Overview of High-speed LAN Technology for Home Use

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Abstract

The storage capacity of optical disks demands higher speed of a network when users copy images of those disks from one host to another. In addition to speed of the network, other bottlenecks may exist in the path between two hosts. The speed of the network depends on a cabling as well as interfaces which implement networking standards. Lifetime of the cabling is from 10 to 15 years which is three times more than lifetime of network devices. The Ethernet evolution provides high-speed networking standards based on the IEEE High Speed Study Group (HSSG) objectives as well as the historical trend of the Ethernet technology adoption. The high-speed Ethernet provides a cost effective solution for the bandwidth demand of homes. This paper helps home users to choose the right infrastructure for the high-speed networks, for example for a 10 Gigabit Ethernet. In addition to the 10 Gigabit Ethernet, also a 100 Gigabit Ethernet is studied based on the literature from IEEE HSSG.

KEYWORDS: High-Speed Home LAN, 10 Gbit/s Ethernet, 100 Gbit/s Ethernet, structured cabling in the home LAN, home server.

1 Introduction

The storage capacity is one of the fastest growing area in the computer technology. New high definition movies for high definition screens will increase storage capacity of optical disks. Home users will face even more prolonged data transfer, if they want to copy an image of optical disk from one host to another. Copying massive amount of data between hosts at home will increase the demand for quicker transfer time in the network that interconnects hosts. In addition to speed of the network, other bottlenecks may exist in the path between hosts. These bottlenecks could be in the computer input/output (I/O) devices, network interfaces, cabling or network devices.

This paper is a literature survey of the wired high-speed Ethernet technology including 10 and 100 Gigabit Ethernet standards. The object of this paper is to show what the home user should consider when he or she is building an infrastructure for their high-speed home Local Area Network (LAN). This infrastructure includes hosts, cabling and network devices at home.

2 Transfer Method between Personal Computers

The problem discussed in this paper is following: The home user sends a large file, such as a disk image file, from one computer to another over the home LAN. The size of the disk image from single-side DVD could be 4.7 Giga Bytes (GB). At the moment, home users have their computers equipped with a 100 Mbit/s or a 1 Gbit/s network interface and typically there is a small network switch that operates 10 Mbit/s or 100 Mbit/s at home. The small switch is included usually in a customer equipment for the Internet connection, for example in the chassis of an ADSL modem. If the user sets the speed of all network interfaces to the 10 Mbit/s, transferring a DVD image from computer to computer takes about one hour and forty minutes. Setting the speed of interfaces to the 100 Mbit/s cuts transfer time to ten minutes.

What about high definition disks? One layer of a High Definition DVD (HD DVD) may contain 15 GB data and respectively one layer of a Blu-ray disk contains 25 GB data. Disks can have up to four layers. If the user wants to copy an image of double-layer Blu-ray from one computer to another within the 100 Mbit/s Ethernet network, it would take not less than 1 hour and 45 minutes in the ideal situation. How to make this faster? Amount of transferred data and distance of hosts excludes slower technologies for example wireless and short-range communication which lie outside the scope of this paper.

3 Components in Bottleneck Path

There are two common architectural models in the scenario presented above. The first architectural model is a peer to peer (P2P) network where two computers are connected directly through a network, in this case through the home LAN. The second architectural model is called client/server architecture where powerful computer with a large storage and processing power is a server and normal desktop computers or laptops are clients. Each client is connected to the server.

These architectural models have similar procedure for data transfer. An example with one network device follows: Piece of data is read from a mass storage drive, transferred through the Serial Advanced Technology Attachment (SATA) or the Small Computer System Interface (SCSI) bus, and through the Peripheral Component Interconnect (PCI) bus to the Network Interface Card (NIC). The NIC will transfer data to network through network medium until it reaches interface of a network device. The network device sends data to a corresponding output interface based on receiver's physical address and forwarding rules of the network device. From this point, data is transferred as earlier but in reverse order until it is written to the target mass storage. As we can see here, sequential data transfers occur in the host and between hosts.

In the example presented above, there was a modern out-of-the-box PC that is capable of storing and transferring large amount of data. The network was the bottleneck because the speed of the network is the same as it was in mid-1990's (IEEE 802.3u). Most of the out-of-the-box computers provide by default all sufficient components needed for the 1 Gbit/s transfer from the hard drive to network. Is the network upgrade needed or do we need to upgrade the components in the computer?

3.1 Components inside Computer

The internal mass storage drive is connected with SATA or SCSI interface to the PCI bus via mother board. SATA is mainly for home and non-critical environments and SCSI is commonly used in high-end computers, servers and mission-critical computing. The mass storage drive, except optical disks, can utilize nearly all available capacity from the interface it is attached to. The transfer speed of components needs to be examined to discover possible bottlenecks inside the computer. Following transfer speeds of components are theoretical maximum of the bus or interface.

SATA: "Serial ATA will be introduced at 150Mbytes/sec, with a roadmap already planned to 600Mbytes/sec, supporting up to 10 years of storage evolution based on historical trends" [1] announces Serial ATA Workgroup.

SCSI: SCSI is a interface for peripheral devices. Ultra-320 SCSI provides 320 MB/s (2.56 Gbit/s) [2]. New Serial Attached SCSI - 2 (SAS-2) uses serial transfer instead parallel interface as in the Ultra-320. SAS-2 speeds up to 6 Gbit/s [3].

PCI: PCI is a computer bus for attaching devices, such as NIC, to the computer motherboard. In January 2007, PCI Special Interest Group (SIG) published new version of PCI Express. "PCI Express 2.0 effectively increases the aggregate bandwidth of a 16-lane link to approximately 16 GB/s" [4]. That is 160 Gbit/s (there is 10b/8b encoding in the PCI bus).

NIC: NIC is connected to the PCI bus and operates the speed of the PCI bus inside the computer. Today, most of the computers include 1 Gbit/s Ethernet NIC which provides 1 Gbit/s theoretical speed to and from the network. Few home users have 1 Gbit/s capability in their network devices although.

These transfer speeds of components show that bottlenecks are in the desktop computer's mass storage interface and in the network connection. Transfer speed of the mass storage can be enhanced by adding parallel hard disks and interface controllers. The idea of the parallel mass storage is normally employed in the server environment for better throughput and improved data security. The bottleneck remains in the home networks.

3.2 Network Devices in LAN

This paper is focused on the Ethernet technology for two reasons: Almost every computer has Ethernet NIC installed by default and Ethernet standards are evolving towards very high-speed networks [5].

Hosts of the Ethernet LAN can be connected with several network devices, such as bridges, hubs, switches and routers. Ethernet switches provide wire-speed switching capability in the Gigabit networks. Network hubs are not discussed here because they have too large collision domain and poor performance. Routers are not basically needed for host-to-host connections and usually there are no multiple routing networks in one home network. Network bridges are not in use anymore.

The Ethernet LAN switch has multiple interfaces or ports for either copper or optical fiber connection. The switch creates a virtual connection between a source interface and a target interface and then switches Ethernet frames between those two ports. The switching decision can be implemented in the Application Specific Integrated Circuit (ASIC). The ASIC implementation makes possible to switch frames or packets in wire-speed, which means that there is no delay caused by switching. However, delay might occur if the switch blocks and buffers traffic in some interfaces, when all or almost all of the interfaces are fully utilized. A non-blocking switch provides full wire-speed in all ports at the same time, but most of the less expensive switches are partially non-blocking.

There are several reasonable priced network switches for home and small office LANs. At the moment an unmanaged Ethernet switch with 8 Gigabit copper interfaces costs about 80 euros and the managed switch about 200 euros. There are also far more expensive 10 Gbit/s switches available for professional use.

3.3 Cabling in LAN

Homes have various cabling, for example coaxial cable for TV and Radio, electricity cabling and telephone wiring. These cabling do not support high-speed networking because of their low quality.

ISO Standard 15018 defines generic cabling for homes [6]. The standard recommends the Unshielded Twisted Pair (UTP) Category 6 (Cat 6) cabling in which every room should have at least two RJ-45 connectors. The topology of the cabling is a star which is appropriate for the Ethernet and switches. Center of the star is a cross-connection point with a patch panel for the cabling. This is also a natural place to put the Ethernet switch and the customer equipment for the Internet connection. In the case of a multi-store house, vertical cabling or backbone between stores and switches is needed. A multi mode fiber is the best solution and twisted pair copper is the second for the home backbone cabling.

Fig. 1 shows that Cat 6 copper (10GBase-T) enables 10 Gbit/s with its 250 MHz channel inside the range of 55 meters. This range is enough for most homes. The Category 6a cabling provides normal 100 meters operating range in the Ethernet and its channel capacity is 500 MHz. Fig. 1 shows also the designation of the cabling to the corresponding IEEE standard.

IEEE Standard	Designation	Bandwidth	Distance Limitation
802.3ab	Twisted pair copper	1000 Mb/s	100 meters (Cat 5 / 5e)
802.3z	Multimode fiber	1000 Mb/s	220 to 550 meters
	Single-mode fiber	1000 Mb/s	10 kilometers
802.3an	Twisted pair copper	10 Gb/s	100 meters (Cat 6a) 55 meters (Cat 6)
802.3ae	Multimode fiber	10 Gb/s	300 meters
	Single-mode fiber	10 Gb/s	10 to 40 kilometers
	Multimode fiber using WDM or single-mode fiber	10 Gb/s	300 meters to 10 kilometers
802.3af	Power over Ethernet copper cabling	10/100/1000 Mb/s	100 meters

Figure 1: Ethernet standards vs. cabling distance and type.[7]

The Cat 5 and 5e (enhanced) UTP are widely in use around the world in corporate and home LANs. The Category 5 cabling supports the 100 Mbit/s Ethernet and the 1 Gigabit Ethernet with some limitations. The Category 5e cabling is suitable for the 1 Gigabit Ethernet. Active components such as computers, servers, routers and switches have a maximum lifetime of three to five years before they come obsolete. In a contrast, the structured cabling has a useful lifetime of 10 to 15 years.[7]

The EIA/TIA Category 7 is an informal name applied to the ISO/IEC Class F cabling since Category 7 is not standardized yet. The Class F defines a channel with bandwidth up to 600 MHz and the Class Fa up to 1000 MHz using the fully-shielded twisted pair cabling. The Class F supports the 10 Gigabit copper Ethernet as well as the broadband cable TV (CATV).[8]

In addition to copper cables, optical fibers enable very high-speed networking in long distances. In comparison to the traditional optical transmission, Wavelength Division Multiplexing (WDM) is a technique where optical signals are transmitted using different wavelengths in a single fiber. WDM enables N times bandwidth in a single fiber and it is especially useful when there is a need for higher speed or the availability of (long-range) physical fiber medium is limited. The WDM technology for the home use is not studied on this paper.

4 Home LAN in Future

The well known Moore's law gives us an estimation that the number of transistors on a chip doubles every two years. In addition, Moore's law also means decreasing cost of manufacturing and therefore price of the product decreases for consumers. From 1993 to 2000, World Wide Web (www), the Internet and the number of networked hosts with graphical user interface grew rapidly and the price of personal computer decreased at the same time. This technological evolution of networking and computers enabled in the late '90's the situation where home users build their first home networks to share the Internet connection.

After year 2000 the evolution has continued even faster. All kinds of devices are networked using the same protocol, IP. This has led to the so called IP Convergence, where different applications in different devices are networked through the IP network. The IP is independent of the underlying transmission system. The high-speed Ethernet has replaced other transmission systems also in the wide and metropolitan area networks (WAN, MAN). According to the 10 Gigabit Ethernet Alliance's Oliva, "Ethernet is IP's best friend, and in the end, IP wants Ethernet"[9].

Fig. 2 shows the trend of wired Ethernet standardization. There have been only three years between Ethernet standards from 100 Mbit/s to 1 Gigabit and four years from 1 Gbit/s to 10 Gigabit. The evolution has been faster than would have been expected by Moore's law.

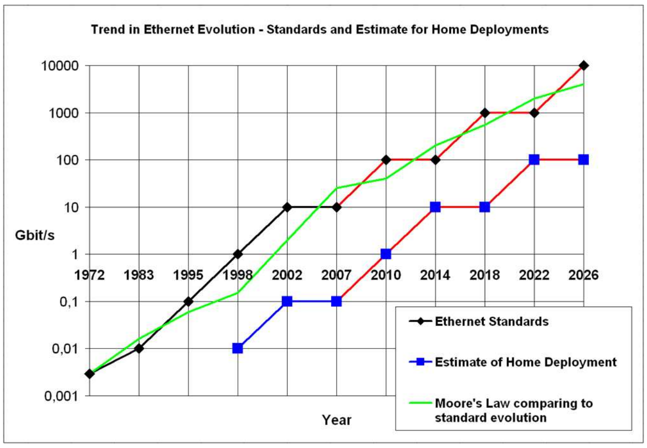

Figure 2: The trend in Ethernet evolution.

The trend of home deployments is based on my own estimate. My estimation shows that home deployments are 10 to 15 years behind the timeline of the standardization. This is mainly caused by the cost of devices that implements new standard. We can see this evolution in the deployment of the 1 Gigabit Ethernet: Standard for the 1 Gigabit Ethernet came 1998 and now, almost ten years later, network switches and computers are equipped with 1 Gigabit network interfaces.

Red lines show an estimation of evolution based on the historical trend and Moore's law. IEEE 802.3 Working Group has formed a Higher Speed Study Group (HSSG) to evaluate the definition of the 100 Gbit/s Ethernet. The standardization of the 100 Gigabit Ethernet is estimated to take place around 2010 [10]. As seen before, devices that implement prior standard are cheaper than devices that implement current standard. Network devices and cabling that are in the market follow standardization usually rapidly since many vendors take part in standardization work groups. Based on these economic expectations we may assume that the 10 Gigabit Ethernet devices will be cheaper after 2010. From the viewpoint of the technological evolution and the expanding markets of the Ethernet dominant products, we can expect that also the 10 and 100 Gigabit Ethernet will be deployed in future home LANs.

4.1 10 Gigabit Ethernet

IEEE Standard 802.3ae (2002) is the standard for the 10 Gigabit Ethernet [11]. 802.3ae defines only fiber medium such as single mode fiber (SMF) for a long range connection and multi mode fiber (MMF) for a short range connection. 10-micron SMF has a range from 10 kilometers to 80 kilometers and 50 micron MMF has a range from 66 meters to 300 meters. An addition to fiber medium, IEEE Standard 802.3an (2006) defines UTP copper interface, 10GBase-T, for 10 Gigabit Ethernet [12]. Category 6 cabling provides 55 meters range and the Augmented Category 6 (Cat 6a) provides 100 meters in the 10GBase-T. The Category 5 / 5e cabling is not supported in the 10GBase-T.

At the moment, the 10 Gigabit Ethernet is deployed in data centers, storage networks, core network and a backbone. The storage network is one of the most popular applications in the 10 Gigabit Ethernet since the demand for storage capacity is continuously increasing in corporations.

The 10 Gigabit Ethernet requires updates to the storage access, network interfaces and switches as well as to the cabling. According to my estimation presented in Fig. 2, these components will be widely available and affordable enough for home use in 10 to 15 years. When these components are deployed in home LAN with no bottlenecks in the path, and user wants the image of the double-layer Blu-ray disk (50 GB) from one computer to another, it would take just one minute to copy it. The evolution of optical disks will increase capacity of new disks in 10 years also. If an optical disk can store hundred times more data than today, we have exactly the same copy time as we had with the 100 Megabit Ethernet and Blu-ray disk.

Traditionally servers, among high capacity switches and routers, have high-speed network interfaces first and this applies to the 10 Gigabit Ethernet as well. A server that is located at home may have the first 10 Gigabit interface in the home LAN. Home servers are discussed in the Sec. 4.3.

4.2 100 Gigabit Ethernet

IEEE 802.3 has formed the HSSG to evaluate the 100 Gigabit Ethernet. So far, objectives of the HSSG include[13]:

- Support full-duplex operation only.
- Preserve the 802.3/Ethernet frame format at the MAC Client service interface.
- Preserve minimum and maximum FrameSize of current 802.3 Standard.
- Support a speed of 100 Gb/s at the MAC/PLS service interface.
- Support at least 10km on SMF and at least 100 meters on MMF.

These objects maintain compatibility of previously installed Ethernet interfaces while increasing operating speed to the 100 Gigabit. As an expansion to these objects, the copper interface for the 100 Gigabit Ethernet has been studied also [14]. The copper interface is needed in computer rooms and data centers where distance between interfaces in different racks is shorter than 10 meters. At HSSG meetings, many combinations are presented to achieve 100 Gigabit/s, such as 10x10G, 5x20G, 4x25G, 2x50 and 1x100G. HSSG studies are at the early stage since group has been established in fall 2006.

Based on my estimation, the wider adoption of the 100 Gigabit home LANs takes about 20 years. It is obvious that in 20 years technological and economical evolution produce unseen needs and solutions which may offer alternatives to the 100 Gigabit Ethernet. The cabling installed today would be in the end of its life after twenty years. When the standardization of the 100 Gigabit Ethernet proceeds to the Task Force, cabling can be defined more accurately. At the moment it seems that the low-cost multi mode fiber is the most suitable for the future home installation.

4.3 Servers and Architecture of Home LAN

Home users will encounter the increasing need of the storage capacity in the future. Most of the data including movies, audio records and pictures are in the digital format already. Among other digital media, the Digital Video Recorder (DVR) that records digital TV broadcasts produces additional need for the storage, especially if the recorded broadcast is in the HDTV format. Some DVRs, such as TiVo Series 2 Boxes and LinkSys KiSS, provide an Ethernet connection that enables easier attachment to the home LAN. All of these digital formats can be stored to the computer's hard drive and played from the hard drive directly.

The hard drive of the computer forms a digital library of home. This digital library must be reliable, always available and it must offer a high-speed access to the data. Server hardware fulfills these requirements - many parallel hard drives for backup and faster access, the hardware itself is designed to always-on power scheme and server can be equipped with multiple high-speed Ethernet adapters easily. One implementation of this idea is from Microsoft that presented Windows Home Server at the 2007 International Consumer Electronic Show. "By automatically backing up home PCs, centralizing a family's digital "stuff" and allowing access to it away from home, Windows Home Server will help simplify and enhance family life"[15], according to Bill Gates.

The home server together with PCs and other networked devices forms client/server architecture for homes. Usually, the client/server architecture is asymmetric from the network point of view. This means that the server has faster connection to the LAN than clients have. For example, the server is connected to the switch using the 1 Gigabit Ethernet and PCs are connected using the 100 Megabit Ethernet. This makes possible to serve simultaneously up to 10 different clients using the full speed of the client's network interface. This is a desirable situation when there is a high probability to have simultaneous connections from multiple clients to the one destination, server. On the other hand, the home LAN may not have multiple concurrent connections to the server and symmetric speed in the home LAN is a better choice. If the server is equipped with multiple Ethernet adapters, the server may use link aggregation of the switch offering higher speed and load balancing. Link aggregation[16] is a feature in some switches to create one logical channel of multiple physical connections between a switch and other device. Link aggregation is affordable solution to upgrade speed between two devices. The client/server architecture may accelerate the adoption of the new Ethernet standards because upgrade is needed only in the server connection(s).

5 Conclusion

The demand for storage capacity at home is increasing rapidly. When home users want to copy or transfer large amount of digital content, it takes a long time. The path between source and target of copying can contain several bottlenecks. The short review of components inside the computer shows that bottleneck exists in the home network. Home LANs and network devices use old standards comparing to desktop and laptop computers at home. The most widely installed LAN technology is the Ethernet.

Based on the historical trend of the Ethernet standardization and its further evolution, my estimation is that the Ethernet provides high-speed networks for a long time. Fig. 2 shows an estimate that home users adopt Ethernet standards in 10 to 15 years from their standardization. The cost of devices that implements the brand new technology is the main reason behind long adoption time.

The most appropriate device for the LAN interconnection is the Ethernet switch. The unmanaged switch provides high-speed connection between hosts with a reasonable price. At the moment, the 1-Gigabit Ethernet is affordable for home users. The 10 and 100-Gigabit Ethernet switches for home use will come in the future. The managed switch can provide higher speed using link aggregation in the meantime. Link aggregation enables, for example, N times 1 Gigabit connections between switch and other device. The link aggregation may offer high-speed network connection to the high capacity home server. The home server with data storage will be the centralized digital library in the future home.

Structured cabling is a corner stone of the high-speed Ethernet. Even when new standards of wireless LAN (WLAN) speed up, cabling enables faster solution for the high-speed networking. The newest standard for home cabling is ISO/IEC 15018, which defines two RJ-45 connectors in each room. The topology of the home cabling is the star. The center of the star is a cross-connection point or telecommunication closet for horizontal cabling in each floor. Switch(es) are usually located in the telecommunication closet.

The Category 6a or the Class F (Cat 7) cabling is the most suitable for the near future installation at home. Cat 6a or 7 provides medium and connectors for the 10 Gigabit Ethernet and beyond. If the present cabling is the Cat 5, cabling upgrade takes place when the 10 Gigabit Ethernet arrives home. After the 10 Gigabit Ethernet is affordable to the home use, low-cost multi mode fiber, especially for server connections, might be needed for future bandwidth demand. The copper-based medium in the Ethernet has proven many times that it can achieve speed required by the new standard.

The copper-based 10 Gigabit Ethernet will arrive to homes approximately in ten years when devices are affordable enough. Updates in the storage access, network interfaces and switches as well as in the cabling are required for the 10 Gigabit Ethernet. IEEE HSSG has studied the 100 Gigabit Ethernet and its standardization is estimated to occur in 2010. The 100 Gigabit Ethernet will support existing fibers and Ethernet frame format according to objectives of HSSG.

The computer technology evolves continuously, but home networks are challenging because some components are a decade behind in evolution and some components are new. Ensuring that all components, especially expensive network devices, are up-to-date, requires heavy investments from the average home user point of view. The future will tell if the techno-economic balance between available bandwidth and required bandwidth become smoother.

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