Gigabit Ethernet

and

Expanding Network Environments
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Ethernet Background

Nearly thirty years ago, Robert Metcalfe, David Boggs, and a team of Xerox researchers began developing a means of interconnecting graphical computers at their Palo Alto Research Center (PARC) in California (10GigE Technology, 9/01). Envisioned as a way for computers within a single building or campus to share data among each other, this technology soon became known as the Ethernet, so named because it created a network of computers seemingly interconnected through the “ether.” While the coaxial cable design was relatively simplistic, the idea of interconnecting computers within a network architecture was nevertheless powerful and, over time, attracted the attention of several influential companies, including Xerox, Intel, and Digital Equipment Corporation. During the early 1980’s, these companies formed a consortium to promote the technology as a local area network (LAN) implementation that delivered relatively high performance at a minimal cost (GigE Equipment, 2001). Around the same time, Ethernet gained additional substantiation when the Institute of Electrical and Electronics Engineers (IEEE) announced the 802.3 standard for the technology.

Since that time, Ethernet technology and its associated 802.3 standards have evolved substantially (Table 1).

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Medium</th>
<th>Max Length (m)</th>
<th>IEEE Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>10Base-T</td>
<td>Cat 3/4 TP</td>
<td></td>
<td>802.3i</td>
</tr>
<tr>
<td>100Base-TX</td>
<td>Cat 5 TP</td>
<td></td>
<td>802.3u</td>
</tr>
<tr>
<td>1000Base-SX</td>
<td>Short λ MM Fiber</td>
<td>550 (new) / 220 (old)</td>
<td>802.3z</td>
</tr>
<tr>
<td>1000Base-LX</td>
<td>Long λ MM Fiber</td>
<td>550</td>
<td>802.3z</td>
</tr>
<tr>
<td>1000Base-LX</td>
<td>Long λ SM Fiber</td>
<td>5000</td>
<td>802.3z</td>
</tr>
<tr>
<td>1000Base-CX</td>
<td>Cat 5e STP</td>
<td>25</td>
<td>802.3z</td>
</tr>
<tr>
<td>1000Base-T</td>
<td>4-pair Cat 5e UTP</td>
<td>100</td>
<td>802.3ab</td>
</tr>
<tr>
<td>10Gbase-LX?</td>
<td>MM Fiber</td>
<td>350+</td>
<td>802.3ae</td>
</tr>
<tr>
<td>10Gbase-LX?</td>
<td>SM Fiber</td>
<td>40,000+</td>
<td>802.3ae</td>
</tr>
</tbody>
</table>

Table 1 - Ethernet Choices

With the introduction of different physical media, topologies, ranges, and speeds, Ethernet has gained significant improvements in functionality and has expanded its network scope beyond the original local area environment. In fact, the newest versions of the technology, Gigabit Ethernet and 10 Gigabit Ethernet, are now attempting to expand into the larger scale network markets of
Metro Area Networks (MAN) and Wide Area Networks (WAN). With corporate backing from industry leaders like 3Com, Cisco Systems, Extreme Networks, Intel, Nortel, and Sun Microsystems, Gigabit Ethernet, or Gig-E, as it has come to be called, promises levels of operability to successfully compete with legacy architecture in these areas (10GigE Technology, 9/01).

**Technical Description**

At its most fundamental level, the Ethernet is a simple network architecture designed to interconnect computers and transport data over a bus using a physical medium such as copper, coaxial, or fiber optic cable. To accomplish this, it utilizes a Data-Link Layer protocol further defined in IEEE 802.3 media access control standards to handle actual transmission and error-free delivery of data across the Physical Layer. Together, these layers define how multiple computers can access and share the network simultaneously without interference from one another. In keeping with these roots, Gigabit Ethernet (1000Base-X) and its follow-on 10 Gigabit Ethernet cousin are built upon the same fundamentals as the original Ethernet model and share a number of commonalities, including frame format and packet size.

This is not to say, however, that Gigabit Ethernet is the carbon copy of its ancestors. Indeed, to keep pace with current and projected network growth, 1-Gig-E and 10-Gig-E have some notable changes introduced to accommodate new or competing technologies, enhance performance at higher speeds, and broaden their appeal in the world of metro area and wide area networks.
Gig-E and Network Environments

In its original design, Ethernet was designed to handle communications within local area networks only. Such networks span a relatively small area and typically link computers and peripheral devices confined to a building or a group of buildings. As the numbers of users and applications have grown, however, networks have begun to expand and interconnect to form larger networks known as metro area networks (MAN) and wide area networks (WAN). These networks are typically longer in range than LAN’s and involve increased volumes of data transfer. MAN’s, for example, are typically used for business applications to interconnect firms within geographic areas like districts using high-speed connections such as fiber optic cabling or other digital media. Covering even larger geographic areas are WAN’s, which typically connect cities with large high-speed fiber optic trunk lines to interconnect individual LAN’s. With this in mind, several new features have been built into 1-Gig-E and 10-Gig-E in order to expand into these networking environments, including improved media and hardware, altered MAC protocols, and more versatile physical layers.

Physical Media and Growing Ranges

As before with Fast Ethernet, 1-Gig-E can still utilize several different media types, including both twisted pair copper (shielded and unshielded) and fiber optic cabling (Table 2). This enables smooth migration of current Category 5 Twisted Pair systems to faster speeds with little change in infrastructure. Reliable 1Gbps service over longer medium lengths has also been achieved using single and multimode fiber optic cable for distances up to 5000 meters (Easy Migration – White Paper). Among other things, this range extension over previous versions has many reconsidering the merits of Ethernet in the Metro Area Network environment.
Conversely, 10-Gig-E will be available over optical media only in order to maximize range capability and data capacity. Adding a long haul optical transceiver when using single-mode fiber, for example, can extend ranges out to 40 km, making 10-Gig-E an increasingly attractive alternative at the Metro Area Network and even Wide Area Network level as well (10Gig-E Gets, 2/11/00).

**Media Access Protocols and Changing Traffic Patterns**

1-Gig-E has been built to accommodate both half- and full-duplexing of data transmission to enable backward compatibility with legacy systems using 10Base-T and 100Base-TX technology, while simultaneously maximizing efficiency with state-of-the-art devices. Since traffic control over the Ethernet has traditionally been accomplished with half-duplexing and the Carrier Sense Multiple Access and Collision Detection (CSMA/CD) protocol, 1-Gig-E also employs this technology to satisfy backward compatibility with legacy systems. The protocol monitors network congestion and sends data over a shared channel in the absence of other data that might potentially cause a collision. Because of the increased transmission speed however, the minimum data packet size

<table>
<thead>
<tr>
<th>Time</th>
<th>Accomplishment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973-76</td>
<td>Xerox develops Ethernet</td>
</tr>
<tr>
<td>1980</td>
<td>Ethernet Specification (Version 1.0) – 10 Mbps</td>
</tr>
<tr>
<td>1982</td>
<td>First 10 Mbps shared access available</td>
</tr>
<tr>
<td>1983</td>
<td>IEEE releases 802.3 - Initial standard for CSMA/CD LAN (Ethernet)</td>
</tr>
<tr>
<td>1985</td>
<td>IEEE releases 802.3a - “thin” coaxial cable (Coaxial Thinnet)</td>
</tr>
<tr>
<td>1987</td>
<td>IEEE releases 802.3d - 1000m max distance between 10 Mbps repeaters</td>
</tr>
<tr>
<td>1990</td>
<td>IEEE releases 802.3i - 10 Mbps over Cat 3 UTP cable</td>
</tr>
<tr>
<td>1992</td>
<td>First switching introduced for 10 Mbps LANs – no more need for CSMA/CD</td>
</tr>
<tr>
<td>1993</td>
<td>IEEE releases 802.3j - 2000m max distance between repeaters</td>
</tr>
<tr>
<td>1993</td>
<td>Fast Ethernet (100 Mbps) supports 10/100 Mbps AND fiber optic version</td>
</tr>
<tr>
<td>1995</td>
<td>IEEE releases 802.3u – Speeds increased to 100 Mbps</td>
</tr>
<tr>
<td>1997</td>
<td>IEEE releases 802.3x – Concurrent transmit/receive with Full duplex vice half-duplex</td>
</tr>
<tr>
<td>1997</td>
<td>First 1 Gig-E used for Intranet backbones and large file transmissions</td>
</tr>
<tr>
<td>1998</td>
<td>IEEE releases 802.3z – Speeds increased to 1000 Mbps (1 Gig-E) over fiber optics</td>
</tr>
<tr>
<td>1999</td>
<td>IEEE releases 802.3ab – 1Gig-E over Cat 5 UTP cable (Twisted Pair - COPPER!)</td>
</tr>
<tr>
<td>2000-02</td>
<td>Works begins on 802.3 HSSG – 10 Gig-E standard</td>
</tr>
<tr>
<td>2001-02</td>
<td>First 10Gbps networks installed for MAN</td>
</tr>
<tr>
<td>2002</td>
<td>IEEE set to release 802.3ae – 10 Gig-E standard (Fiber Optic only)</td>
</tr>
</tbody>
</table>

Table 2 - Evolution of Ethernet
for 1-Gig-E transmission had to be extended from 64 to 512 bytes to allow the transmitting station time to sense a collision before a packet had reached its final destination. Thus, small packets are now augmented with an extension to bring them up to the minimum 512 bytes required by CSMA/CD to maintain a 200-meter collision diameter (GigE: Accelerating, 5/99).

In contrast, the advent of high-speed switches in recent years has eliminated the need for channel sharing by providing nearly instantaneous “dedicated lines” between nodes, and many platforms, including Gigabit Ethernet, now utilize full-duplex operating modes for simultaneous two-way traffic to enhance system performance (GigE: Accelerating, 5/99). Devices operating on this 802.3 specification are not susceptible to data collisions because of the dedicated connection and, therefore, do not need carrier extensions. Therefore, such devices continue to use the original minimum packet size and inter-frame gap (GigE: Accelerating, 5/99). On the other hand, 10-Gig-E is only being designed with full-duplex operation in mind in order to compete on even footing with current MAN and WAN architectures.

**Synchronous Optical Network vs. Gigabit Ethernet**

Over the years, Ethernet has become synonymous with LAN and, in recent years, enterprise networks. However, while nearly all agree on Ethernet’s capabilities and dominance in these networks, some still doubt the ability of Gigabit Ethernet to make the successful transition to MAN and WAN environments as a viable networking solution. They claim that the thirty-year-old technology lacks the robustness and operability to compete with the current MAN and WAN infrastructures of Synchronous Optical Network (SONet). Others predict Ethernet will never replace SONet because it lacks long haul capability and is troubled by low resiliency and high latency shortcomings.
Synchronous Optical Network, or SONet for short, is the optical transport standard and technology used in legacy metro area and wide area networks, and, as such, Ethernet’s primary competition. Developed by the Exchange Carriers Standards Association for the American National Standards Institute (ANSI), SONet is typically employed using a ring topology around large metropolitan areas and cities (SONet 101). Though originally developed for the Regional Bell telecommunications companies as a means of handling massive amounts of voice traffic, the technology has been proven to handle high-speed data and video transmissions as well. It utilizes a basic transmission rate of 51.84 Mbps (OC-1), but also carries higher-level signals at integer multiples of the base all the way to 9.95328 Gbps (OC-192) (Table 3) (SONet 101). These discrete “optical carrier levels” allow for the simultaneous transmission of different data streams at various transmission rates using single-multiplexing (SONet 101). Together with the nearly identical European version, Synchronous Digital Hierarchy (SDH), SONet has enabled otherwise incompatible carriers throughout the world to interconnect their existing digital carrier and fiber optic systems using an extremely effective and resilient ring architecture.

### The Costs of Networking

SONet and all of its associated hardware, while durable, are an extremely expensive technology platform to build, maintain, and upgrade. A typical OC-192 SONet switch, for example, sells for over $200,000, whereas its Ethernet counterpart is offered by Foundry for $45,000. While it would seem that this fact would help Ethernet’s cause, it is not necessarily the
case, at least in the immediate future. In fact, because of SONet’s relative expense compared to Ethernet, incumbent local exchange carriers who have already made serious capital investments in the technology “aren’t going to rip out billions of dollars of equipment on a whim and re-do their entire network on Ethernet,” states Doug McEuen, senior market analyst of optical networking for Boston-based Pioneer Consulting (GigE Market, 11/12/01). Stu Elby of Verizon’s Network Architecture Group agrees, “Our biggest selling service is still SONet” (Caisse, 9/24/01).

For Gig-E to uproot and overtake the incumbent SONet in the MAN and WAN environments, it will have to prove an overwhelming economic superiority and an ability to deliver unparalleled service to its users. Even still, proponents of Gig-E are quick to point out the significant savings that can be realized with Ethernet, not only from minimal maintenance and retraining costs, but also from economies of scale and manufacturing competition, as well as from the on-demand bandwidth and scalability offered by the technology. Indeed, as Bill Scanlon, senior writer for Interactive Weekly proclaims, Gigabit Ethernet is “the hottest play in the metro area because it can carry heavy traffic from office to branch office and onto the public network – and do so at a tenth of the cost of the Synchronous Optical Network infrastructure traditionally used in metro rings.”

A significant portion of these savings stem from the fact that companies making the leap to Gigabit Ethernet will not have to contend with expensive retraining or “forklift upgrades.” Because Ethernet has been around for decades, IT teams and maintenance technicians are intimately familiar and comfortable with the technology at the office level. Similarly, rigid 802.3 standards promulgated by IEEE have helped ensure that today’s 1-Gig-E and tomorrow’s 10-Gig-E are, for all intents and purposes, the same fundamental technology introduced thirty
years ago in Palo Alto. For these reasons, very minimal retraining and hardware replacement will be necessary for Ethernet’s migration into the public network (Scanlon, 9/10/01).

Additionally, Ethernet’s large installed base in the LAN environment has created economies of scale and fierce competition in today’s IT sector that have acted in concert to drive down implementation and hardware maintenance costs for network providers (Garrod, 8/6/01). Gigabit Ethernet and even 10-Gig-E will not be any different in this respect, as both have received overwhelming corporate backing from alliances that include such giants as Intel, Nortel, Cisco Systems, Lucent, and 3Com, among others. These firms, wanting to accelerate the acceptance of Gig-E, are collectively working in conjunction with IEEE standards committees to promote the technology within the MAN and WAN communities through conferences and tradeshows that showcase the interoperability of Gig-E products (10GigE Gets, 2/11/00).

Another cost advantage to the user comes from Ethernet’s scalability and on-demand bandwidth capabilities. When a company using SONet infrastructure desires more capacity, the carrier must either upgrade the entire ring or install an overlay ring, followed by a manual provisioning of the time-division multiplexing used in SONet (Caisse, 9/24/01). With Ethernet, carriers can provision a network connection to the customer’s specifications within minutes instead of months. If, for example, a consumer is planning to conduct a videoconference between 2:00 and 4:00, he can contact his carrier earlier that day to double his normal bandwidth during that period of time (Lawson, 11/1/01). Thus, Ethernet allows providers to deliver just the right amount of bandwidth that a customer needs, when she needs it. Companies like PreviewPort, for instance, who host video and voice chats with best-selling authors, need the ability to “crank the bandwidth up and down, and pay only for what it uses” (Scanlon, 9/10/01).
System Performance

Metro and wide area networks have grown significantly under Synchronous Optical Network (SONet) technology in the last decade. With its simple ring architecture, SONet works, and it delivers communications with a high degree of resiliency and reliability. Though originally designed to carry large volumes of voice traffic, SONet has also been proven to handle data traffic as well with negligible latency or jitter (Scanlon, 9/10/01). Indeed, as Jonathan Reeves, President and CEO of Sirroco Systems, proffers, “With SONet, you can take an OC-192 circuit and allocate one OC-48 for voice, a second for ATM, and two for IP data. You can’t do that with Ethernet (and expect to) achieve the same level of rigidity” (10GigE Gets, 2/11/00).

As more and more of today’s communication lines are filled with data transfer instead of voice traffic, however, Ethernet, a technology designed to move data, is in the perfect position to overtake SONet and other infrastructures originally designed with voice in mind. Reeves admits, “In a pure data environment, where the only traffic consists of IP packets, it’s an excellent choice” (10GigE Gets, 2/11/00). Ethernet already moves over 90% of data traffic in current networks, most of which begins on one Ethernet network and ends on another with interconnection provided by SONet lines (Scanlon, 9/10/01). As Ethernet’s scope expands to bridge the gap between LAN’s in the long-haul environment, it will be able, for the first time, to provide the customer with a complete end-to-end networking solution. Thus, networks will eventually become, in effect, one large LAN with no complex protocol conversion necessary at the current network boundaries (GigE Market, 11/12/01).

Carrier demands of high resiliency and low-latency, currently associated with SONet systems, are also being addressed in 1-Gig-E and 10-Gig-E. Multiprotocol Label Switching (MPLS), for instance, is a relatively new technology designed to “bring discipline to traffic
engineering on a Gig-E IP network” by speeding up the switching used for packet data bursts (Scanlon, 9/10/01). It streamlines packet handling by labeling streams in such a way that routers need only read the first packet in a stream of packets. Also, several chipmakers, service providers, and equipment vendors have formed the Metro Ethernet Forum (MEF) to finally nail down a standard on Resilient Packet Ring (RPR), a technology that promises to match the reliability of SONet and the microsecond latency required by carriers transmitting both voice and data. While still in the development stages, RPR would provide a means of carrying Ethernet frames in a token ring configuration while still enabling access to the ring by numerous devices (Scanlon, 9/10/01).

**Long Haul Shortcomings**

Even with its attractive economic savings and improving robustness and resiliency, Gigabit Ethernet still faces the issue of limited transmission length when compared to SONet. Despite new 10-Gig-E narrow bore, single-mode fiber standards boasting distances of over 40 km, Ethernet’s successful transition to long-haul networks is far from complete (Hunter, 7/19/01). But as IEEE’s 802.3ae standards are ratified in the second quarter of 2002, companies will continue to push the envelope of Ethernet capabilities. Already, several are testing innovative products and accomplishing many “firsts” for the thirty-year-old technology. Foundry and Sycamore Networks, for example, teamed up in May of this year to link Helsinki and Stockholm, Sweden using high-speed switches and the Gig-E protocol.

To deal with the problem in the short term, Gig-E has an existing WAN physical interface already in place that allows Ethernet to be transported across legacy SONet/SDH lines. Thus, providers are afforded a great deal of flexibility when it comes to deploying Gig-E
technology in the WAN environment and are not forced into “forklift upgrades” or immediate obsolescence of existing backbones.

**Gigabit Ethernet As An End-to-End Solution**

The many benefits that Gigabit Ethernet brings to the network environment including affordability, scalability, ease of maintenance, corporate and IEEE backing, and simplicity of design, will guarantee its eventual, if not immediate, expansion into the metro and wide area networks. Such expansion, however, will begin at the LAN level.

**Local Area Network Deployment**

While already the medium of choice at the local level, the introduction of 1-Gig-E technology to existing LAN’s is a natural extension to existing Ethernet service by offering faster speeds and on-demand bandwidth at relatively low costs. As applications evolve to incorporate rich media types like high-resolution graphics and video, pressure is growing, not only at the network and server levels, but also at the business desktop level for increased capacity (GigE Networking). A growing number of applications are appearing that are very bandwidth-intensive, including scientific modeling and engineering applications like CAD and CAM, medical data transfer like x-ray graphics, and data warehousing to include storage system backup, all of which require the transfer of huge files (10GigE Technology, 9/01). So, as bandwidth demands continue to grow at the small-to-mid-size business level, local area network backbones will need upgrading to support this increased data flow. Gig-E, with its on-demand bandwidth capability, will provide cost-conscious businesses the volume capability when and only when they need it.

Moreover, 1-Gig-E, with its ability to travel over copper or fiber, offers nearly seamless introduction into existing Cat 5 copper networks with no “forklift upgrading” required.
Companies can boost performance simply by upgrading servers and switches to accommodate multiple connection speeds without expensive rewiring, and, in doing so, they can maximize existing copper networks and still increase productivity by alleviating current server bottlenecks.

Larger businesses, on the other hand, should consider upgrading to fiber optic lines using 1-Gig-E, or possibly even 10-Gig-E in the long run. Utilizing multi-mode fiber, or single-mode fiber, businesses can connect groups of buildings, link segment switches to the data center, and connect servers outside the enterprise as much as 5 km apart with 1-Gig-E (Patenaude, 11/1/01). This setup has been proven particularly wise for organizations that use video conferencing and interactive white-boarding which require near-constant data streaming and predictable, low latency (GigE Accelerating, 5/99). Such upgrades, however, may also require a significant capital investment, as the installation of fiber optic cabling may be required, if not already in place, in addition to new servers and switches.

10-Gig-E extends the maximum range even more by expanding large-organization network backbones up to 40 km. Such expansion will further blur the traditional geographic boundaries between local and metro area networks and give those companies/institutions that manage their own networks the added flexibility of interconnecting multiple campus sites up to 40 km apart. However, because of the expense, firms interested in 10-Gig-E may be wise to wait on the upgrade until at least mid-2002, when the 802.3ae standards are expected to be ratified by IEEE. This will ensure that the capital investment is spent in purchasing equipment that meets industry standards.

*Metro Area Network Deployment and Beyond*

Deployment of 1-Gig-E into the Metro Area Network environment makes fiscal sense as a viable networking solution today. It has significant advantages over current SONet technology
with its significantly lower cost, easier provisioning, and centralized management due to use of a single protocol (Allen, 7/5/01). Moreover, as the Gigabit Ethernet Alliance (GEA) and follow-on 10GEA actively develop and demonstrate increasingly reliable equipment, concerns over quality of service and packet loss associated with Gig-E at the MAN level continue to diminish. In addition, Resilient Packet Ring technology, while still under development, also promises to give Gig-E data protection and reliability equivalent to that of SONet, with a data link layer geared towards data packet flow (Allen, 7/15/01). For these reasons, Gig-E is ready for deployment on the MAN level now, with the potential for gradual deployment in WAN environments. It offers the necessary bandwidth to meet growing demands at a fraction of the cost of SONet and has copper capabilities for existing backbones, with room for upgrade to fiber.

10-Gig-E, on the other hand, still has issues that must be resolved before it is fully implemented into WAN or even MAN environments. With standards that still need ratification and significant limitations on range, full implementation into wide area networks is still years away. Even so, a growing number of experts agree that 10-Gig-E has too many benefits to be dismissed as a long-haul networking solution and will eventually “stumble to a bright future” in that world as well (Scanlon, 9/10/01).
Works Cited


Caisse, K., (2001, September 24), Shedding Light on Optical Ethernet; Ethernet in the MAN Shows Great Promise, but Legacy SONet Equipment Remains a Barrier. Network World.


