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Meeting the broadband access infrastructure demands: The promise of Gigabit Ethernet

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Abstract

Global Internet traffic growth continues to create bandwidth demand in the telecommunications network. As 100 Mb/s Ethernet and Gigabit Ethernet LANs are widely installed in enterprises, the Intranet bandwidth grows quickly. With active adoption of ADSL and cable modem broadband accesses in the SOHO and residential markets, more data traffic is generated in these markets as well. Presently, most telecom carriers use synchronous optical network/synchronous digital hierarchy (SONET/SDH) equipment to "aggregate" data traffic in the metropolitan area network (MAN) before accessing the Internet backbone network. Because of the intrinsic limitations of SONET/SDH equipment in transporting data traffic, especially in terms of bandwidth scalability and provisioning efficiency, there is a need to find a broadband access solution that can overcome the drawbacks of SONET/SDH. Because the inherent simplicity of the technology, Ethernet offers cost effectiveness, ease of networking, packet-based IP friendly protocol, and rapid provisioning advantages while competing with other networking technologies. These advantages coupled with the newly developed gigabit WAN capability have well-positioned Gigabit Ethernet as a compelling technology to break the bandwidth bottleneck in the MAN environment. In this paper, we review the enhancement of Gigabit Ethernet technology and discuss the pros and cons of using Gigabit Ethernet technology in the MAN. We also address the implications of this technology evolution on telecom carriers.

Keywords: Ethernet; SONET/SDH; LAN; MAN; WAN

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1. Introduction

Rapid increase of Internet users throughout the world has resulted in exponential growth of Internet traffic in wide area networks (WANs). Despite the recent telecom industry slowdown, worldwide Internet traffic, which is continuing to double every year, is forecasted to reach 5175 petabits per day in 2007 from 180 petabits per day in 2002 [1]. In addition to more users, Internet applications have become more bandwidth intensive as multimedia content becomes indispensable. To meet the increased demand for bandwidth, dense wavelength division multiplexing (DWDM) optical systems have been widely deployed in the backbone network [2]. Residential networks deploy asynchronous digital subscriber line (ADSL) and cable modems to provide subscribers with broadband access [3]. Connecting the broadband access network and the broadband backbone network is the metropolitan area network (MAN).

Originally, the MANs were designed and deployed to handle voice traffic. Data requirements arose only as an afterthought. The infrastructure of MANs is mostly based on time division multiplexing (TDM) technology, such as synchronous optical network/synchronous digital hierarchy (SONET/SDH) system, which was designed for connection-oriented voice traffic rather than connectionless data traffic. As Internet data traffic has outgrown the traditional voice traffic and has become the dominant traffic type, the transmission throughput limitation of the MAN to handle data traffic has become a bottleneck. Enterprises face a growing bandwidth mismatch as they try to push 100 Mb/s LAN or Gigabit Ethernet applications through T1/E1 or T3/E3 pipes to the core network. The convergence of data, toll-quality voice, and broadcast-quality video bit streams in the metropolitan network requires MAN to evolve into a data-centric architecture [4].

Due to the simplicity and cost effectiveness of the protocol, Ethernet has been widely deployed in the enterprise local area network (LAN) environment to handle the data traffic. Standard interfaces are readily available for 10/100/1000 Mbps Ethernet and the 10-Gbps Ethernet standard will also follow suit, given its IEEE standardization status. Because of Ethernet's relative simplicity and the economies of scale from the existing Ethernet installed based, infrastructure equipment costs for Ethernet are significantly less than for frame relay and asynchronous transfer mode (ATM). The implications of this wide deployment extend beyond economics of scale to less obvious benefits. For example, Ethernet is much easier to learn than SONET and ATM technologies, which has an important impact on employ hiring and availability. This inexpensive "good enough" technology/protocol is an asynchronous frame-based technology that has certain flexibility advantages over its more rigid cell-based or synchronous competitors. With suitable rate-limiting functions to manage the available resources and with sufficiently large trunk capacity, Ethernet can provide rapid bandwidth on demand. For networking, it is important to remove the interworking issues between platforms and environments in order to make service provisioning and activation simpler. Because of its IP friendly nature, Ethernet eliminates a layer of complexity (e.g., ATM and SONET) from WAN access, thus reducing configuration requirements. Ethernet's plug-and-play feature also enables a simple migration path from low to high speeds. Consequently, integrating and interfacing end-customer information technology (IT) systems are relatively simple with Ethernet metro services. All of the above advantages coupled with the newly developed Gigabit WAN capability have well-positioned Gigabit Ethernet as a compelling technology to break the bandwidth bottleneck in the MAN environment [5].

This paper first discussed the current mode of broadband service operations in the carrier's MAN environment. The enhancement of Gigabit Ethernet technology and the pros and cons of using Gigabit Ethernet technology in the MAN network are also reviewed. Finally, the implications of this technology evolution on carriers are discussed.

2. Present mode of MAN operations

To provide enterprises with broadband services, Telecom carriers have deployed SONET/SDH rings in the MANs. With the promise of ATM providing necessary quality of service (QoS) for multimedia services, ATM and SONET/SDH rings have become the choice of network architecture for most MAN carriers [4].

In order to accommodate the burst nature of data traffic, customers are asking for features such as flexible bandwidth allocation and short service provisioning time. However, due to the TDM nature of the SONET/SDH network architecture, telecom carriers can offer only leased lines in fixed increments of DS0s (64 kb/s), e.g., DS1 (24 DS0s) and DS3 (28 DS1s) or fixed bandwidths in optical carriers [6]. Variable bandwidth-leased line service is not possible under the SONET/SDH architecture. There exists the throughput mismatch issue of fitting Ethernet service rates into SONET/SDH transmission rates. If a client wants a 100-Mb/s Ethernet service, a carrier must provision a 155-Mb/s SONET channel to carry it, often throwing away the other 55 Mb/s. This inefficiency does not exist with Ethernet as the transmission layer. Furthermore, to provide an end-to-end SONET/SDH service requires a long lead time for the coordination of equipment and facilities before service can be activated. At times, the provisioning time for a SONET/SDH service can range from weeks to months. This long service provisioning time has become detrimental in the competitive business environment [7].

Because of the lack of bandwidth flexibility and the long service provisioning time of SONET/SDH equipment, service carriers face the following business risks:

1. Revenue loss: Since SONET/SDH cannot offer variable bandwidth service, customers who need such flexibility, for example 10 Mb/s bandwidth, turn to other service providers who can meet this demand. This means a revenue loss for the SONET/SDH carriers.
2. High operating cost: The complexity of the ATM and SDH/SONET equipment provisioning not only requires a skilled workforce to do planning, engineering, installation, and maintenance, but also needs comprehensive backend operations support systems (OSSs) support in order to offer ATM over SONET/SDH services. Maintaining a well-trained workforce and sophisticated backend OSSs translates into high operating costs. In addition, the relatively high cost of ATM equipment further erodes a carrier's profitability.

To address the above business challenges, a solution with flexible bandwidth allocation, data/IP friendly, and quick provisioning in the MAN is essential. Several competing technologies potentially address the above objectives. For example, ATM VP ring, SONET/SDH MSPP, resilient protection ring (RPR), and Gigabit Ethernet over WDM optical network are all emerging solutions for the MAN network. This paper focuses on exploring the feasibility of adopting the Gigabit Ethernet technology in the MAN environment. Challenges as well as pros and cons of deploying Gigabit Ethernet technology in the MAN network will also be discussed [8].

3. Evolution of Ethernet technology: from LAN to MAN and WAN

Ethernet is the most widely used LAN technology for data communications applications. The most popular version of Ethernet supports a data transmission rate of 10 Mb/s, while newer versions of Ethernet called "Fast Ethernet" and "Gigabit Ethernet" support data rates up to 100 Mb/s and 1 Gb/s (1000 Mb/s). Ten-Gigabit Ethernet has been proposed and is under development. In addition to the traditional physical twisted pair copper cable, Gigabit Ethernet can also use fiber optical cable as the transmission media to take advantage of its large bandwidth capability. Today, Ethernet-based LANs already own 95% of the corporate desktops market share [8]. The share is steadily increasing as Ethernet continues to enhance its features and transmission rates.

Ethernet success in the LAN environment can be attributed to its continued technology enhancements to meet users' needs.

1. Initially, Ethernet employed basic technology and simple protocols to provide fundamental LAN functionalities. This simplicity translated into high reliability and low maintenance cost for Ethernet users. As a result, Ethernet became widely accepted in the LAN market.
2. Because each Ethernet node must first "sense" the medium before starting to transmit data, this requires the transmission delay to be small enough so that the node at the other end of the cable knows when to transmit in order to avoid a collision. This effectively limits the cable length of Ethernet LANs. As a result, Ethernet "islands" proliferated in the business environment. As more Ethernet islands were deployed, connecting Ethernet islands together for intercommunications became a challenge.
3. In 1984, the Ethernet switch (also known as Bridge) was introduced. It provided a simple, fast, self-learning algorithm, enabling multiple Ethernet networks to be transparently interconnected. This allows the expansion of the Ethernet LAN coverage in the enterprise environment. Furthermore, an Ethernet switch can increase the bandwidth efficiency of individual LANs by assigning users that do not communicate with each other very often to separate LANs and users that do communicate with each other frequently to the same LAN. By doing so, the total effective LAN bandwidth can be increased. However, a basic Ethernet switch is limited to a single spanning tree environment and requires that no loops exist in the LAN topology.
4. In 1985, Virtual LAN (VLAN), also known as the multitree Bridge, was invented. VLAN removes the single spanning tree limitation and enables arbitrary LAN topology. Furthermore, VLAN offers unlimited capacity and redundancy, traffic priority, and easy reconfiguration advantages for Ethernet users. With the introduction of the VLAN, Ethernet switches began to dominate routers in the LAN environment [9].

Due to the characteristics of carrier sense multiple access with collision detection (CSMA/CD) protocol, Ethernet LAN transmission distance has to be proportionally reduced as the transmission rate increases. For example, for a minimum packet size of 64 bytes, a 10-Mb/s Ethernet can reach a maximum length of 2500 m. Under the same packet size, a 100-Mb/s Ethernet LAN can only extend 250 m. This distance limitation is of a particular concern for the introduction of Gigabit Ethernet. With the high data rate of a Gigabit Ethernet LAN, the applicable coverage is too small relative to the physical environment of an enterprise. Any resolution to this distance shrinking issue has to keep the integrity of

Table 1
Ethernet technology evolution

Ethernet	Provide LAN functions
Ethernet switch (bridge)	Connecting and providing switching functions for Ethernet LANs and increasing Ethernet LAN bandwidth efficiency
VLAN (multitree bridge)	Eliminating LAN loop-free topology limitation, enabling arbitrary LAN topology and capacity
Gigabit Ethernet without CSMA/CD	Ethernet transmission distance is only limited by the transmission characteristics of the physical media

the Ethernet frame structure in order to maintain backward compatibility with the large number of existing Ethernet equipment [7].

To solve this problem while keeping the same Ethernet frame format, the concept of full-duplex Ethernet was developed. In a full-duplex Ethernet, the CSMA/CD protocol is replaced by the function of a switch. By removing the CSMA/CD protocol constraints and replacing it with a switch, Ethernet transmission distance is no longer limited. For example, using fiber optic transmission media, an Ethernet LAN can cover up to 80 km. With this enhancement, Gigabit Ethernet can be extended to cover a metropolitan area. As a result, Ethernet LAN can expand into an Ethernet MAN [7]. The evolution of Ethernet technologies is summarized in Table 1.

The advantages of Ethernet are summarized below:

1. Plug and play fast provisioning time
2. Unlimited transmission distance (the removal of CSMA/CD)
3. No network topology limitation (the introduction of VLAN)
4. Multiple kinds of transmission media (fiber optical or coaxial twisted cable)
5. High transmission rate (10 Mb/s, 100 Mb/s, 1 Gb/s, 10 Gb/s, and higher rates)
6. Good price/performance (line speed switching)
7. Enormous number of installed base worldwide
8. Internet IP friendly
9. Scaleable bandwidth
10. Applicable for LAN, MAN, and WAN applications

In light of the above attributes, Gigabit Ethernet that uses fiber optical cable as the transmission medium can be used for MAN or even WAN applications. Because Ethernet has the attributes of easy provisioning and bandwidth flexibility, it appears that Gigabit Ethernet could be candidate for MAN access to alleviate the bandwidth bottleneck in broadband access.

4. Benefits of using Gigabit Ethernet technology for MAN access

Since Gigabit Ethernet is ideal for extension to the MAN environment, telecom carriers can integrate it into a broadband solution that offers bandwidth scalability and easy deployment. In addition to fast provisioning and bandwidth scalability, additional benefits of simplified network architecture and reduced cost can also be realized [8].

4.1. Simplified network architecture

If carriers offer conventional DS3 (45 Mb/s) broadband service, they will have to provision digital cross-connect system (DCS) and SONET/SDH add-drop multiplex (ADM) ring in their existing network. With Gigabit Ethernet technology, a telecom carrier could provide broadband connection to users by deploying a series of Ethernet switches linked with leased fiber cables. The elimination of DCS and SONET/SDH ADM equipment in the network architecture not only translates into equipment cost savings, but also simplifies the network operations. It is because service provisioning and activation process now require fewer operations tasks with Gigabit Ethernet architecture. This, in turn, could result in substantial operations savings for the telecom carriers.

4.2. Eliminate protocol conversion

Compared to ATM-based xDSL service, IP-based xDSL service can simplify the network protocol conversion process by using Gigabit Ethernet as the transport vehicle. For ATM-based xDSL service, an ATM PVC circuit has to be set up between the xDSL remote terminal and the ATM network. This requires the Layer 2 ATM and Layer 3 AAL5 protocol stacks to be established before an IP layer protocol can be transmitted. However, if the xDSL service is offered via the IP-based equipment such as Gigabit Ethernet, an ATM PVC connection is not needed. Therefore, there is no need to perform ATM and AAL5 protocol conversions.

4.3. Asynchronous network versus synchronous network

Because SONET/SDH network operates in synchronous mode, it requires highly accurate network timing. Complex network synchronization mechanism based on Strata1 to 4 timing clock is needed to keep SONET/SDH equipment interoperating synchronously. Without strict synchronization in timing, transmission impairments such as jitter and slip occur. Therefore, it is critical to have a comprehensive network synchronization plan in terms of timing signal redundancy and protection to ensure the network integrity. The cost of engineering and maintaining such a network synchronization mechanism, particularly for the accuracy and stability of Stratum 1 clock, is prohibitively high. In addition, at each equipment line card, a phase-locked loop (PLL) is needed to extract the timing signal from the core network. The cost of PLLs, which constitutes a significant portion of the line card cost, adds to the total capital investment of a synchronous network [10].

Since Gigabit Ethernet operates in asynchronous mode, it does not require network synchronization nor sophisticated PLL in each line card. This can reduce overall network equipment costs as well as operating expenses.

4.4. Ethernet equipment cost advantage

A study conducted by the Dell'Oro Group [8] reported that Ethernet bandwidth is approximately 85% cheaper than SONET bandwidth. Telecom carriers need to spend only US$150,000 on Ethernet equipment to get bandwidth equivalent to a US$1 million SONET network.

The Dell'Oro study compared the average selling price of Fast Ethernet (100 Mb/s), Gigabit Ethernet, and 10-Gigabit Ethernet switches with that of the OC-3 (155 Mb/s), OC-12 (622 Mb/s), OC-48 (2.5 Gb/s), and OC-192 (10 Gb/s) SONET equipment. A common price/performance metric can be used; these prices are converted into dollars per Gigabit of bandwidth. As shown in Fig. 1, by 2004, the cost difference in deploying one Gigabit of bandwidth using 10 Gb/s Ethernet versus SONET OC-192 is several thousand dollars.

With over 100 million installed Ethernet LANs in the world, there are a large group of users and skillful technicians who are familiar with Ethernet technology. The convenience of the "plug and play" feature and the backward compatibility to lower speed Ethernet LANs suggest a smooth migration path for enterprise IT applications, which might push the demand for Gigabit Ethernet high and eventually drive its cost down. In addition to applications such as fast Internet access and low cost transport of IP data among multiple sites within a metro area, other advanced applications of MANs will be possible through leveraging Gigabit Ethernet capabilities.

4.5. Global end-to-end LAN connection

Because Gigabit Ethernet maintains the Ethernet frame format throughout the core network, an end-to-end Ethernet LAN connection becomes possible for enterprise customers. The advantages include no necessity for protocol conversion at the network edge, improved network performance, and efficiency in bandwidth utilization. The transparent LAN-to-LAN connection will allow enterprise LANs to exchange data and files without the worry of losing data integrity. Implied in this is that the large number of the installed enterprise Ethernet LANs will not become obsolete with the emergence of Gigabit Ethernet technology [11].

4.6. High-speed application service providers (ASP) and storage service providers (SSP) access

Most ASPs and SSPs experience slow transmission speed and throughput bottlenecks in the access network. To prevent service quality from degrading, ASPs and SSPs have to put a limit on the number of simultaneous users they can serve. Since Gigabit Ethernet offers gigabit per second access bandwidth, the network access bottleneck is alleviated and the ASP and SSP should have no problem servicing all of their customers. The bandwidth flexibility of Gigabit Ethernet offers much better broadband access than hard-wired private lines. It should be noted that for SSPs, the storage devices could either be distributed

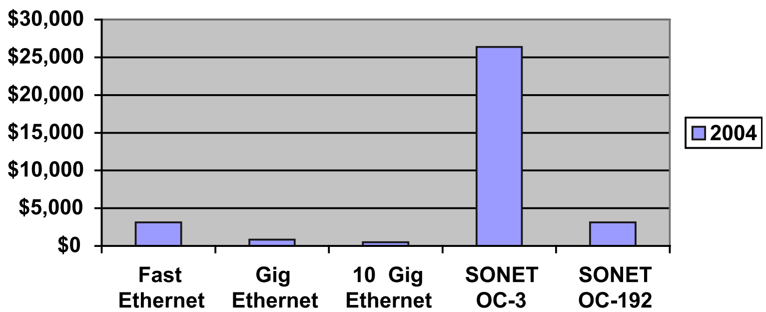

Fig. 1. Dollar per gigabit of bandwidth in 2004, by the Dell'Oro Group.

over locations connected via Gigabit Ethernet WAN or MAN or attached to a Gigabit Ethernet LAN within a single premise [11,12].

5. Ethernet challenges in the network operations and management

Although Gigabit Ethernet offers many unique capabilities and advantages that can satisfy business needs in a metropolitan network, there are challenging issues that need to be resolved with respect to interworking with or replacing the existing SONET/SDH and ATM networks.

5.1. Can Gigabit Ethernet provide the equivalent QoS that is currently provided by SONET/SDH and ATM?

Providing quality service that meets customers' requirements is a fundamental concern of telecom carriers. Enterprise customers demand guaranteed QoS to ensure reliable business operations. Therefore, if telecom carriers were to apply Gigabit Ethernet technology to achieve bandwidth scalability and fast provisioning time for their business customers, it would be critical to maintain the existing level of QoS.

Unlike ATM, Gigabit Ethernet does not have admission control capability to regulate individual user's traffic stream. Gigabit Ethernet can only rely on "policy-based" QoS to manage the aggregated traffic. The policy-based QoS always reserves additional bandwidth capacity (i.e., over engineering the bandwidth requirement) sufficient to meet the QoS objective at peak hour traffic demand. Since Gigabit Ethernet equipment has a cost advantage over SONET/SDH and ATM equipment, "over engineering" is a small price to pay to reap the benefit of bandwidth flexibility. In the future, the QoS capability may be provided at the IP layer (such as IP/MPLS protocol) once the IP QoS capability becomes mature.

5.2. Can Gigabit Ethernet provide the network performance monitoring capability that is currently provided by SONET/SDH and ATM?

There are several overhead bytes (e.g., the B1 byte) in the current SONET/SDH frame format designed for monitoring the network transmission performance [10]. By analyzing the network performance monitoring information, carriers can detect network degradation, localize fault, and take proper maintenance actions before service-affecting failures take place. In contrast, however, in the Gigabit Ethernet frame format, there exists no overhead byte for performance monitoring. Gigabit Ethernet can only monitor whether the incoming packets are in error. Once an error occurs, Gigabit Ethernet will report error messages to the network management system through the standard SNMP interface. The error reporting mechanism is much slower compared to the performance monitoring capability of SONET/SDH or ATM technologies.

The IEEE 802.3 standards committee is in the process of defining a WAN PHY layer protocol for the transmission of Gigabit Ethernet traffic via the existing SONET/SDH equipment. Having Gigabit Ethernet transported in the SONET/SDH payloads can leverage the existing performance monitoring capability of SONET/SDH equipment. This WAN PHY layer protocol provides a foundation for telecom carriers to monitor the transmission performance of Gigabit Ethernet [7].

The drawback of the lack of performance monitoring capability of Gigabit Ethernet is becoming less critical. Because most transmission networks are fiber-based with high performance and reliability, the majority of failures are event driven (e.g., fiber cut) rather then caused by equipment or facility degradation. The existence of performance monitoring capability may not be as critical as in the past [12].

5.3. Can Gigabit Ethernet provide network protection switching and fault isolation capabilities that are currently provided by SONET/SDH and ATM?

SONET/SDH frame structure has signaling overhead bytes (e.g., the K1 and K2 bytes) that can be used to provide protection-switching functions within a 50-ms interval [10]. Furthermore, there are overhead bytes in the SONET/SDH format to provide fault isolation.

Gigabit Ethernet has no signaling capability to provide any protection switching or fault isolation functions. Alarms will be reported through the SNMP interface to the appropriate network management center. Although the Ethernet aggregate link capability can also provide similar protection function within 1 s, it is incompatible with the 50-ms switching time with SONET/SDH. The WAN PHY layer protocol can leverage the protection switching and fault isolation functions built in the SONET/SDH frame format.

5.4. How can Gigabit Ethernet scale up in large carrier network?

Because Ethernet is traditionally used as a LAN in private enterprise environment, the scale and size of any single Ethernet network are much smaller compared to a public telecom network. However, there will be multiple Gigabit Ethernets complementing the functions of SONET/SDH systems. The SNMP network management interface can be scaled up to manage clusters of Gigabit Ethernets. An end-to-end Ethernet connection (LAN, MAN to WAN) has the benefit of a homogenous Layer 2 network management system that can simplify the operations management of a telecom network.

6. Conclusion

Ethernet technology has evolved into multigigabit bandwidth with applications extending from LAN, MAN, and even to WAN. Telecom carriers are faced with fast growing Internet data traffic that exceeds traditional voice traffic. Gigabit Ethernet technology holds the promise to relieve the critical bandwidth bottleneck in the access network.

The simple protocol of Ethernet can offer telecom carriers many advantages in terms of simplified network architecture and substantial equipment cost reduction. The dynamic bandwidth allocation flexibility makes many new business applications possible. This, in turn, will create new revenue opportunities while reducing capital investments for telecom carriers. Compared with existing SONET/SDH and ATM infrastructure, Ethernet technology has some weaknesses in the areas of network operations and management. As Gigabit Ethernet can be transported over the existing SONET/SDH and ATM infrastructure, the characteristics of both technologies can complement each other. For applications less concerned about QoS, the Gigabit Ethernet is already an ideal solution. As Ethernet technology and its communications protocols continue to evolve, its potential and impact as a broadband end-to-end architecture are emerging. When and how to leverage Gigabit Ethernet technology's capabilities will remain a business challenge for telecom carriers.

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