Gigabit Ethernet Technology and Solutions

How 1000Mbps connectivity is helping organizations meet the need for increased network performance

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Executive Summary

In a scenario all too familiar to network managers, users begin complaining of slower response times. Network management tools indicate that a high-transaction server is hogging bandwidth in a shared domain or that server CPU utilization is not optimal – classic bottleneck symptoms. What's the best solution? More and more often, IT managers are turning to Gigabit Ethernet technology.

When Gigabit Ethernet was standardized for fiber optic cabling in the late 1990s, IT managers began to see the benefits of Gigabit speeds applied to the network backbone and in the data center. Today, with Gigabit over copper, 1000Mbps connectivity is being deployed even more widely – including switch stacks, servers and desktops – using the cabling that is already in place in most buildings.

This paper provides information about Gigabit Ethernet, including the ways your network can benefit from standard Gigabit implementations, and offers a variety of deployment examples using fiber and/or copper cabling.

What Is Gigabit Ethernet?

Invented by Dr. Robert Metcalf and pioneered by Intel, Digital and Xerox, Ethernet has become the most commonly used LAN technology worldwide. More than 85% of all installed network connections are Ethernet, according to International Data Corporation (IDC, 2000). As a transport protocol, Ethernet operates at Layers 1 and 2 of the 7-layer OSI networking model, delivering its data packets to any device connected to the network cable.

IT managers have found that Ethernet is simple, easy to use and readily upgradeable. An organization can scale from 10 to 100 or 1000Mbps Ethernet, either network-wide or a segment at a time, knowing that the new equipment will be backwards compatible with legacy equipment. This reduces the infrastructure investment that an organization must make. Ethernet is also a reliable technology. Experience shows that it can be deployed with confidence for mission-critical applications.

Standards Evolution

A prime reason for the success of Ethernet is the fact that Ethernet standards, over 25 years old, have progressed along with networking requirements. This progression of standards provides a clear and straightforward migration path for companies as their bandwidth requirements increase.

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 (10,000Mbps) is being ratified, supported by the IEEE and the 10-Gigabit Ethernet Alliance.

In June of 1998, the IEEE adopted a standard for Gigabit Ethernet over fiber optic cabling, IEEE 802.3z, and its implementation was widely supported by networking vendors. As a result, companies could rely on a well-understood, standards-based approach to improve traffic flow in congested areas. A year later, in June of 1999, the IEEE standardized IEEE 802.3ab Gigabit Ethernet over copper as 1000BASE-T, allowing Gigabit speeds to be transmitted over Cat-5 cable (Figure 1).

In general, upgrading to Gigabit Ethernet over copper is ideal even when budgets are tight, because it increases performance by building on a company's current investment in cabling. Typically, the network infrastructure simply adjusts to this higher speed. No technician re-training is needed, 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.

Gigabit Ethernet is also a good choice because it supports Quality of Service (QoS) methods that are increasingly important for avoiding latency problems as voice, video and data share the cable for Next-Generation Networking (NGN) applications. 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 Multi Protocol Label Switching (MPLS).

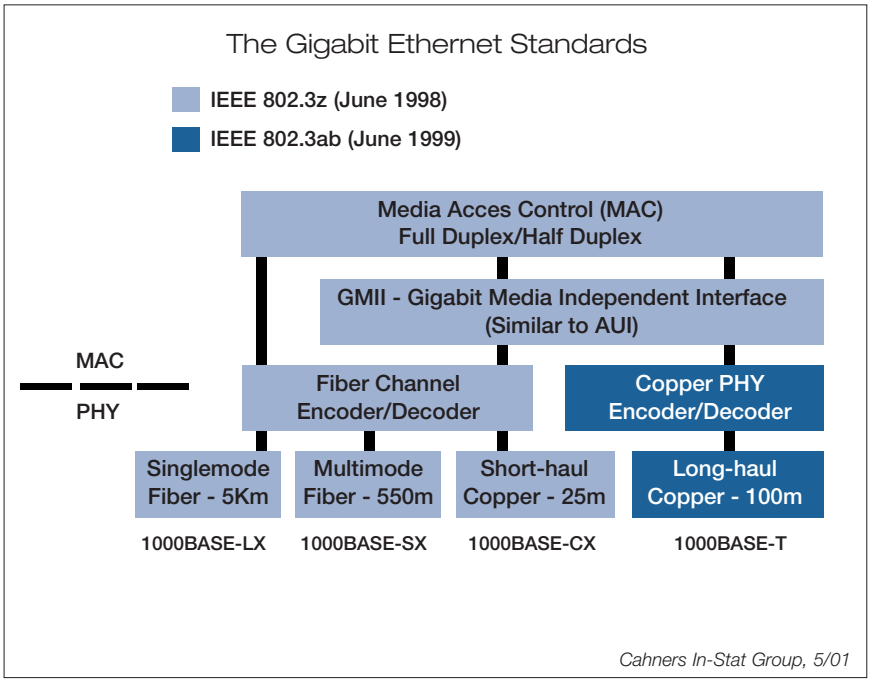

Figure 1

Benefits of Gigabit

Gigabit Ethernet is 100 times faster than regular 10Mbps Ethernet and 10 times faster than 100Mbps Fast Ethernet. The principal benefits of Gigabit Ethernet include:

- Increased bandwidth for higher performance and elimination of bottlenecks
- Full-duplex capacity, allowing the effective bandwidth to be virtually doubled
- Aggregating bandwidth to multi-Gigabit speeds using Gigabit server adapters and switches
- Quality of Service (QoS) features to help eliminate jittery video or distorted audio
- Low cost of acquisition and ownership
- Full compatibility with the large installed base of Ethernet and Fast Ethernet nodes
- Transferring large amounts of data across a network quickly

What Is Driving the Need for Gigabit Speed?

Backbones and Switch Stacks

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, that pipe should be large enough to carry several times the bandwidth of a desktop. Likewise, the network backbone must be large enough to support many workgroups or segments.

With the rapid growth of Internet technologies and applications in the 1990s, and the centralized data center model that developed along with the Internet, more network traffic began traveling across IP or IPX subnets. It became necessary to aggregate this traffic at switch stacks and backbone levels before moving it across subnets or out onto the WAN. Gigabit Ethernet provides a "large pipe" to alleviate congestion at these aggregation points.

Greater Demands on Servers

Many high-performance LAN purchases are driven by server bottlenecks, the addition of new servers to the network and the increased use of applications such as data warehousing and database query. 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. Pressure on server performance also comes from ever-increasing desktop speeds. The number of PCs migrating to Fast Ethernet has grown rapidly in recent years (Figure 2).

Today, with more than 85% of desktops running at 100Mbps (Infonetics Research, Inc., "User Plans for High Performance LANs 2000," April 2000), virtually every server needs at least one Gigabit Ethernet connection. High-demand servers require more than one Gigabit Ethernet connection. For example, application and database servers will require multiple Gigabit connections to serve a larger number of Web servers. As you begin to migrate your desktop PCs to Gigabit throughput, scalability in your backbone and servers will become increasingly important. Technologies that come standard on Intel adapters, such as load balancing and link aggregation, allow multi-Gigabit scalability to remove network bottlenecks as bandwidth demands increase.

The Ongoing Desktop Revolution

Demand for faster PCs continues to grow as it has in the past. Not long ago,

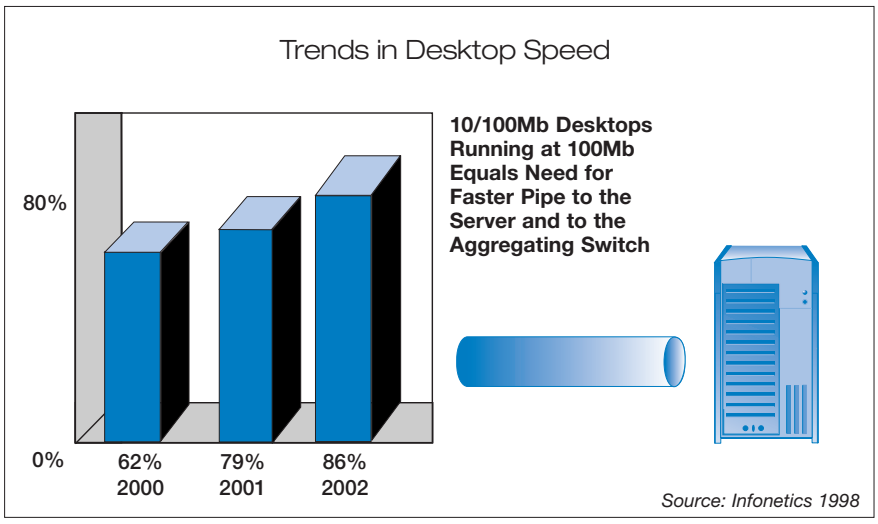

Figure 2

desktop connections and PC processing power were considered more than adequate if the user could simultaneously open Microsoft Word* and an Excel* spreadsheet. The kind of visually rich multi-tasking that is routine today, such as editing video while downloading photographs or exchanging graphic designs while talking on an Internet phone line, were not part of the equation.

As applications grew more bandwidth-hungry, the view that 10Mbps was adequate at the desktop began to change, and the trend to 100Mbps desktops developed. This trend greatly accelerated when the cost of dual-speed 10/100Mbps Ethernet connections approached the cost of regular Ethernet. Network managers could build 100Mbps capability into their new PCs at the time of purchase and avoid the higher costs of retrofitting these desktops in the future. The industry is now in a similar circumstance with 1000Mbps Gigabit Ethernet connections (Figure 3).

Shrinking price deltas are ramping the growth of desktop Gigabit connections and continuing a now-familiar pattern as 1000Mbps replaces 100Mbps. It is estimated that by the middle of 2002, over 50% of worldwide NIC revenues will come from Gigabit Ethernet products (Cahners In-Stat, 2001).

The move to Gigabit-enabled desktops is being driven by several factors, including:

- Collaborative work environments
- Routine sharing of large files
- Converged applications
- Multi-tasking, where multiple high-bandwidth applications are open simultaneously

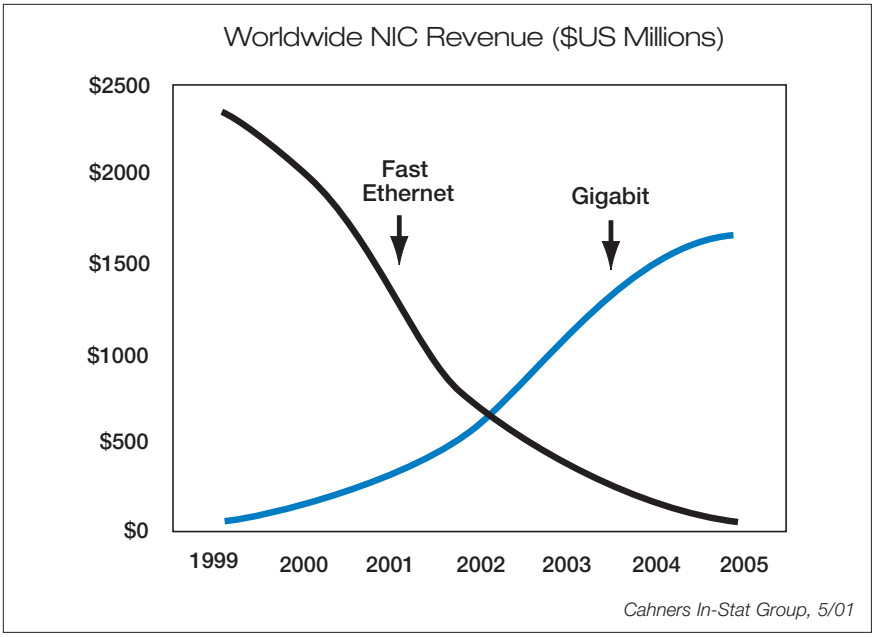

Figure 3

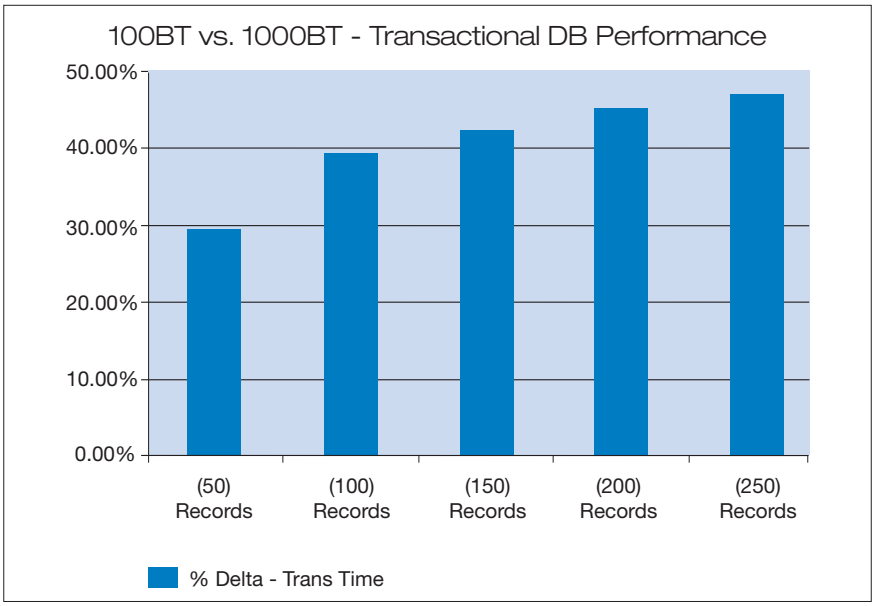

Figure 4

Recent third-party tests published by 8wire (8Wire.com, "Is It Time For Gigabit To The Desktop?," 9/25/2001) show that Gigabit at the desktop can significantly boost application performance – even in standard business applications. Testing an all-Intel, Gigabit over copper solution, CSA Research was able to measure up to 47% performance gains over traditional 10/100Mbps deployment. (Competitive Systems Analysis, Inc., "Gigabit To The Desktop," October, 2001). Commonly used, mainstream applications such as client/server database tasks (Figure 4)

and messaging workloads were tested while running Microsoft SQL Server* and Exchange Server.

Typical Progression

Not surprisingly, workgroups with unusually heavy bandwidth requirements are the first to be considered for Gigabit Ethernet. Prime candidates are engineering and R&D departments, which not only use CAD, 3D modeling and collaborative design, but also tend to have more powerful workstations that can immediately take advantage of high-performance connections. Specialized business categories such as medical imaging, cartography, graphic design and advertising production are also early adopters.

As bandwidth requirements increase for mainstream applications, high-speed connections become more widely deployed. In a common scenario, the shift to higher speeds might occur in several phases:

- Phase I – High-performance Gigabit switches are used to aggregate backbone traffic.
- Phase II – Gigabit Ethernet is switched and routed at the network backbone with switch-to-switch connections.
- Phase III – Greater server-to-switch bandwidth is deployed using a Gigabit switch to support Gigabit Ethernet network adapter cards, boosting server connections to 1000Mbps. All servers have at least one Gigabit connection, and Gigabit becomes standard for the highest-demand desktops and workgroups.
- Phase IV – As PCs are replaced due to normal attrition, 10/100/1000Mbps network interfaces are specified to replace 10/100Mbps connections. Servers are scaled to multi-Gigabit speeds. Older switches are replaced to take Gigabit down to the desktop. Gigabit Ethernet becomes standard for virtually all desktops.

Impact of Gigabit Over Copper

Gigabit Ethernet was first standardized only for fiber. This meant network managers wanting to deploy Gigabit were often faced with costly re-wiring of their buildings in order to upgrade the infrastructure to fiber cable. The situation was alleviated when the IEEE standardized Gigabit over Cat-5 copper cabling. Widespread deployment of Gigabit Ethernet became possible at less expense over the existing copper infrastructure.

The vast majority of desktop connections today are Cat-5 copper, and this standard has made the deployment of Gigabit Ethernet to the desktop possible. For most organizations, deploying Gigabit to the desktop is a matter of "when" rather than "if."

Gigabit to the Desktop: Is It Time?

Following is a partial list of activities that may indicate it is time for your organization to deploy Gigabit Ethernet desktop connections. You may need Gigabit PCs to:

- Enable emerging desktop-centric applications and technologies such as streaming video, MP3 audio and digital photography
- Support specialized applications such as CAD, 3D modeling or medical imaging
- Make it faster and easier to push operating system upgrades to client PCs
- Attract and retain new business with more effective e-Communications to customers and suppliers
- Create professional-quality e-Business content and customer communications faster
- Perform real-time file transfers
- Increase employee productivity by speeding access to databases and messaging applications

Today's high-end PCs have enough processing power to handle the increased input and output that comes with a Gigabit connection. Desktop computing power has been accelerating (Figure 5) and as of this year, with the Intel® Pentium® 4 processor, speeds are reaching 2GHz. Bus speeds are also much greater. To get full value from high-performance systems, such as those with Intel Pentium 4 processors and the new Windows* XP operating system, companies should seriously consider Gigabit connectivity.

The real test of the PC network connection comes when a number of demanding applications are used at the same time.

For example, it is not unusual today for a worker to be engaged in a conference call via NetMeeting* while simultaneously running video sent by one of the callers, detaching a 6-Megabyte file from an e-mail and going to the Web for additional information. Today's multi-application environment also includes background tasks such as real-time virus checking, encryption, compression

and e-mail synchronization. This new desktop work paradigm can greatly boost productivity, but requires more processing power.

Solutions to the Two Most Common Challenges

Two of the most common concerns expressed by network managers regarding Gigabit desktops are:

- Will Gigabit really run on my current Cat-5 desktop and workgroup cabling?
- If my desktops are Gigabit-enabled, don't my server and backbone connections need to be faster than Gigabit?

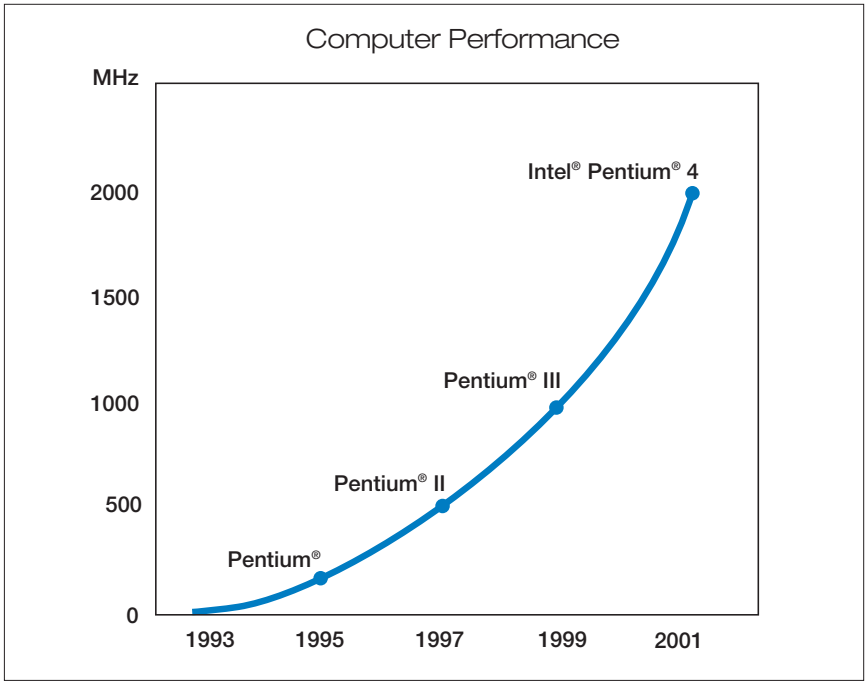

Figure 5

Key Gigabit Over Copper Specifications

- **Cable configuration** – 1000BASE-T provides 1Gbps Ethernet signal transmission over four pairs of Category-5 UTP cable. 250Mbps per wire pair multiplied by 4 pairs = 1000Mbps.
- **Distances** – The copper standard covers cabling distances of up to 100 meters, or networks with a diameter of 200 meters (assumes 100 meters in two directions from a switch).
- **Half duplex and CSMA/CD** – Although the standard includes half-duplex operation, few Gigabit products support half duplex to date. Full duplex is preferred to maximize performance. Gigabit Ethernet uses the CSMA/CD protocol only when running in half-duplex mode.
- **Full duplex and flow control** – In full duplex, CSMA/CD collision detection is impractical. Instead, flow control methodology is used to avoid congestion and overloading.

These are valid and thoughtful concerns, and solutions are readily available.

First, a vast majority of organizations will be able to run Gigabit Ethernet over the same Cat-5 copper wiring that is presently installed in most buildings. According to Sage Research, 87% of companies are running their networks on Cat-5 cable (Sage Research, 2000), and it is estimated that 90% of these existing installations already meet the requirements for Gigabit throughput (Gigabit Ethernet Alliance, 2000). If a cabling link doesn't support Gigabit, the problem is most likely in the connectors or patch cable rather than the horizontal cable.

Second, network managers can easily avoid server/network bottlenecks by scaling their Gigabit backbone and server bandwidth using proven technologies that are available today:

- Adaptive Load Balancing (ALB)
- Intel® Link Aggregation
- Gigabit EtherChannel* (GEC)
- IEEE 802.3ad

Load balancing can increase server bandwidth up to 8Gbps by automatically balancing traffic across as many as eight network adapters, while technologies such as Intel Link Aggregation, Gigabit EtherChannel and IEEE 802.3ad can increase bandwidth up to 16Gbps.** In addition, switching technologies can be used to increase the usable bandwidth available.

Deployment Considerations

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 the different floors within a building

As discussed previously, Gigabit Ethernet has now been approved for fiber optic cable in 550M and 5Km lengths, and for Cat-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.

Fiber is typically reserved for situations that require cabling distances greater than the 100-meter copper limit – for example, between buildings or vertical connections between floors. 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.

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 extremely difficult 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 Cat-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 less than 10% of existing Cat-5 installations will not meet the requirements (Gigabit Ethernet Alliance, 2000). 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, ANSTI/TIA/EIA standard TSB-95 (1998) defines five relatively simple options for correcting performance. For new cable installations, network designers might want to consider the enhanced Cat-5 cable (Cat-5e) to gain extra signal margin. However, this is not a requirement for Gigabit throughput.

Implementation Examples

While the following examples are general in nature, they reflect the capabilities provided by Intel® products. Intel offers a variety of Gigabit Ethernet solutions.

Corporate Campus

Corporate campus settings (Figure 6) are characterized by a large number of users, servers and multiple network segments, resulting in complex needs. Cat-5 copper cabling is likely to be in place within the data center, while fiber is typically used for connections between 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 multiple auto-negotiating 10/100/1000Mbps adapters for copper, 1000Mbps for fiber.
- In the R&D department, replace 10/100 desktop adapters with Gigabit adapters and replace the 10/100Mbps segment switch with a Layer 2 Gigabit switch.
- Install Gigabit uplinks from 10/100 switch stacks to the data center.
- Replace the 10/100Mbps backbone switch with a high-performance, Layer 3 Gigabit 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.
- Begin replacing 10/100 desktop adapters with Gigabit adapters in other departments besides R&D.

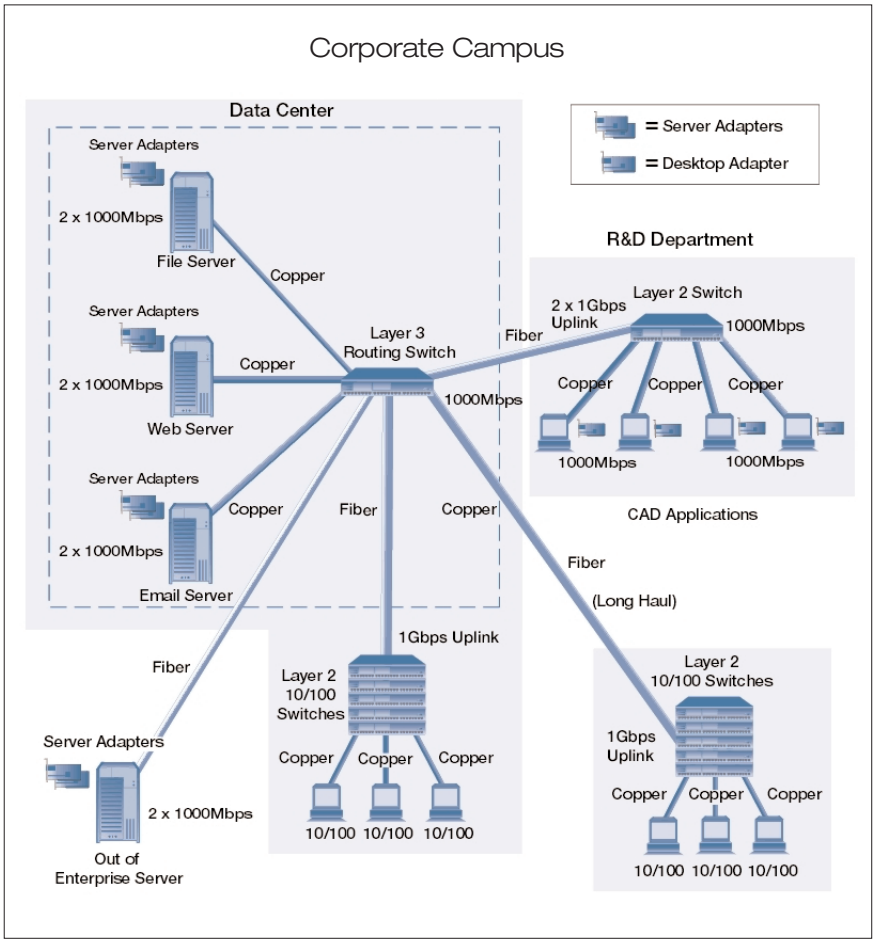

Figure 6, Corporate Campus.

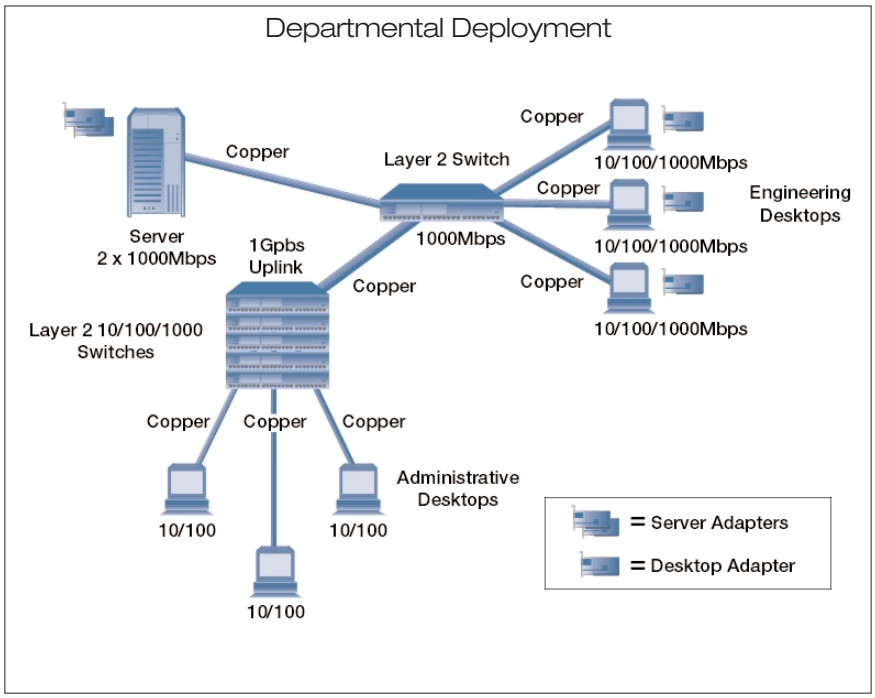

Figure 7, Departmental Deployment.

Departmental Deployment

At the department level (Figure 7), organizations may find that more bandwidth is needed for high-performance PCs to run multiple applications at once, or to run specialized applications like medical imaging. The same department may also contain administrative workgroups where 10/100Mbps 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 10/100Mbps server adapter with multiple Gigabit adapters.
- Boost bandwidth at the key aggregation point for administrative desktops by installing a Gigabit uplink from the 10/100Mbps switch stack to the departmental Gigabit switch.

Internet Service Provider

Due to the rapid growth experienced by service providers today (Figure 8), 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.

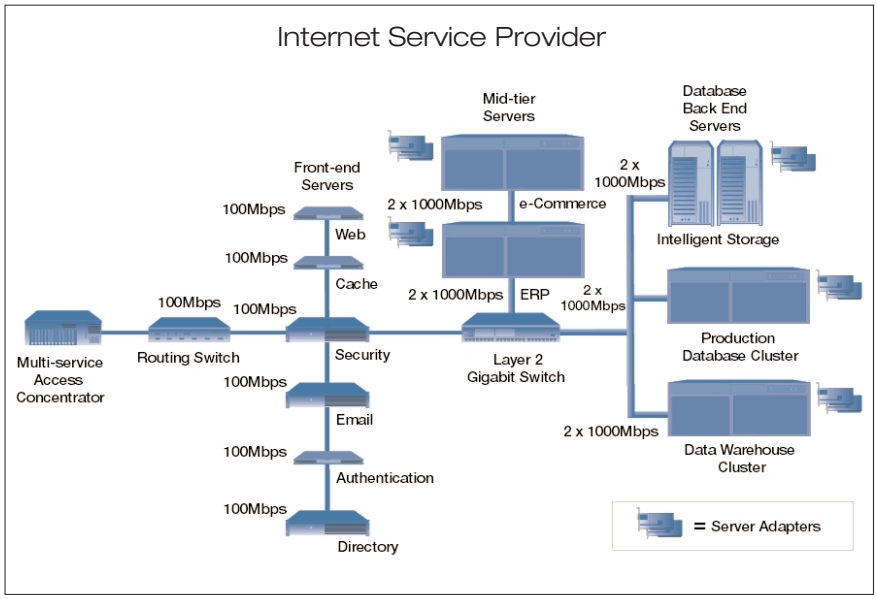

Figure 8, Deployment at an ISP.

Recommended steps include:

- Installing multiple Gigabit adapters in all mid-tier and back-end servers for added reliability and multi-Gigabit scalability
- Installing a Layer 2 Gigabit switch for linking these 1000Mbps servers to the front end

Fast-Growing Organization

In rapidly growing organizations (Figure 9), the demands of adding new 10/100/1000Mbps desktops will eventually outstrip network capacity, especially if users regularly need to multi-task and move large files. As more desktop PCs begin running at 1000Mbps, users will experience slow response times and sluggish retrieval of files stored on the server. The following Gigabit solution can significantly increase throughput to and from the server using the existing copper infrastructure.

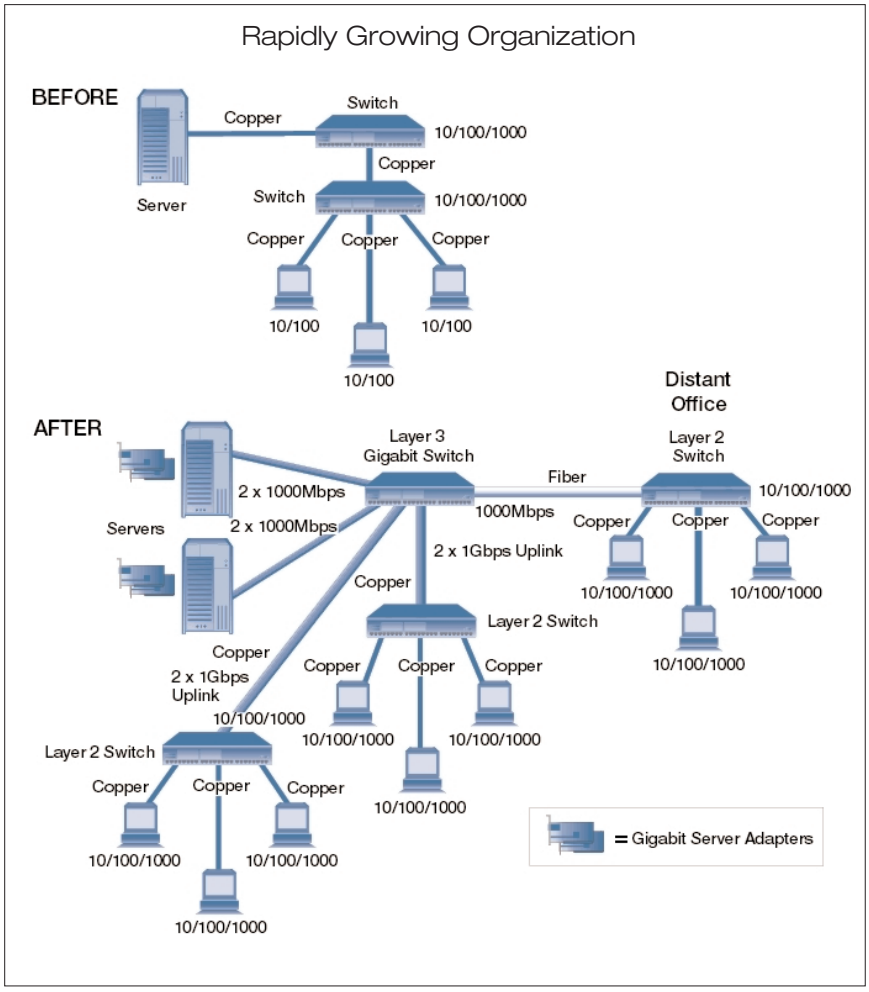

Figure 9, Deploying in a growing organization.

Deployment for this solution includes:

- Replacing all 10/100Mbps server adapters with multiple Gigabit adapters

- Using link aggregation to increase effective server bandwidth to 8Gbps or 16Gbps†
- Installing Gigabit segment switches as needed and a Layer 3 Gigabit backbone switch linked to servers

Conclusion

Deployment of bandwidth-hungry applications, more powerful processors and increasingly powerful operating systems are likely to continue for the foreseeable future, requiring faster network connections. Just as networking has historically moved to higher-speed connections in stages, individual networks also proceed from early to mainstream adoption.

First, network managers must think through the network environment to identify the power users/segments of their network that would need high-performance connections first. These users or segments are often retrofitted with Gigabit connections without waiting for the normal cycle of PC replacement.

Network managers then begin purchasing Gigabit-enabled systems for other segments in the organization. The most cost-effective method is to order new PCs equipped with triple-speed 10/100/1000Mbps connections to prepare these desktops for the coming increases in bandwidth requirements. Organizations want to avoid being "blind-sided" by the new wave of next generation applications.

For anyone who depends on the fast, efficient flow of information, Intel offers advanced networking technology to provide solutions that take Gigabit performance from the backbone to the server and to the desktop. Gigabit Ethernet network adapters include the Intel® PRO/1000 XT (copper) Server Adapter, Intel® PRO/1000 XF (fiber) Server Adapter, and Intel® PRO/1000 T (copper) Desktop Adapter.

For More Information

For more information about the Intel's Gigabit solutions, please see: http://www.intel.com/network/connectivity

For more about Gigabit Ethernet standards, visit: http://Standards.ieee.org/catalog and http://grouper.ieee.org/groups/802/3

**Actual throughput may be limited by constraints of the system platform

†Performance tests and ratings are measured using specific computer systems and/or components and reflect the approximate performance of Intel products as measured by those tests. Any difference in system hardware or software design or configuration may affect actual performance. Buyers should consult other sources of information to evaluate the performance of systems or components they are considering purchasing. For more information on performance tests and on the performance of Intel products, reference www.intel.com/procs/perf/limits.htm or call (U.S.) 1-800-628-8686 or 1-916-356-3104.

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