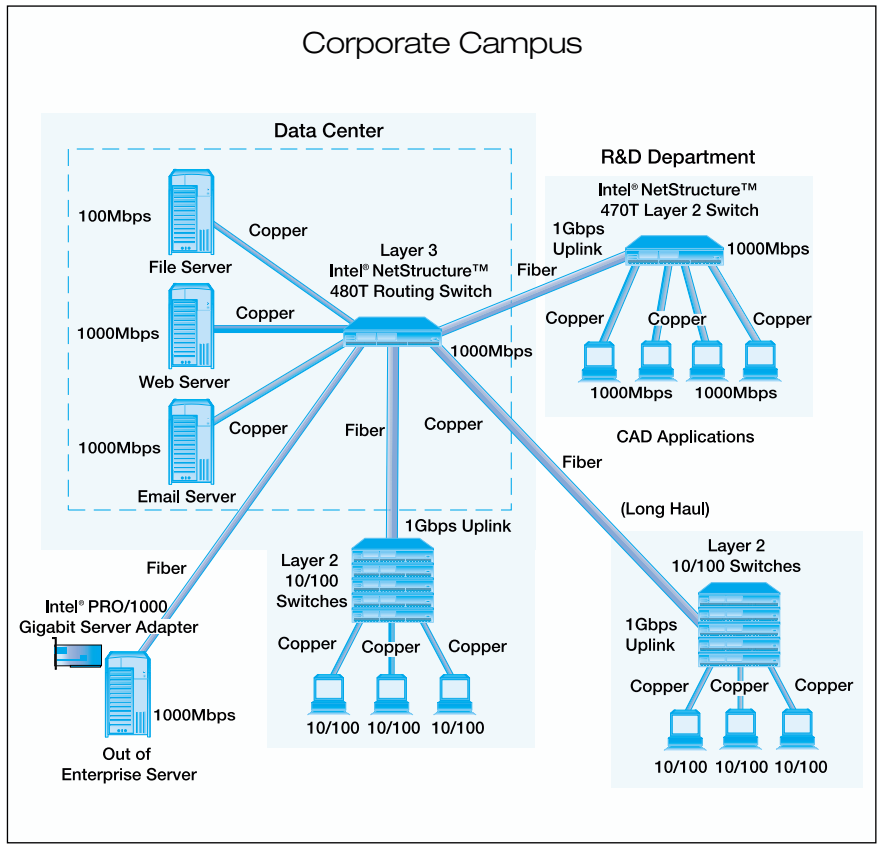

Figure 3, Campus deployment.
Corporate campus settings are characterized by a large number of users and multiple network segments, resulting in complex needs. Copper cabling (CAT 5) is likely to be in place within the data center, while fiber is typically used to connect buildings, to link segment switches to the data center, and to connect servers outside the enterprise. Gradual migration to Gigabit Ethernet will provide more bandwidth for high performance desktops, server connections, and switch-to-switch connections. Deployment steps include: For high-demand servers, replace 10/100Mbps adapters with auto-negotiating 1000Mbps fiber adapters. In the R&D department, replace 10/100 desktop adapters with Gigabit adapters and replace the 10/100 segment switch with a Layer 2 Gigabit switch such as the Intel® NetStructure™ 470T Switch. Install Gigabit uplinks from 10/100 switch stacks to the data center. Replace the 10/100 backbone switch with a high performance, Layer 3 Gigabit switch such as the Intel® NetStructure™ 480T Routing Switch. At this point, the legacy CAT 5 cabling within the data center and existing fiber cabling to segment switches will begin running at Gigabit speed.

Deployment Considerations

A variety of specific deployment examples are provided in this paper (figures 3 to 6). General deployment considerations are discussed below.

Media Selection

Network managers deploying Gigabit Ethernet have a choice of media to match different situations. Factors influencing this choice include cabling distance, physical location and environmental effects.

For example:

- CAT 5 cable is the most common medium for horizontal cabling in ceilings and floors
- Fiber cable is the most common choice for connecting buildings in campus settings
- Either is used in the vertical risers that connect different floors within a building

As discussed previously, Gigabit Ethernet has now been approved for fiber optic cable in 550M and 5Km lengths, for short copper connections (intended for data centers but not supported by vendor products), and for Category 5 copper cable up to 100 meters. Additionally, through the use of vendor-specific Long-haul Gigabit Interface Connectors (LH GBICs) in switches, Gigabit connections can be established at lengths of up to 70Km.

Since fiber is more expensive than copper, it is often reserved for situations that require cabling distances greater than the 100-meter copper limit – for example, between buildings. Environmental factors can also make fiber the best choice even when long distances are not involved. Copper cable is susceptible to electromagnetic interference, which can corrupt files, while fiber optic cable is not. Thus, fiber can be used to bring Gigabit Ethernet from servers to high performance workstations even when these machines are located near elevators, fluorescent light fixtures or other sources of high external noise.

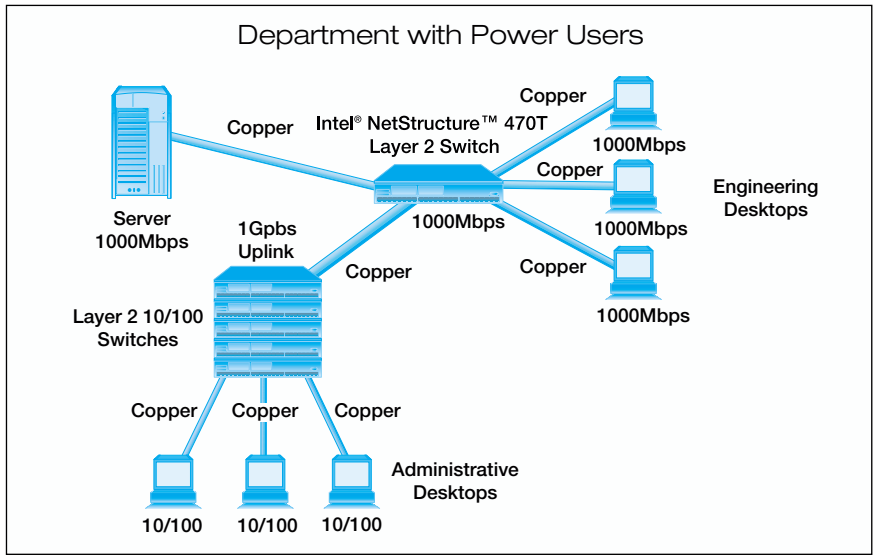

Figure 4, Departmental deployment.
At the department level, organizations may find that more bandwidth is needed for high performance workstations to run bandwidth-intensive applications such as engineering, design or medical imaging. The same department may also contain administrative workgroups where 10Mbps or 100Mbps performance is sufficient. A Gigabit solution can be deployed on the department's existing CAT 5 copper cabling as follows: Install a Layer 2 Gigabit departmental switch with direct connections to power user desktops. Create a high performance server connection by replacing the existing 10/100 server adapter with a Gigabit adapter. Boost bandwidth at the key aggregation point for administrative desktops by installing a Gigabit uplink from the 10/100 switch stack to the departmental Gigabit switch.

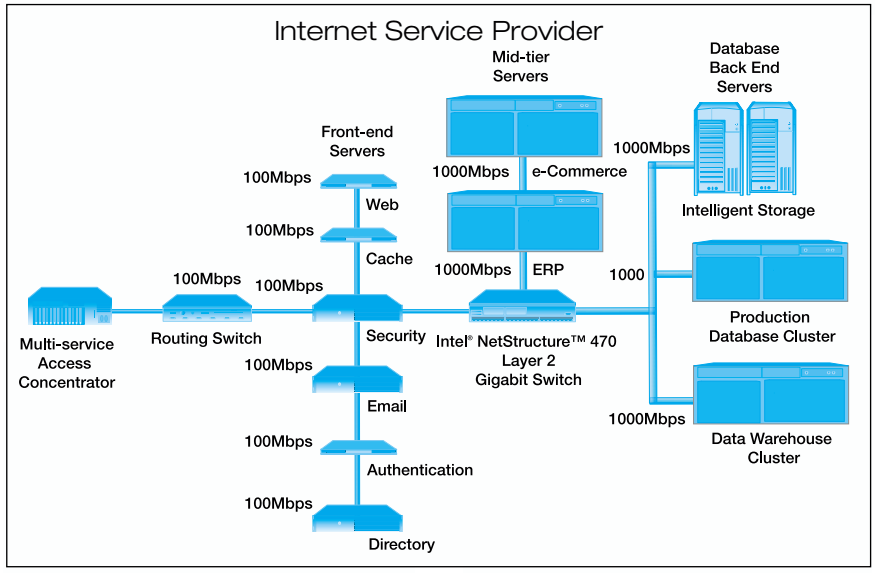

Figure 5, Deployment at an ISP.
Due to the rapid growth experienced by service providers today, an ISP must look 3 to 5 years ahead for infrastructure planning. More and more customers are being added, along with more and more servers, and traffic must be parsed for a variety of different service levels. Confined spaces and short cabling distances often mean that an all-copper network is in place. A Gigabit solution can help ensure responsiveness by moving traffic quickly from the back end to the front end. Recommended steps include: Install Gigabit adapters in all mid-tier and back end servers. Install a Layer 2 Gigabit switch for linking these 1000Mbps servers to the front end. For added reliability, install a Gigabit adapter and a 10/100 adapter in each back end server, with automatic fail-over to the 10/100.

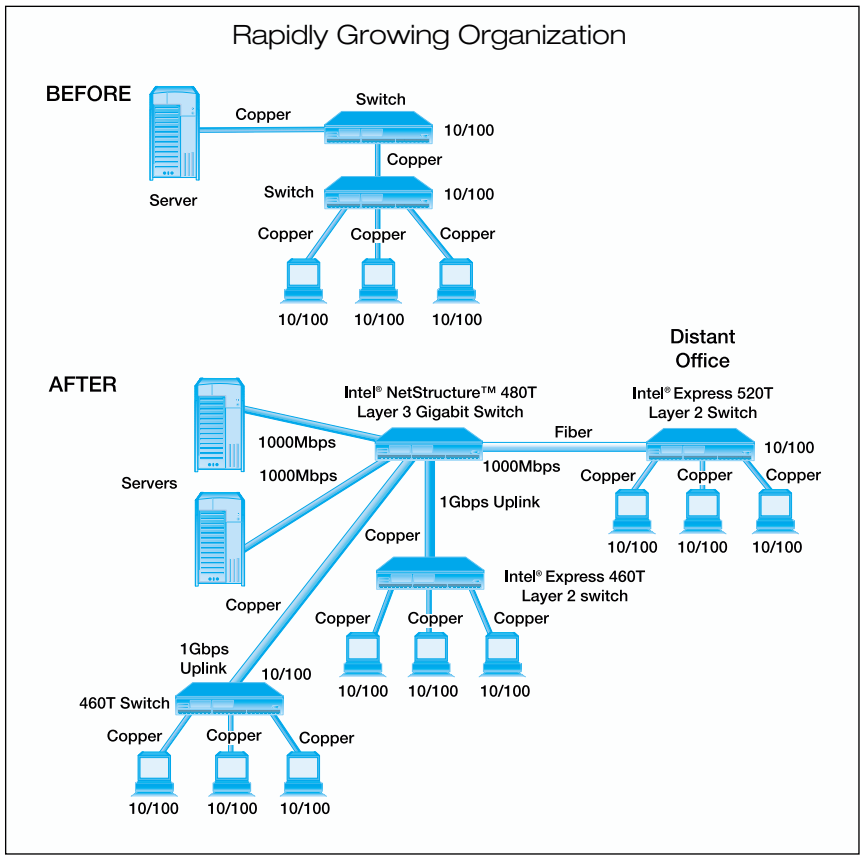

Figure 6, Deploying in a growing organization.
In rapidly growing organizations, the demands of adding new 10/100Mbps desktops will eventually outstrip network capacity, especially if users regularly need to move large files. With all desktop PCs running at 100Mbps, users will experience slow response times and sluggish retrieval of files stored on the server. The following Gigabit solution can increase throughput to and from the server by a factor of 10 using the existing copper infrastructure. In addition, it will allow the organization to deploy new workgroups using copper or fiber cabling as required by distances or environmental factors. Deployment includes: Replacing 10/100 server adapters with Gigabit adapters. Installing Gigabit uplinks from existing or new 10/100 segment switches. Installing a Layer 3 Gigabit backbone switch linked to servers and segment switches.

Many experts believe that fiber will continue to be the main infrastructure in risers due to the possibility of electromagnetic interference. In risers where environmental factors are not a problem, it is less expensive to use CAT 5 cabling.

Accessing legacy wiring in risers is difficult and therefore costly. Prior to the approval of Gigabit over copper, companies wanting to deploy Gigabit Ethernet often had to choose between replacing existing CAT 5 in risers, which was potentially cost-prohibitive, or delaying the move to high-speed networking. Today, this is no longer an issue. With 1000BASE-T, organizations can have the benefits of Gigabit performance without the expense of upgrading to fiber cabling.

Still another reason to choose fiber in some situations is the need for security. Fiber cable cannot be spliced except under clean-room conditions, making it nearly impossible for a hacker to tap into the cable at a work site and gain unauthorized access to information. This means fiber might be the best choice for intra-building uses where cabling runs must be left exposed.

Testing Existing Cable

Existing Category 5 cabling must meet certain transmission characteristics before it can be used for Gigabit Ethernet. Network managers need not be overly concerned, since it is estimated that only ten percent of existing CAT 5 installations will not meet the requirements. These installations would also not support 100BASE-TX Fast Ethernet.

Legacy cable destined for 1000BASE-T use should be tested for Far-end Crosstalk and Return Loss, and corrected if necessary. If the cabling link doesn't pass, the problem is most likely in the connectors or patch cable rather than the horizontal cable. ANSTI/TIA/EIA TSB-95 (1998) defines five relatively simple options for correcting performance.

Far-end Crosstalk and Return Loss were not specified in the 1995 cabling standards because they were not well understood at the time. It has since been determined that they can significantly affect 100BASE-TX and 1000BASE-T signals, even though they have negligible impact on 10BASE-T.

Return Loss

This parameter defines the amount of signal energy that is reflected back towards the transmitter due to impedance mismatches in the link, such as those caused by connectors. Category 5 systems installed prior to the completion of ANSI/TIA/EIA569-A in 1995 may contain connecting hardware that does not comply with the standard.

Far-end Crosstalk

This defines noise on a wire pair at the far end from the transmitter – that is, at the receiver. Crosstalk is caused by signals leaking from adjoining wire pairs. It is measured at each wire pair as Equal Level Far-end Crosstalk (ELFEXT), or as Power Sum ELFEXT (PSELFEXT) by adding up the total noise from all adjacent wire pairs.

New Installations

The Gigabit Ethernet Alliance suggests that network designers installing new cable might want to consider the new, enhanced Category 5 cable (CAT 5e) to gain extra signal margin. More detailed information on the enhanced cable, as well as test procedures for existing cable and sources of testing equipment, can be found by visiting the Gigabit Ethernet Alliance Web site at www.Gigabit-ethernet.org.

Conclusion

As the Internet explosion continues, deployment of bandwidth-hungry applications is likely to grow at all levels of the enterprise for the foreseeable future. At the same time, managers will often be faced with budgets that do not allow forklift upgrades to handle this increased load. The most appropriate solution is to future-proof the network with Gigabit-enabled adapters and uplinks, and add Gigabit infrastructure in incremental stages. A variety of connectivity products are available that can easily be shifted to 100Mbps or 1000Mbps as Fast and Gigabit Ethernet are deployed. The Gigabit over copper standard is an important part of the solution, allowing managers to quickly and inexpensively turn up the speed on the Category 5 cabling already installed.

Intel offers a variety of Gigabit Ethernet solutions. Among these are Gigabit over copper devices including switches, uplinks and network adapter cards.

For More Information

The following sources can provide more detail on Gigabit Ethernet, cabling for Gigabit Ethernet over copper and Intel's Gigabit Ethernet product solutions.

Intel Networking Products:
www.intel.com/network

Gigabit Ethernet Alliance:
www.Gigabit-ethernet.org

Cabling:
www.bicsi.com

Gigabit Ethernet Standards:
standards.ieee.org/catalog/IEEE802.3.html
and
grouper.ieee.org/groups/802/3/index.html

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