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Bandwidth Driven Networking Needs and Infrastructure Implications

Network planning. It never has been an easy process. In fact it can often lead to many a sleepless night for network managers. But it seems that lately, this task has become even more daunting. Visions of spiraling demand for network bandwidth have stimulated the development of LAN technologies promising to deliver anywhere from 10 Mb/s up to 100 Gb/s data rates. What it means for network managers is a wide array of choices that requires decisions about which technology, architecture, or physical infrastructure is best suited for their needs. As with most new technologies or innovations, the networking industry has jumped on the latest: 10 Gigabit Ethernet over copper cabling. This paper looks at the drivers for 10 Gb/s, developments in this area, and the implications for cabling infrastructures.

Growth in Bandwidth

The speed at which computer performance increases is clear for all to see and continues to grow exponentially over time. What is less obvious is the connection between growth in processor power and network traffic.

As a rule-of-thumb, each GIPS (billion instructions per second) handled by the CPU can produce 1 Gb/s of LAN traffic. PCs now also possess the Interface (I/O) buses to transport this capability. This potential may not be fully utilized today, as current business software does not use all of the PC's communications capability, but this is changing. As it does, some network users will face serious capacity problems. The size of the challenge can be judged from predictions that CPUs operating at 100 GIPS will be widely used within the lifespan of cabling now being installed.

Advances in high-speed LAN applications and multimedia software invite developers to create powerful new software products that need much more bandwidth. Just as they have capitalized on higher CPU performance, developers will take advantage of new, faster networking technologies. Couple this with the falling cost of gigabit interfaces and their appearance as standard in most new computers, and gigabit networking is already a reality to the desktop today, so forward thinking enterprises need to consider what the next step will be tomorrow.

In today's high-bandwidth computing environments it is not unusual to find multiple applications running in the foreground such as: Microsoft Office, Microsoft Outlook, Lotus Notes, Adobe Acrobat, Instant Messaging Applications, Media Player, Streaming Media, Videoconferencing and VoIP. Background tasks, such as virus scanning, software updates, system monitoring, encryption, compression and proactive information organization, are creating an additional drain on bandwidth that is not seen by the end-user.

Large enterprises are also faced with a growing need for higher bandwidth in the horizontal and backbone to support such applications as Storage Area Networks, Network Attached Storage, high-performance and grid computing.

- **Storage Area Networks (SAN)/ Network Attached Storage (NAS):** 10 Gigabit Ethernet enables costeffective, high-speed infrastructure for both network-attached storage (NAS) and storage area networks (SAN). 10 Gigabit Ethernet can offer equivalent or superior data carrying capacity at latencies similar to many other storage networking technologies, including Fibre Channel, ATM OC-3, OC-12 and OC-192, and Infiniband. The development of 10 Gigabit over copper offers a very cost effective solution for connection under 100 meters compared to these traditional fiber based technologies.

- **High-Performance Computing:** A number of industry sectors utilize high-performance computing platforms to support highly bandwidth-intensive applications such as streaming video, medical imaging, centralized applications, high-end graphics, visualization technologies, and data clustering. For example:
  - Government, medical and scientific research;
  - Government defense testing, simulation and cryptography activities;
  - Bioscience and pharmaceutical activities;
  - Financial services firms for quantitative analysis, statistical and econometric modeling;
  - Architectural and engineering firms for computerized CAD/CAM applications and sharing of CAD files; and
  - Geological and physical science surveying companies.
- **Multi-Site Collaboration:** Collaboration tools are emerging that enable conference participants to write or draw on a blank slide, to connect to a Web site, and engage in private communication with the conferencing host or any other participants. To ensure their effectiveness, these collaborative tools will increasingly require more bandwidth, and 10 Gigabit Ethernet connections will be the primary link for enabling multi-site collaboration within an enterprise.
- **Streaming Media:** Streaming media enhances a company's internal and external communications. It can play a role in hosting meetings, holding press conferences, demonstrating new products, supporting marketing/advertising activities, training employees, providing user support as well as the fun stuff too, like HDTV, video on-demand or extreme Internet gaming. Since data being transmitted for streaming media requires an uninterrupted path between source and user, bandwidth will be the key enabler and accelerator to streaming media adoption.
- **Grid Computing:** Grid computing makes "spare" desktop CPU horsepower available across the network to large jobs that require it. There are many scientific applications that need the computing power of arrays, but up to now the cost of a supercomputer or a massively parallel array was prohibitive. Grid computing is a technique that effectively provides the horsepower "across the network" to support these kinds of applications. Grid computing is highly dependent upon very fast interconnections among all of the participating computing platforms. Present successful implementations of this are found in the form of clusters of servers that are set aside and tied together, often in the data centers, via a fast Fibre Channel or other types of optical interface. As discussed earlier, the network of the near future is being populated right now with workstations that offer unprecedented computing power. The simple ability to harness these common appliances together with a very fast, cost effective interconnection scheme would make it possible to deploy grid computing across an organization. Today, grid computing is being used to amass spare compute cycles to power complex modeling and simulations in applications such as pharmaceutical research, financial portfolio risk analysis, electronic design automation and other computer-intensive applications. Grids also allow for collaboration and sharing. For grids to be the basis of a corporate infrastructure, more types of applications that can take advantage of the grid will be developed but in the meantime, grid technologies can and are being used to facilitate resource sharing, utilization and collaboration for a growing number of applications and industries.

Even if these applications attain just 10% of the PC's network traffic potential, as current rates of processor speed increase, 10 Gb/s desktop communication is within a planning horizon of five to ten years.

Application Bandwidth Needs and Directions

Let's take a more detailed look at the type of applications becoming prevalent and their bandwidth needs. Network applications can be divided into two classes, file transfer and real-time streaming media.

File Transfer

These applications include downloading files from a server to a user's desktop device (or vice versa). In many cases the user or device must wait for the file transfer to complete before allowing the user to act on the file. If a file transfer takes too long, the user may find the delay unacceptable and may also lose productivity. It is the user's subjective reaction that determines what data rate is acceptable.

The need for file transfers is increasing, driven by several related trends:

- Internet access: This ever-growing application area continues to stimulate carrier and enterprise LAN traffic. Downloads from web sites can only increase the burden on network bandwidth especially as Internet file sizes will almost certainly continue to increase.
- Thin-client architecture: Thin-client PCs have operating systems with small (or no) hard drives, so that software application and data files must be downloaded from a server before the user can start working. Sometimes known as network computers, these machines reduce the administrative overhead for IT organizations. Acceptance is increasing as enterprises look to protect their data centrally.
- Client/server applications: In these applications, the software application resides on a client PC while associated data is stored on a server. The server-resident data (or extracts from the data) must be downloaded to a client for processing and presentation to the user.
- Database downloads from servers: Spreadsheets, documents and databases may be located on servers, and then downloaded to a PC before they are viewed or processed. Leading-edge applications include:
  - Data warehousing and back-up applications - may include terabytes of enterprise information distributed on hundreds of network servers and accessed by thousands of users seeking near-real-time data. The load impacts the LAN backbone and the WAN, where traffic is aggregated.
  - Scientific and engineering applications - examples include: 3-D visualizations of complex objects ranging from molecules to aircraft; full-color publications sent from desktops to printing facilities; transmittal of complex medical images to enable sharing of expensive equipment.

The size of files transferred vary over many orders of magnitude and the time it takes to transfer the information is linked primarily to the data rate of the network. For file transfer applications, it may appear that data rates of 10 Gb/s may not be required today, except in specialized cases and areas where the data streams aggregate. However, this assumption does rely on what is regarded as acceptable wait times.

Real-Time Streaming Media

These applications, such as desktop video teleconferencing and Internet radio/TV, require that sound (e.g., voice, music) and moving images (e.g., video, animation) be sent in real time. These streaming applications involve the transmission, reconstruction and presentation of information to a desktop user. In order to preserve the appearance of continuous sound or image, such applications are delay-intolerant, providing real challenges for network equipment developers and network designers. But for cabling-to-the-desk, the medium simply must carry data at an adequate rate.

Data compression techniques have reduced the bandwidth requirements by an order of magnitude while network data rates have steadily increased. The degree of compression that is acceptable depends on the quality desired for the sound or image. Various algorithms are available that allow developers and end users to tune the degree of compression to an application's requirements, but there is always a cost in terms of quality. The other penalty is latency – sophisticated compression schemes increase latency that is burdensome for real-time 2-way video interactions.

Multimedia applications are made up of individual elements that have widely different information transfer properties. For example, printed text requires the reader to scan sequences of code and reconstruct the code into words, sentences and paragraphs. While vision is capable of perceiving a large amount of material instantly, it is not efficiently utilized for text-oriented data. As elements become more graphic, the information they contain becomes easier and faster to process. The following paragraphs summarize the estimated data rates required to run various network multimedia applications at acceptable levels of performance and illustrate the need for gigabit networking.

Still images most often refer to photographic reproductions of existing objects. There is a famous saying 'A Picture Paints A Thousand Words'. A still image can transfer information faster than text, since human beings process visual information much faster than written information. Photographs can be created digitally or converted to a digital format, usually through a scanning process. A photograph can contain millions of color variations, which can be recreated in digital format. Since image files tend to be large, especially if millions of colors are used, they benefit from compression techniques. Many compressed file formats are used for the storage of digital still images.

Let's consider the data rate requirements for these applications. At 1200 dots per inch (dpi), an 8.5 inch x 11 inch page translates into (8.5 x 1200) x (11 x 1200) = 10200 x 13200 = 134,640,000 dots. If the 8.5 inch x 11 inch page is a grey scale image that uses 256 shades of grey, each dot represents one byte of storage space. Therefore, the whole image requires 134,640,000 bytes or 134.6 MB of storage space, uncompressed. Even with compression, if many such images are expected to be simultaneously transmitted over a network during normal operations, the network must be specifically designed to accommodate such traffic.

While imaging and graphics software generate large data files, audio and video applications create larger ones, even after compression algorithms have been applied.

Audio is a dynamic element that can be used to enhance multimedia applications in many different ways. Uses for audio include the following:

- Voice recognition of computer commands
- Spoken help functions
- Voice-annotated documents
- Voice-annotated e-mail messages
- Sound effects associated with video and animation
- Music

The use of sound contributes to a more realistic representation of information. Capturing and converting audio into digital format can result in very large files, especially if compact disc (CD)-quality sound is desired. The ultimate size of the captured audio file depends on four factors:

- The length of the audio clip
- The sampling rate-11, 22, or 44 kilohertz (kHz)
- The number of bits used to represent each sample-8 or 16 bits can be used
- Whether the recording is stereo or mono - stereo sound produces a file that is twice the size of a mono file, since two channels must be recorded.

For CD-quality sound, the recording must be in stereo, with a samplingFor CD-quality sound, the recording must be in stereo, with a sampling rate of 44,000 hertz (44 kHz) and 16 bits used for each sample. Therefore, a one-minute recording of this type requires over 10 MB of disk storage capacity.

The calculation is as follows:

44,000 samples/second x 16 bits/sample x 2 = 1,408,000 bits/second = 1.408 megabits/second

1.408 megabits/second x 60 seconds/minute = 84.48 megabits/minute

With 8 bits/byte, this leads to approximately 10 MB/minute.

At 1.408 Mb/s each, multiple CD-quality sound files played over a network simultaneously can quickly use up a considerable amount of bandwidth. Alternatively, downloading as a full CD sound file takes considerable bandwidth to undertake in a timely fashion.

Video is the element most often associated with the term multimedia. It can be used in real-time telecommunications (e.g., a video conference) or captured and stored for later use (e.g., a video clip in a digital document). The ability to digitize video has enabled audiovisual technologies associated with film and television to be deployed in any office. The communications channel capacity and storage requirements for transmitting and storing digital video are the most demanding of the multimedia elements. One minute of high-quality uncompressed video can consume 500 megabytes (MB) of storage space.

Expanding the earlier saying 'A Video Portrays A Thousand Pictures', video is a sequence of frames (still images) played back in rapid succession. In the case of digital video, the screen images displayed are in a digital format made up of many individual dots or pixels. Video graphics array (VGA) monitors can display resolutions of 640 pixels across by 480 pixels down, up to ultra video graphics array (UXGA) resolutions of 1600 pixels across by 1200 pixels down. To digitally display true, photo-realistic color, each pixel requires three bytes of storage - one each to describe the red, green, and blue (RGB) color components of each pixel. Therefore, the 1600 x 1200 pixel display showing full screen video that is uncompressed would require 5,760,000 bytes (1600 pixels x 1200 pixels x 3 bytes/pixel) of information to display one frame of video. In reality, most video is transmitted compressed using standards based encoding schemes such as MPEG2 or MPEG4 (Motion Picture Entertainment Group) that require a fraction of the digital information required for uncompressed, but there are a growing number of applications such as medical CT scans, X-Rays and entertainment formats that require this uncompressed capability.

The perception of motion occurs when a series of frames are displayed in rapid succession known as the refresh rate. For example, standard analog television displays use a refresh rate of 30 frames per second (25 frames per second in many parts of the world). Higher resolution applications such as VGA require analog refresh rates more than double that, in the order of 72 frames per second. To achieve this digitally uncompressed over a data network would require a data throughput of 8 bits/byte x 5,760,000 bytes/frame x 72 frames/second = 3.3 Gb/s.

At 3.3 Gb/s, it is clear that constant digital video traffic would rapidly cause most networks to fail due to congestion, especially if document sharing and text/image file transfer is added and occurring at the same time in real-time. Gigabit networking is fully justified for these applications, but what about others to be deployed in the future:

- Moving images: Full-motion video with digital HDTV quality is probably the most demanding streaming application. The bit–rate required for an RGB HDTV studio signal with 1080 active lines, 1920 samples per active line, 8 bits per sample, and 30 pictures per second is 3 x 1080 x 1920 x 8 x 30 that equates to approximately 1.5 Gb/s. To broadcast to today's consumers requires the data rate to be compressed to something less than 20 Mb/s, a factor of 75.
- Future applications: There are a few streaming applications on the horizon that would require still higher data rates to the desk. Any such applications would increase the realism (and effectiveness) of the experience.
  Some possibilities could include:
  - Use of large, ultra-high-resolution LCD displays for enhanced videoconferencing.
  - Virtual reality or "telepresence" applications with sound and high-resolution 3-D images, possibly with other senses engaged as well. This technology would allow the desktop user to feel physically present at the remote site.

The success of multimedia applications can be a double-edged sword for network managers. State-of-the-art multimedia, Internet and groupware applications can bring the enterprise major advances in productivity and cost savings. At the same time, these applications can tax the bandwidth needs of even the most robust networks, applying pressure at the desktop, the server and the switch, while creating higher capacity demands at the network core.

The Bit-Rate Race to the Desktop

As recently as two years ago the hottest topic in the LAN industry was Gigabit Ethernet development at 1000 Mb/s. The fact that it was still "Ethernet," but ten times faster than existing LANs, made it the clear winner in the high bit-rate race to the desktop. In cabling terms, this fast technology accelerated the trend towards Category 5e and 6 cabling. The introduction of tri-speed 10/100/1000 U/UTP Ethernet interface cards allowed network managers to leverage their existing installed base of Ethernet switch electronics, yet provide a simple upgrade path to higher speed capability in the future. As the cost of these gigabit interface cards dropped, Gigabit Ethernet grew dramatically in the LAN.

Of all the LAN protocols, Ethernet is clearly the marketplace winner. As Ethernet has evolved to higher-speed forms, it addressed the needs of end users with a cost-effective reliable solution to their data networking needs. Additionally, switched Ethernet networks have shown themselves to be extremely robust, performing over every physical media layer available, from coaxial cables to all types of fiber-optic cables.

As the demand for bandwidth continues to increase, the next step in the evolution of Ethernet has appeared - 10 Gigabit Ethernet. The compelling reasons for 10 Gigabit Ethernet are that it:

- Supports all services (packetized voice and video, data) and Layer 3 through Layer 7 intelligence of the OSI model
- Easily scales enterprise and service provider networks
- Leverages the hundreds of millions of installed base of Ethernet switch ports
- Enables superior Quality of Service (QoS)
- Supports LANs, MANs and WANs
- Matches the MAN/WAN backbone speed of OC-192

Because almost all network traffic today starts out as Ethernet and Internet protocol (IP) traffic, building Ethernet networks with the next step up in speed is one of the ways to scale enterprise and service provider networks. A fundamental rule of building switched networks is that a faster technology is always needed to aggregate multiple, lower-speed segments. In short, for enterprise LAN applications, 10 Gigabit Ethernet will enable network managers to scale their Ethernet networks from 10 Mb/s, 100 Mb/s or 1000 Mb/s to 10,000 Mb/s, while leveraging their investments in Ethernet as they increase their network performance. For service provider metropolitan and wide-area applications, 10 Gigabit Ethernet will provide high-performance, cost-effective links that are easily managed with Ethernet tools and, with the adoption of wavelength division multiplexing (WDM) techniques, scale up to terabit speeds and beyond. With WDM, hundreds and in the future thousands of 10 Gb/s channels can be transmitted onto a single fiber at different optical wavelengths or colors of light.

Infrastructure Implications

As higher capacity network equipment is introduced, new cabling systems that support that capacity are more than often required and deployed. The typical sequence of introduction is:

- R&D and planning start; industry study groups are formed
- Cabling and LAN standards groups are formed and draft proposed standards
- Cabling that anticipates the standards is introduced
- Standards are ratified and standards-based LAN equipment is introduced. Standard cabling is widely installed in new and re-cabled facilities. (NICs generally are able to support the old and new data rates without change out.)
- LAN equipment is deployed, first in the backbone, then in the horizontal
- Applications emerge that exploit the higher network speeds

The initial 10 Gigabit Ethernet standard was undertaken by the IEEE 802.3ae Committee and was published in 2002, and is based primarily on fiber-optic technology. Four optical transceivers were selected: 1310 nm serial for singlemode fiber, 1550 nm serial for singlemode fiber, 850 nm serial for laser optimized multimode fiber (referred to as OM3 fiber in international standards), 1310 nm wide wavelength division multiplexing (WWDM) for installed multimode fiber and singlemode fiber.

From an infrastructure perspective, choosing fiber-optic cabling to deploy that offers the most cost effective support for the aforementioned options has become a relatively simple decision:

- For the lowest cost, fully backwards compatible LAN implementation for distances up to 300 meters, the laser optimized (OM3) multimode solution is the optimum choice. The SYSTIMAX® LazrSPEED® Solution offers options up to 550 meters.
- For LAN, MAN and WAN implementations with extended distances, the singlemode solution is the optimum choice. Within the MAN and the LAN, the trend is toward singlemode fiber such as SYSTIMAX TeraSPEED™ Low Water Peak (LWP) fiber, which has eliminated the hydroxyl peak that has been so associated with fiberoptic cable performance and opened up a larger window of wavelengths for use with WDM applications in metro/campus applications.
- The use of the small form factor LC connector gives the lowest loss, highest density solution. The LC connector has become the connector of choice for the high-speed optical transceivers for 1 and 10 Gigabit Ethernet.

The value of performance excellence in copper cabling is now also being highlighted with the development of 10 Gb/s over copper cabling. With the ratification of the IEEE 802.3an 10GBASE-T standard, the development of 10 Gigabit Ethernet specification for copper cabling is now a reality. Due to the complexity of electronics to support 10GBASE-T, an early objective to support Category 5e was dropped, and the exact maximum distance over minimally compliant Category 6 cabling is still uncertain. Many expect that, as the clever chip designers further dive into this project, novel techniques will be developed which will increase the minimum guaranteed distance over generic Category 6 cabling. Margin over the minimum Category 6 specifications will also extend the distance capability.

A new set of cabling requirements to provide a 100-meter, 4-connection channel capable of supporting 10GBASE-T have been ratified and published as ANSI/TIA-568-B.2-10 for Category 6A and Amendment 1 to ISO/IEC 11801:2002 for Class E_A. The message this should send to end-users who are considering or have recently installed horizontal cabling systems is “don’t panic,” but be aware of the potential areas in your infrastructure where 10 Gb/s may be required first. You probably will not have to pull out your existing cabling system in anticipation of 10 Gb/s applications appearing tomorrow, but there will be a need for evaluation of that infrastructure once it does.

With the above in mind and with a history of network speeds increasing, CommScope's SYSTIMAX GigaSPEED® X10D Solution enables endusers to install a high-performance cabling system designed to support 10 Gb/s, and prepare for future performance.

Due to the hierarchical nature of the LAN and the “funneling” effects of LAN switching, the “need for speed” clearly grows the further one gets out from the desktop. The natural evolution for the general business LAN over the next few years will involve a migration to switched 1000 Mb/s at the desktop, switched 10 Gb/s capability first at the server interface and then in the building backbone, and finally switched 10 Gb/s capability in the mainstream enterprise environment. The infrastructure portion will experience a similar migration over the same time period, with high performance U/UTP strongly positioned as the horizontal medium, laser optimized multimode fiber in the building backbone and singlemode fiber in the campus.

TABLE 1: TIMELINES FOR 100 MB/S, 1 GB/S AND 10 GB/S ETHERNET OVER COPPER

Milestone	100 Mb/s Ethernet	1 Gb/s Ethernet	10 Gb/s Ethernet
R&D starts (cable & equipment)	~1990	1995	2002
Cabling available for horizontal	1991 (Pre-standard Cat 5)	1995 (Cat 5e) 1998 (Cat 6)	2004 (GigaSPEED X10D Solution)
Rapid cabling growth in horizontal	1993	1998 (Cat 5e) 2001 (Cat 6)	2006
Standards approved	1995 (cabling) 1996-1997 (equipment)	1999 (equipment) 2000 (cabling)	2006
Equipment available for LAN backbone	1995	2000	2005
Start installation of equipment for desktop connection	1997	2002	2008
Rapid growth of equipment for desktop connection	1998	2004	2009/2010

Conclusion

The rate of technology adoption or application development is very difficult to predict with any certainty. What appears more and more likely is that desktop bandwidth growth will continue to increase, but in a controlled fashion, driven by the aggregate requirements of mainstream business applications which continue to become more sophisticated and the reducing costs of interface cards. Given this evolution, a well-engineered combination of switched 100 Mb/s Ethernet and switched 1000 Mb/s Ethernet over high-performance U/UTP to the desktop will be the common approach to network design today, while satisfying the general business LAN user community for the next few years. The aggressive pricing action filtering through the industry has made these technologies marginally more expensive than traditional Ethernet.

There are certainly select vertical markets that have bandwidth needs falling outside of this norm. High-speed technologies such as 10 Gigabit Ethernet are needed already in areas of the LAN. For the near term, that need will be limited to the interconnection of high-performance servers, switches and CAD stations, and in backbone applications supporting increased usage of Gigabit Ethernet to the desktop. However, 10 Gigabit speeds to the desktop will become a reality due to steadily increasing bandwidth demands, coupled with reducing cost of interface electronics and the potential adoption of technologies such as grid computing. From a cabling infrastructure perspective, installing the SYSTIMAX GigaSPEED X10D cabling solution offers an inexpensive investment to prepare for an unpredictable future.

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