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High Performance Local Area Network Technologies

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Abstract: Evolution of computer technology in conjunction with the wide use of Internet and related technologies changed the Local Area Network (LAN) traffic model from the conventional 80/20 (80% of the traffic stays in the workgroup, 20% moves over the backbone) to 20/80 rule [1]. By the development of bandwidth hungry and delay sensitive applications, design and operability of the networks became a serious problem. School of thoughts like "bandwidth management" and "more bandwidth" started to compete. The improvements in the media technology reproduced different alternatives to build high performance LAN. This paper overviews copper and fiber optic based physical media and analyzes benefits and drawbacks of challenging technology like Gigabit Ethernet (GE) and Asynchronous Transfer Mode (ATM) in terms of technology and cost of ownership in the design stage of a high performance LAN.

Key Words: High Performance Local Area Network, Asynchronous Transfer Mode (ATM), Gigabit Ethernet (GE), and Fiber Optic

Introduction

The developments in computer industry brought faster processors, larger memory and disk capacities, better visualization techniques and so on. As a result of increasing demand toward collaboration, autonomous, interconnected computers formed today's local area computer networks. The establishment and increasing use of Internet and related protocols (TCP/IP) over Local Area Networks (LAN) as well as well on Wide Area Networks (WAN) put the gear to develop high performance networks to sustain necessary bandwidth for data, voice and video traffic.

To design a high performance network Open System Interconnection's (OSI) layered architecture of International Standards Organization (ISO) must be taken into account. So we will first focus on different physical media characteristics and challenging networking technologies. Later on we will explain the design criteria of High Speed Networks and conclude with a comparison of networking technologies whose are in a competition to be dominant in the market.

Physical Media :The physical connection basically can be established using guided (copper and fiber) and unguided (radio frequency and infrared) technologies each of which with different *environmental* (speed and physical distance), *cost* and *operational requirements* (modularity, extendibility, ease of installation and maintenance). A simple comparison of media types is shown on Table 1.

From our experience during decates we know that the cabling (physical media) is the core component which lasts long and costs less (Fig. 1). So if the appropriate cabling technology can be choosen in accordance with the environmental requirements, cabling structure can last for years and can easily adapt to newer technologies.

Shared type media like coax cable is no more suitable for today's applications due the its performance and maintenance bottlenecks. At the other hand wireless technologies using Radio Frequency (RF) are getting popular. The pro of the wireless technology is the mobility, but the limiting factors are the extent and the physical capacity. As a matter of fact we can conculude that it is only a contributing technology where it is impossible to use guided connection and a need for mobility. So a network structure providing switched (dedicated) bandwith to end stations using star, tree or hybrid topologies uses copper or fiber.

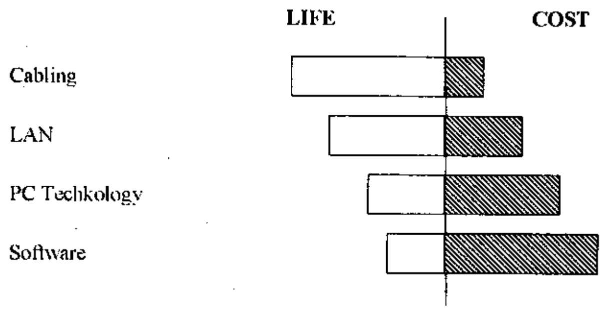

Fig. 1: Life/Cost Relationship

Copper: Today most common form of copper cabling is Unshielded Twisted Pair (UTP). They are categorized according number of wire pairs, twist per foot and the frequency. Cat 2 through Cat 4 cables are out of scope because indusry abandoned them in favor of Cat 5 and higher grade cables. (Table 2) UTP cable can handle data transfer rates up to 1 Gbps (using Gigabit Ethernet) and up to 100 meters without a repeater. Approximately 80% of the cabling on LAN is copper based [2]. The benfits and drawbacks of copper cabling are shown on Table 3.

Fiber Optic: Fiber optic cabling is the technology where electrical signals are converted into optical signals, transmitted through a thin glass fiber and reconverted back into electrical signals. Light source can be Light Emitting Diode (LED) or Laser Diode (LD). The specifications of are shown in Table 4.Multi Mode Fiber (MMF) allows many paths of light to propagate down the fiber optic path. It has good coupling from inexpensive LEDs light sources and use of inexpensive couplers and connectors. Single Mode Fiber (SMF) has a core diameter that is so small that only a single mode of light is propagated. Small core of single- mode fiber makes coupling light into the fiber more difficult. So more expensive lasers must be used as a light source. Single-mode fiber is capable of supporting much longer segment lengths than multi-mode fiber.

Copper vs. Fiber Optic: Fiber optic cabling has some significant advantages over copper cabling. With fiber optic it is possible to transmit data at longer distance, which eliminates or minimizes the need of wiring closets throughout the building. Fiber is thinner then copper so takes up less space, immune to Electromagnetic Interference (EMI) and provides higher bandwidth (approximately 50 Gbps over multi-mode and even higher in single-mode [2]). At the other hand the price of fiber optic media, ports on switches or Network Interface Cards (NIC) are expensive compared to copper based ports and NIC. Installation and termination difficulties of fiber optic are also some drawbacks.

Since it is possible to transmit 1 Gbps over existing Cat 5 / Cat 5e, copper cabling will dominate over desktop for a while. By the deployment of higher bandwidth technologies (like 10 Gigabit Ethernet which has no copper specification) fiber optic will be the physical medium of high-speed communication and Storage Area Networks (SAN). [29]

Challenging Technologies: In the area of switching, two concepts are the prime candidates for market domination: cell-based ATM switching and frame-based IP switching. The major question is which one is more efficient than the other. The answer depends on the particular environment or the traffic type. If the originating traffic is IP based, i.e., most of the LAN (dominated by Ethernet technology [7]), Internet traffic, and the traffic can tolerate variable delay, then the answer is IP switching is more efficient. On the other hand, if the traffic is highly delay sensitive such as voice and we have to deal with the existing PCM-based telephony infrastructure, then the cell-based ATM is the answer. The telecommunication equipment manufacturers are promoting various communication technologies to gain market domination. The two key technologies are ATM and Ethernet. [27]

ATM (Asynchronous Transfer Mode) : Organizing different streams of traffic in separate calls allows the user to specify the resources required and allows the network to allocate resources based on these needs [8]. The session's establishment, which is the most time consuming and complex process, is done once and fixed size cells are routed directly from source to the destination without any trouble. During the session establishment, traffic type specification brings the required prioritization to sustain the necessary Quality of Service (QoS). ATM operates from 25 Mbps to 622 Mbps and serves as an excellent backbone merging Fast Ethernet and FDDI networks. It is also suitable for WAN connection, LAN backbone, and desktop networking technology. And it may become a protocol of choice for meeting the extremely high bandwidth requirements of real-time, bi-directional multimedia applications merging voice, video and data. ATM does not directly support the way LAN currently work, but instead must be configured to emulate conventional LAN operation [9]. ATM is a switched, connection-oriented LAN and WAN technology that allows a virtually unlimited number of users to have dedicated, high speed connections with each other and with high performance network servers.

There are three primary differences between ATM and conventional shared-media networks such as those based on Ethernet, Token Ring and FDDI. These three differences are ATM's use of dedicated media, its fixed length and its connection-oriented nature [10]. ATM tries to emulate Ethernet networks via LANE (LAN Emulation) and IP (IPOA - IP over ATM).

Ethernet – Fast Ethernet – Gigabit Ethernet (GE): Ethernet is a base band network with a bus topology and data transmission rate of 10 Mbps. The access method is CSMA/CD (IEEE 802.3) In a CSMA/CD environment a station can access the network any time. Before sending data, stations listen to the network until no traffic detected. A collision occurs when two stations transmit simultaneously. In this situation both transmission are damaged and stations must retransmit at some later time. A back-off algorithm determines when the colliding stations should retransmit.

Fast Ethernet use the existing IEEE 802.3 CSMA/CD specifications. It supports all applications and networking software currently running on existing Ethernet infrastructure. In addition, Fast Ethernet supports dual speeds of 10 and 100Mbps using switched star or tree topology.

Gigabit Ethernet (GE) is an extension of IEEE 802.3 Ethernet standard. GE increases speeds tenfold over Fast Ethernet to 1000 Mbps or 1 Gbps. To accelerate from 100 Mbps to 1 Gbps, several changes need to be made to the physical interface. GE is identical to Ethernet from data link layer upward. To sustain necessary speed, IEEE 802.3 and ANSI X3T11 Fiber Channel technologies are merged. The MAC layer of GE is similar to those of standard Ethernet and Fast Ethernet. The MAC layer of GE supports both full and half-duplex transmission. The characteristics of Ethernet, such as collision detection, maximum network diameter, repeaters rules, and so forth, are the same of GE. As it is in Fast EtherChannel technology, several (up to 8) GE can form a Gigabit EtherChannel to obtain higher bandwidth. "GE is an evolution not revolution"[7].

Design Criteria for High Speed Network : As mentioned in the previous sections the major point to care about networks are, environmental requirements, cost and operational requirements In addition, Network Complexity must be taken into account to. Combining voice, data, and video (multimedia) services under one transport system creates significant economies. Particularly in the LAN, technologies such as Fast Ethernet, GE, Fiber Channel and ATM are being promoted.

Environmental Requirements: It is not possible to implement a single technology due to different needs, necessity of backward compatibility and the impossibility to deploy it in a sudden. In addition, the use of different protocols, vendors, products and type of applications brings the Network Complexity. So it is usual to see heterogeneous networks, which takes advantage of all challenging technologies.

Bandwidth is the main factor that causes a customer to look for new transport equipment to meet the expanding demand. Particularly, mid to large size corporations and universities tend to exhaust their available bandwidth within a 2 to 3 year period due to expansion of computer networking and software applications requiring higher bandwidth per user. [27] Intranet experiences have shown that networks are evolving. The Client/Server type distributed computing applications flipped the classical 80/20 rules [1]. In addition, support for more complex data streams such as graphics, animations and

Table 1: Media Specifications [3],[14],[19]

	Coax		Twisted (Cat)			MMF (μ)		SMF (μ)		RF (Ghz)	
	Thin	Thick	5	5e	6/7	50	62.5	9		0.9	2.4
Wave Length (nm)	N/A		N/A			850	1310	1310	1550	N/A	
Speed Up to (Mbps)	10		100	1000		1000-10000		10000		2	11
Distance(m)	185	500	100			65	300	10000	40000	30-120	
EMI	Moderate		High-Moderate			Low		Low		High	
Attennuation	Moderate		High-Moderate			Low		Low		Low-High	
Security	Low		Low			High		High		Low	

Table 2: UTP Cabling Specifications [14]

Category	Cat-5	Cat-5-e	Cat-6	Cat-7
Type	Data	Data	Proposal	Proposal
Frequency(MHz)	100	100	250	600
Connection	RJ-45	RJ-45	RJ-45	NA

Table 3: Twisted Pair Cabling Benefits and Drawbacks

Benefits	Drawbacks
Simple, easy to install	Possible to tap
Flexible	EMI(if not shielded)
Low weight	Attention
Easy spliced and connected	

sound requires more bandwidth (Table 7).

Today the challenging technologies for LAN are; FDDI (100 Mbps), Fast Ethernet (100 Mbps), Fast EtherChannel, ATM (155/622 Mbps), GE (1 Gbps) and Gigabit EtherChannel. Copper or fiber optic links within the range of 100 meters up to few kilometers are used as physical media. So we can conclude that in term of environmental requirements ATM and GE technologies are adequate.

Cost Requirements : As a common mistake, while estimating cost of network ownership, capital spent for equipments (NICs, Switches and other active devices and cabling) are taken into account. But this is only 48% of the total cost of network ownership. At the other hand the hidden costs of support staff and facility costs are usually ignored or forgotten. They are 36% and 18% of the total cost of ownership respectively. The cost of ownership goes beyond the price/performance of initial capital equipment purchased and takes into account the long-term effects of technology change on support staff and facilities. As a consequence, the complexity drivers (Table 8) for two compete technology represent 31.2 person/month for the ATM implementation conversely 16.2 person/month for GE. This impact, called complexity inflation, is multiplied with fixed staff cost [11].

Operational Requirements: While designing the network infrastructure besides the bandwidth, one had to take into account the non-blocking architecture and solve the over subscription problem at distribution points in order to obtain the required performance. Can a device handle the traffic load that all its interfaces can accept or generate? To provide relative balance, non-blocking switches must support trunk link that are several times faster then the incoming links and their back plain capacity must be greater or equal to the switching load generated by all its ports. So scalability, flexibility, stability of the technology and future-proof characteristics is also important factors. Customers tend to prefer incremental upgrades to meet the future bandwidth demand instead of replacing the whole system, i.e., desire to avoid large capital investment. ATM is scalable within 25 / 155 / 622 / 2488 Mbps where Ethernet is scalable within 10 / 100 / 1000 / 10000 Mbps.

Quality of Service (QoS), which provides theoretical service level guarantees for users who need guaranteed timely delivery data, has also an effect over the performance issue. Today there is two paradigms.

GE paradigm says;

"Buy bandwidth instead of bandwidth management because bandwidth is cheap enough to oversupply your network".

The ATM paradigm says;

"Bandwidth management is important; capacity can't be taken for granted, so you will need a network architecture that can manage capacity for you" [24].

In order to obtain ATM like QoS, there is a need for prioritization, which requires a classification of traffic. In a LAN switch, classification of traffic can take place based upon physical port or on information already included within each packet such as MAC address, IP address, TCP/UDP port number, or actual contents of the packet [25].

Since classic Ethernet does not provide the ability to distinguish between applications and provide QoS guarantees, it has not been considered suitable for networks supporting multiple traffic types including applications using audio or video. However, recent works on new protocols such as RSVP (Resource reSerVation Protocol) suggests that appropriate bandwidth reservation can be provided the emergence of new standards such as IEEE 802.1Q (VLAN) and IEEE 802.1p (CoS/Prioritization) will provide VLAN capability and explicit priority information for packets in all networks, including Ethernet. IEEE 802.1p, when combined with RSVP enhances the ability of end systems and switches to deliver high quality, low latency bandwidth on a campus scale [19]. In order to have RSVP function and deliver defined and consistent quality to an application, each network component in the chain between the client and the server must support RSVP and communicate appropriately. IEEE 802.1p and IEEE 802.1Q facilitates quality of service over Ethernet providing a means for "tagging" packets with indications of priority or Class of Service (CoS) desired for the packet. These tags allow applications to communicate the priority of packets to internetworking devices. RSVP support can be achieved by mapping RSVP sessions into 802.1p service class. Together, these standards provide a base for end-to-end policy based QoS in Ethernet networks [22]. To deliver true policy based QoS, an amount of bandwidth, a mechanism between applications and networking equipment, prioritized traffic and an administration and

Table 4: Fiber Optic Specifications [3]

	5-10/125 SMF	50/125 MMF	62.5/125 MMF	85/125 MMF	100/140 MMF
Core	5-10	50	62.5	85	100
Cladding	125	125	125	125	140
Attenuation	0.8 dB/Km	3-4 dB/Km	3,75-6 dB/Km	5 dB/Km	5-6 dB/Km
Frequency	> 1000 MHz	> 400 MHz	160 MHz	200 MHz	10-100 MHz

Table 5: Benefits and Drawbacks of Fiber Optic Cable

Benefits	Drawbacks
Larger bandwidth	Difficult to install
Longer distance	Special connection techniques
No EMI, no cross-talk, no attenuation	
Impossible to tap	

management of the available bandwidth in the network is needed.

To be effective, policy based QoS needs to manage entire data path from the beginning of the frame to its final destination. This end-to-end connectivity is unusual in the LAN environment because most LANs care only about the frame as far as it remains in the same segment. Once the frame crosses over a bridge or router boundary, not enough is known to determine if the frame arrived at its destination. This problem is solved with end-to-end policy based QoS guaranties. To achieve end-to-end QoS successfully, LAN switches must implement multiple queues to support QoS levels assigned. The use of multiple queues will reduce the potential problem of head-of-line blocking, where a lower priority frame could block a higher priority frame [22].

IP ToS (Type of Service) is similar to 802.1p, but implemented at Layer-3. IP ToS also sets aside three bits, in precedence sub-field located in the IP header. It requires Layer-3 intelligence to be recognized by net devices. Many switches now can map 802.1p to IP ToS in order to preserve CoS priorities beyond the LAN. With either CoS type, priorities may be set at the user desktop, through applications or other intelligent software, or priorities may be set at switches in the LAN. Higher priority applications will then get favored treatment in switches output queues. 802.1p and IP ToS technology can set only relative priorities because the connectionless nature of LAN packet rules out the kind of absolute guarantees that true end-to-end circuit would provide. At the ATM edge, however, absolute guarantees are possible due to the connection-oriented nature of ATM [20]. Thus, the supposed unique QoS advantage of ATM is now or will soon be available to all networks [7]. Further more, GE and ATM will both deliver the same effective level of QoS in most real world application, because ATM QoS doesn't extend beyond the ATM cloud [18].

GE, by definition is compatible with legacy Ethernet LANs applications. ATM, on the other hand, requires LANE to handle the routing of packets to cells and back again which brings the complexity. Similarly, GE is IP compatible while ATM requires RFC 1557, IP over LANE today, I-PNNI and/or MPOA in the future (Table 9). GE is excellent choice for high speed LAN. However, GE is limited to a range of 3 km. To achieve MAN or WAN capabilities, one will have to use either FDDI or ATM [7]. But 10 GE breaks these barriers and become an alternative for MAN and WAN [23]

GE provides one of the most important mechanisms needed for "campus scaled" multimedia applications, and that is very high capacity and low latency (Table 10). Many multimedia applications are running today over Ethernet at 10 or 100 Mbps. Ethernet's capabilities to support CoS are being enhanced at Layer 2 by work completed in IEEE 802.1p. IEEE 802.1p specifies the use of priority queuing mechanism to support traffic, which may need lower or higher priority than normal, best effort traffic (Ethernet frame allows 8 priorities) [19], [20].

According to IDC, in 1997, 80% of the installed network connections were based on Ethernet [7] and the remaining were a combination of Token Ring, FDDI, ATM and others [11]. Due the scaleable speed of 10/100/1000Mbps, backward compatibility, modularity, ease of use and all ready installed base, Ethernet based LAN technology is the major candidate for high performance local area networks. According to IDC 4Q99 researches worldwide GE switches represented 479.572 ports and $534 million in revenue [15]. GE switches soared almost 27% to 608.853 ports during 1Q00 and analysts say that, "The world is turning to GE and away from LAN ATM" [16]. The projected revenue from GE market will be approximately $1.500 Million by year 2001 (IDC #12382 Nov.1996) [17].

Conclusions : Corporations are willing to establish or adapt their network infrastructure to newer multi gigabit technologies by deploying switched bandwidth to end stations using star or tree topologies. So Fiber Optic cabling, due to it's environmental specifications is the only choice at the network backbone. But copper based UTP cabling will continue to its presence from the wiring closet to the desktop.

As described in previous sections two key technologies to gain market domination are ATM and GE. ATM is a technology where WAN and LAN can meet. Due its high performance switching capability, dynamic bandwidth for burst traffic and QoS for multimedia it is a good choice for WAN connections where managing bandwidth is a must. Ethernet technology is fully switched, scaleable and with use of Fiber Optics can easily extend its distance limitations. GE technology is the winner on LAN and the strongest opponent of ATM on MAN and WAN. The key points to remember about these technologies are as follows;

- QoS supplied by ATM is only true within the ATM cloud [18]. At the other hand GE uses RSVP (ReSerVation Protocol) and RTSP (Real Time Streaming Protocol) to provide ATM functionality (QoS) over Ethernet/IP infrastructure.
- 80% of the LAN infrastructure is Ethernet based [7], so putting ATM to the desktop is not feasible in terms of price/performance. Cost of ATM NICs and fiber are higher than using Cat5 /Cat5e and Fast Ethernet within the star topology. GE has a superior price/performance, backward compatibility and scalability than ATM.

Table 6:. 1000Base Ethernet Specifications

		1000 Base LX			1000 Base SX		1000 Base CX	1000 Base T
Laser type		LW			SW		N/A	N/A
Transmission media		SMF	MMF		MMF		Copper (150Ω)	Copper (100Ω)
Media diameter (μ)		5/9	50	62,5	50	62,5	N/A	N/A
Distance (m)	1300nm	3000	550	550	N/A	N/A	N/A	N/A
	850 nm	N/A	N/A	N/A	550	250	N/A	N/A
	2pairSTP	N/A	N/A	N/A	N/A	N/A	25	N/A
	Cat-5	N/A	N/A	N/A	N/A	N/A	N/A	100

Table 7: Application and Their Impact on the Network [11]

Application	Data Size/Types	Traffic Implication	Network Need
Scientific Modeling, Engineering	100's MB to GB Data	Bandwidth (BW) required	Higher BW for desktop, server & backbone
Publication, Medical Data	100's MB to GB Data	BW required	Higher BW for desktop, server & backbone
Internet / Intranet	1MB-100MB Data/Audio/Video	BW required, Low latency, High volume of data stream.	Higher BW for server & backbone, Low latency
Data Warehouse Network Backup	GB to TB Data	BW required, Transmitted during fixed time period	Higher BW for server & backbone, Low latency
Desktop Video Conferencing	1.5-3.5 Mbps Data Stream	Class of Service reservation, High volume of data streams	Higher BW for server & backbone, Low and predictable latency

Table 8: Complexity Drivers and Their Impacts [11]

		Complexity Impact		Staff Impact	
Complexity Driver	Initial Cost	ATM	GE	ATM	GE
Protocol	4.2	4.0	1	16.8	4.2
Equipment	2.3	1.0	2	2.3	2.3
Management Agents	2.2	3.0	2.0	6.6	4.2
Management application	2.2	2.5	2.5	5.5	5.5
				31.2	16.2

Table 9: Capabilities of Fast Ethernet, FDDI, GE and ATM [11]

Capability	Fast Ethernet	FDDI	GE	ATM
IP compatible	Yes	Yes	Yes	RFC 1577, I-PNN, MPOA
Ethernet Packets	Yes	Yes 802.1h	Yes	LANE, cell to packet routing
Multimedia	Yes	Yes	Yes	Yes Applications need changes
QoS	Yes RSVP/802.1p	Yes RSVP/802.1p	Yes RSVP/802.1p	Yes SVCs/RSVP
VLANs 802.1Q/p	Yes	Yes	Yes	Yes, LANE, SVCs to 802.1Q

Table 10: Efficiency, Speed and Latency Comparison [18]

	GE			ATM (622Mbps)		
Packet Size (Byte)	Latency	Mbps	Efficiency	Latency	Mbps	Efficiency
64	0.5	95	%76	1.4	47	%59
256	2.0	116	%93	4	62	%77
1500	12	124	%99	22	69	%85

- Since ATM does not have a native support for Ethernet and IP packets (uses LANE, IPOA or MPOA), frame to cell conversion brings 25% to 30% overhead [18], so the real bandwidth for 622 Mbps ATM is around 450 Mbps, which is nearly half of GE. Where as GE supports today's infrastructure and based on existing, proven and widely used technology and protocols i.e. TCP/IP.
- In terms of protocol complexity, ATM is far beyond GE [11]. Staff impacts of ATM is twice of GE (Table 8).
- Latency of ATM is nearly twice of GE and its efficiency is 85% compared to 99% of GE (Table 10).
- The new coming Ethernet technology 10GE [23] (10-Gigabit Ethernet) will be a strongest opponent against ATMs WAN dominance. But ATM is within a movement towards 10 Gbps bandwidths. [31]

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