Tetrad Digital Integrity

Asynchronous Transfer Mode

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I. Introduction

Transmission protocols and network architectures are now at the forefront of computer related issues. The technical jargon of the day is Asynchronous transmission mode, Synchronous optical network and Fiber distributed data interface, and there are valid reasons for their rise in importance. Enterprise network users worldwide are becoming more interested in services and equipment capable of providing them with the ability to handle voice, data and video at variable speeds with a Quality of Service. "Asynchronous transfer mode (ATM) has been conceived as a multiservice and cell-based technology ideal for supporting a wide variety of traffic types and access methods," furnishing a transmission protocol capable of appeasing enterprise network users' demands." [LUSA99] Consequently, this paper is a discussion of Asynchronous transfer mode, its technical characteristics, its use in the marketplace, and its advantages and disadvantages when compared to relative technologies.

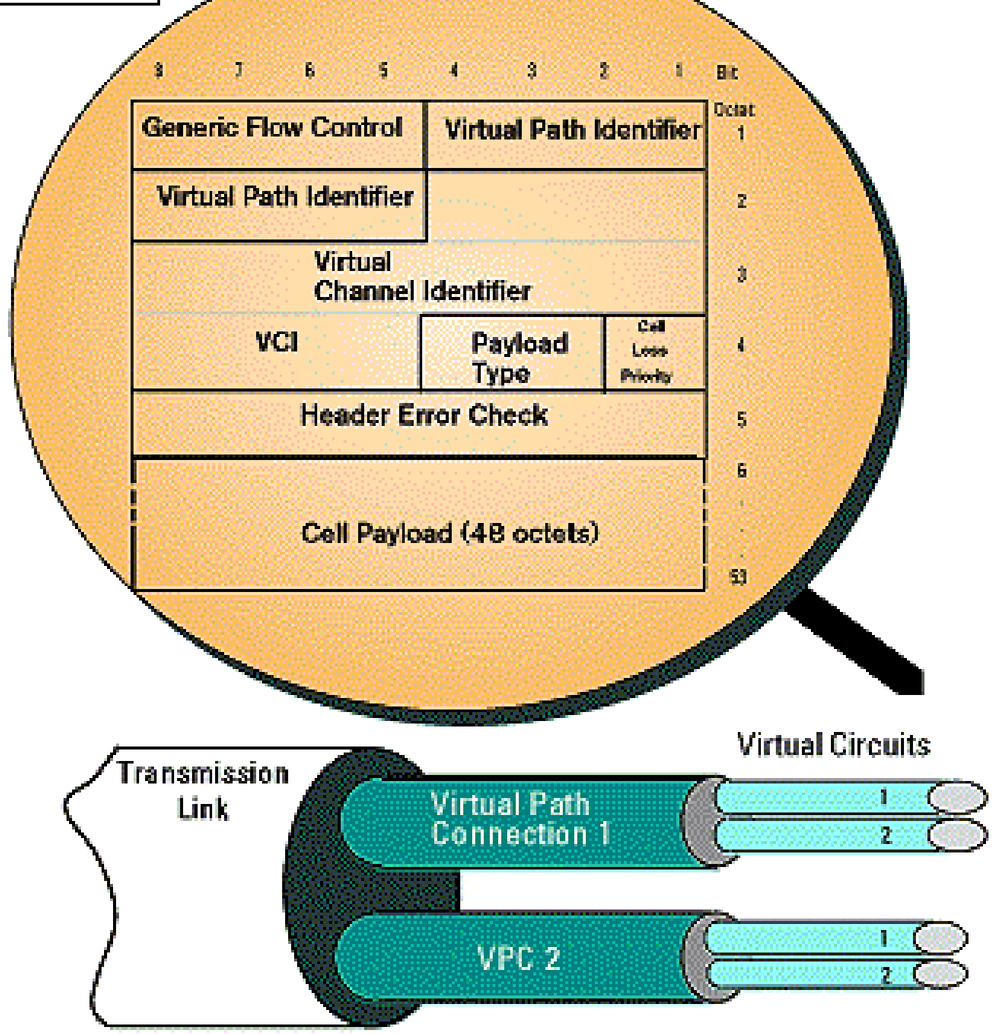
II. ATM Defined

Asynchronous transfer mode (ATM) is a technological breakthrough that sprung out of the effort to design and develop Broadband-ISDN. "ATM first came to the attention of the industry in the late 1980s as part of the International Telecommunication Union's (ITU's) Broadband-ISDN (B-ISDN) project." [AMERICA'S98] One quickly notes that ATM's characteristics may be regarded as an advanced product of packet switching due to the similarities of these two technologies. As with packet switching, ATM combines both the switching operation and the multiplexing capacity, provides the ability for devices operating at variable speeds to communicate, and is quite capable of handling "bursty traffic." Additionally, ATM shares certain attributes with frame relay in that it uses current digital systems in order to attain a packet-switched transmission that is faster than X.25; it is referred to as cell relay due to the use of ATM packets called cells. In short, "Asynchronous transfer mode (ATM) is a high-performance, cell-oriented switching and multiplexing technology that utilizes fixed length packets to carry different types of traffic." [NORTEL99]

Underlying Theoretical Concept

ATM was developed with the goal of attaining extremely high data rates for the transmission of multiple forms of data. "Developers conceived a network switching technology that could meet users demands for integrated voice, data and video throughout the enterprise and harness the power of the Internet." [BERNHARD97] This objective was achieved by making Asynchronous transfer mode "a streamlined protocol with minimal error and flow control capabilities; this reduces the overhead of processing ATM cells and reduces the number of overhead bits required with each cell, thus enabling ATM to operate at high data rates. Further, the use of fixed-size cells simplifies the processing required at each ATM node, again supporting the use of ATM at high data rates." [STALLINGS97]

Figure 1



Information that travels in an ATM network is formatted into cells that are a constant length of 53 bytes, comprised of 48 bytes of payload data and 5 bytes of header data (Figure 1). ATM uses cells of this fixed length, determined by the ITU in 1989, in order to ensure that voice or video data being transmitted is received without a significant time delay. In contrast, other packet transmission protocols can have a detrimental effect on the timely receipt of data due to larger sized packets. The cell's header is minute and precise; it is designed such that switching will be proficient. Within the header is all of the necessary information for flow control, routing, payload type, and error checking. Transmission of these cells occurs within virtual paths that are comprised of virtual circuits.

Asynchronous transfer mode transmission has its foundation rooted in logical connections. There are two logical connection classifications defined by ATM standards: virtual path connections (VPC) and their subset, virtual channel connections (VCC or virtual circuits). "A VCC is analogous to a virtual circuit in X.25 or a data link connection in frame relay; it is the basic unit of switching in an ATM network." [STALLINGS97] The VCC carries the data from end user to end user in an ordered stream of cells with a "variable rate, full duplex flow." [STALLINGS97] These virtual channel connections are then grouped together to form a virtual path connection which has the same endpoints as its virtual channel connections. The theory behind grouping a large number of VCCs into several VPCs is to reduce the resources necessary to control the network by routing all of the cells that belong to a given virtual path through their VPC and not through their VCC. The result of using a less granular approach is increased speed in recovery from network failures since management of the network is simplified down to a small group of virtual circuits as opposed to each individual VCC. This layered approach of cells within virtual circuits still within virtual paths creates a flexible network protocol capable of attaining great speeds with tremendous simplicity.

Finally, ATM was designed such that there is an additional level of transmission flexibility with a collection of Quality of Service (QOS) classes. There are several different QOS classes that make ATM so robust. Constant bit rate (CBR) ensures a constant amount of bandwidth and reliable transmission. This QOS class is generally used for data types that require little to no failure such as mission-critical data, video, and telephony. The next class is variable bit rate (VBR) which "allocates bandwidth resources on a statistical basis, similar to frame relay service." [COCHRAN99] VBR is made up of two subclasses, real-time VBR (rt-VBR) and non-real-time VBR (nrt-VBR); the difference in the two relates to the time delay in transmission. Typically, VBR handles Internet traffic, Local area networks, data transfer, or process monitoring. The third class of QOS is available bit rate (ABR) which will utilize those network resources that are accessible based upon predetermined upper and lower boundaries for data rates. This class is actually rarely implemented and is intended for transmission of non-mission-critical data. Finally, the last Quality of Service class is unspecified bit rate (UBR) which has neither a constant data rate nor predictable performance. UBR is mostly used for applications like electronic mail, remote access and other non-mission-critical applications. "'The key thing is quality of service', says Bo Nyein, 'an ATM product manager at Cisco Systems,'" and ATM provides QOS as part of its framework. [CUPITO97]

Performance characteristics

Asynchronous transfer mode was designed to attain the highest port speeds obtainable, while still transmitting successfully at fluctuating data rates. ATM is proving to be one of the fastest transmission protocols available. In fact, "the only technology that allows access speeds higher than T3" is ATM. [IVERSON97] The near future of ATM holds estimates of speeds starting with OC-48 (2.4 Gbps) and growing from there. Presently, market metrics indicate that "ATM [is] the only way for ISPs to scale their backbone sufficiently to support OC-12 trunks," illustrating its high level of performance versus other technologies, like frame relay, at extremely fast port speeds. [PASSMORE98] "In general, frame relay is suitable up to at least T1 speeds for remote access, while ATM can ramp up to speeds exceeding OC-3 . . . Some 77 percent of enterprise ATM users are operating backbone networks at T3 speeds or faster-up to OC-12." [LUSA99] It is apparent that ATM performs well at high data rates based upon its wide usage under these conditions.

In addition to being able to perform at high data rates, ATM is robust enough to provide transmission at variable port speeds that are standardized by the ATM Forum, a group of merchants, service providers, and R & D associations. These ATM UNI (user network interface) standards indicate that a connection to an ATM network can occur at certain link speeds, such as T-1/E-1, T-3/E-3 (155 Mbps), and OC-12 (622 Mbps), displaying ATM's ability to achieve successful transmission at different data rates. This complements the market demand for T1 and fractional T3 port speeds which is growing more rapidly than the need for the faster port speeds like T3 and up. Currently, the service providers of Asynchronous transfer mode are delivering ATM UNIs at rates ranging from T1 all the way up to OC-12. This is a clear indication of the successful performance of ATM at data rates that cover a broad spectrum.

ATM offers several additional performance characteristics that set it apart from other transmission protocols. Asynchronous transfer mode provides bandwidth of over ten times that of the largest existing private lines. Additionally, "several transmission suppliers showed ATM add-drop multiplexers with SONET ring structures, with 50 ms recovery of the ATM signal during line failures." [RICHARDS98] Finally, statistics indicate that the average measure of "steady-state data traffic" coupled with regular usage voice traffic produced by a user is 176 kbps; over an enterprise, this creates a great deal of network traffic. [NOLLE97] The combination of these transmission data types over a single communications link has been shown to perform best under an ATM protocol. Incidentally, it takes anywhere from 10 to 60 microseconds for these types of transmissions to enter an ATM switch, receive directions, and then depart for a new destination. Asynchronous transfer mode delivers higher voice quality and faster transmission of data.

Though it is a very versatile technology, Asynchronous transfer mode does have its limitations. For instance, ATM is quite dependent on the physical layer of the OSI model. "Unlike voice service, which can tolerate error rates as high as one per 10,000 data bits, ATM is highly susceptible to even moderate error rates." [MCINERNEY97] Consequently, it is necessary to completely examine the capacity of the physical layer to transport ATM successfully. Finally, while data rates of 155 Mbps and 622 Mbps are ideal for ATM transmission, divergent rates like 143 Mbps and 360 Mbps have a tendency to pack the buffers of the ATM switches quicker than they might be cleared. This will, in turn, cause for larger queues at the ATM switches that will of course result in delays. The ATM Forum specifically delineates certain standards for data rates such that this type of occurrence is minimized or avoided. These shortcomings of ATM are in fact quite minimal, and the overall excellent performance of ATM has made it a strong contender in the transmission protocol market.

III. Use in Marketplace

Asynchronous transfer mode's original revenue goal of realizing profits through an assortment of earnings opportunities was aimed at the larger enterprise market; the farther reaching goal was to become the transmission protocol of choice for residential markets as well. Over the past several years, interest in ATM services and hardware has risen dramatically with the growing demand for the different benefits that ATM provides. In fact, up to now, ATM equipment and ATM carrier services constitute the bulk of ATM revenues, and ATM equipment sales is projected to lead the way in profits. With almost all of the major public carriers offering ATM services, these revenues should only increase. The ability of Asynchronous transfer mode to deliver multiple data types at variable rates with Quality of Service classes makes it a perfectly marketable technology for providing communication services as well as serving end-user applications through ATM transmission and equipment.

In 1998, ATM equipment and services generated revenues of nearly $3.5 billion dollars. The majority of the ATM profits were realized through the sale of ATM equipment, which totaled 3.1 billion dollars; this represents 85 percent of all ATM related sales in 1998. These figures also encompass the sales of ATM switches to service providers, carriers, and WANs. It becomes readily apparent that "many ISP networks have a core of ATM switches" based on sales estimates and industry surveys. [PASSMORE98] In addition, almost 400 million dollars in revenues were earned in ATM services last year, accounting for the remaining fifteen percent of the ATM market. This dollar amount refers only to ATM UNI services and does not account for certain ATM related services such as TLS (transparent LAN services) and communication services between PBXs. Market research projects that a compound annual growth rate (CAGR) of 41% can be expected from 1997 to 2001, where revenues for both the sale of ATM hardware and services during that period will rise from 2.4 billion dollars to nearly 50 billion dollars. [COCHRAN99] In short, revenues alone are an important indication of the strength of ATM's actual use in its respective market.

ATM Equipment

ATM equipment sales have risen dramatically and continue to grow at a rate that strongly affirms ATMs use in the communications market place. One statistic indicates that "beyond the year 2000, carriers are likely to spend up to $10 billion per year on ATM equipment." [MCQUILLAN97] A slightly lesser projection estimates that ATM equipment revenues will total 6.7 billion dollars which represents a 33 percent compound annual growth rate when compared to sales summing 2.1 billion dollars in 1997. [COCHRAN99]

There are five vertical markets for ATM equipment sales, which are carrier switches, ISP switches, enterprise WAN switches, ATM WAN access, and ATM LAN. "Throughout today's public network, ATM devices continue to populate carrier switches" [BERNHARD97] The majority of ATM switch sales are in fact made to carriers. Most revenues come from IXCs, ILECs and PITs that are overhauling their network backbones to become ATM; CLECs and some of the fiber-based carriers are also using ATM equipment. The second largest segment of ATM equipment sales is ATM LAN at 27 percent. These sales represent "ATM-capable workgroup hubs and switches, campus backbone switches and ATM uplink modules." [COCHRAN99] Next is enterprise WAN switches that constitute 23 percent and is comprised of hardware used to enable private networks to utilize multiple data forms to capitalize on multimedia applications. This segment is followed by nine percent of ATM sales that come from ATM switches sold to Internet service providers; they are used in a similar fashion to traditional voice carriers for network backbones. Finally, ATM WAN access makes up the last segment of ATM equipment sales at seven percent providing equipment to allow access to an ATM network from slower speed traffic or non-ATM lines.

ATM Services

Complementing the sale of ATM equipment is the sale of ATM services. ATM services are presently a small portion of ATM sales, but they are growing faster than ATM equipment sales and will soon become a larger share of the market. ATM services are projected to have a compound annual growth rate of 78 percent from 1997 to 2001 with sales increasing from 273 million dollars to 2.7 billion dollars during that period. [COCHRAN99] There are currently over fifty service providers for ATM UNI services with the United States handling the majority of that load. ATM services are provided at speeds ranging from T1 priced at 2,000 dollars per month up to higher port speeds of OC-3 and OC-12 coming in at around 15,000 dollars. In addition, ATM service providers also furnish Quality of Service. "An estimated 781 U.S.-based enterprises comprise the year-end 1998 public ATM services customer base, encompassing high-technology companies, healthcare and medical organizations, financial institutions, government agencies, educational institutions, ISPs and other organizations with high-bandwidth applications. The installed ATM port base is estimated at 7,624." [COCHRAN99] ATM services, comprising only the smallest portion of the ATM market, is in and of itself demonstrative of the tremendous presence and usage that ATM has on the market.

Today

To truly understand the presence of ATM in the market place, it is best to highlight specific examples of its existence. "In the US, [ATM] has been deployed by local and long distance carriers, and around the world, where telecom is being deregulated, both old monopolies and new competitors are choosing ATM. Other providers – including Internet service providers, online providers and wireless carriers - are also using ATM." [MCQUILLAN97] Bell Labs has designed a prototype for linking laptop computers to an ATM LAN such that transmission of data in the form of video can occur. "That link allows for low-overhead, single-cell ATM transmission of MPEG2 video and Internet content, according to Bell Labs." [MEYERS97] In addition, BellSouth spearheaded the design of the North Carolina Information Highway (NCIH) which is a WAN using ATM. Since 1996, Pacific Bell has been providing DS1 speed ATM service in several cities throughout California. Finally, Sprint implemented an ATM scenario whereby its client, CDWorld, "will ultimately deploy 4000 to 5000 ATM sites at kiosks throughout the country. From these kiosks, consumers can generate customized compact disks." [LUSA99] These are vivid examples of how ATM has infiltrated the market.

Tomorrow

The future of ATM is projected to yield even greater revenues than the present, especially with the additional predictions for increased usage of ATM. The Wall Street

Telecommunications Association (WSTA) reports that 63 percent of the industry feel that ATM "will have a great impact in 2000", while an additional 14 percent indicated that ATM is a part of their network currently. [BARBETTA97] Additional research by Distributed Networking Associates, Inc. illustrates ATM use in some form or another amongst all enterprise users has risen 75 percent this year; growth in the United States reached 92 percent while growth in the remainder of the world totaled 61 percent. [LUSA99] Susan Barbier, a director at Lucent Technologies states that "ATM holds the promise of resolving, once and for all, the issues associated with mixed media networking, and we believe that it will become the transport medium of choice for both private and public networks." [DIAMOND97] In summary, ATM has established a strong foundation in the communications market place, and it is quite apparent that ATM is utilized to provide communications services in a variety of different ways.

IV. Advantages and Disadvantages

Asynchronous transfer mode provides a long list of high-level benefits through the use of ATM equipment and services, delivering "operational gains soaring to 35% when contrasted to pre-ATM network implementation." [BERNHARD97] The advantages of implementing ATM include: high performance and bandwidth; dynamic bandwidth for bursty traffic; Quality of Service support for multimedia applications, scalability in speed and network size; common LAN/WAN architecture; opportunities for simplification via VC architecture; and international standards compliance. [NORTEL99] Nevertheless, there are other related technologies that are both competition and complementary to ATM; these include SONET, IP, FDDI, frame relay, and other packet switching technologies.

SONET

Synchronous optical network (SONET) is a public standard, used worldwide, for broadband transmission using fiber-optic pipes that accept data rates ranging from 51 Mbps to 10 Gbps. SONET is the actual physical transport mechanism that constitutes the first two layers (physical and data link) of the OSI model. In contrast, ATM is a transmission protocol that resides in the next two layers (network and transport) of the OSI model. ATM then uses the first two layers of the OSI model, operating "over existing technologies worldwide, including . . . SONET." [MCINERNEY97] One minor difference remains, and that deals with the means by which ATM and SONET are deployed. ATM installation has occurred in a like manner worldwide, while SONET has deviations such as SDH. In short, SONET is the physical pipe that carries different transport protocols such as ATM. The use of ATM still requires a physical and data link layer mechanism such as SONET, making it more of an asset than a competitive entity.

SONET and ATM should be viewed as a joint means of providing an integrated communications networking solution, delivering ATM benefits over a fiber-optic link. "Most major carriers in North America, Europe and Asia/Pacific have adopted ATM as the backbone switching technology along with SONET/SDH for fiber optic transmission." [MCQUILLAN97] In fact, the aforementioned ATM Forum has indicated that SONET is the "preferred Layer 1 interface for ATM. The ATM Forum defined formats for mapping ATM cells directly into a SONET STS-1, STS-3c and STS-12c payload." [FINNERAN98]

There are many advantages to using ATM and SONET in conjunction, and the major differences between the two technologies have already been illustrated. SONET provides built-in redundancy that ATM lacks; without the use of SONET, ATM modifications to utilize redundancy are quite costly. SONET with ATM is useful in providing a network solution capable of high-speed data transmissions, transporting all forms of data and integrating legacy communications applications and systems. It is most advantageous to implement a SONET/ATM network in the following environments: large corporations, organizations requiring access to public or private networks, companies with remote locations, and finally networks in need of voice support coupled with security management. This combination will demonstrate itself to be an effective solution for most demanding networks in the enterprise.

SONET and ATM networks, while proving to be the best network solution on the market, are not devoid of flaws. Even though SONET port speeds can reach very fast data rates of OC-s, OC-12, and even OC48, the use of ATM requires a packet switched implementation. To its detriment, "a packet-switched network is still a network of buffers and queues, and buffering and queuing is not the best way to distribute the delay-sensitive traffic of CBR video." [RICE95] This ill effect of data flow delay, defined in the section on *Performance Characteristics*, reduces the benefits of using SONET and ATM. Nevertheless, the advantages of using ATM with SONET significantly outweigh the disadvantages.

Internet Protocol

Internet Protocol is defined by Stallings as "an internetworking protocol that provides connectionless service across multiple packet switching networks." [STALLINGS97] This protocol then complements ATM in that it delivers service over ATM networks as well; IP routers can transmit data through a packet-switched ATM network. Though this effort displays certain merits, it is very difficult to implement and manage. One attempt at designing just such an implementation, Multiprotocol Label Switching, (MPLS) has been unsuccessful for just those reasons; Nokia's IP Switching, Toshiba's Cell-Switched Router, and Cisco's Tag Switching are further examples of failed attempts at linking the two technologies. In reality, ATM and IP technologies are in relative competition. Furthermore, an ATM/SONET network solution also presents a market threat to IP.

ATM's infiltration into the enterprise has given it a firm hold on the market and an empirical basis for demonstrating its pros and cons versus IP. The rising requirement over the past several years for higher performance by Internet service providers has resulted in the increase of ATM backbones being implemented by these ISPs. Consequently, ISPs have developed networks with ATMs as the backbone and IP routers at the perimeter. Now, with the design of terabit-per-second IP routers, ATM has a formidable competitor with regard to performance capabilities; certain vendors attest to their IP router speeds of OC-768 (40 Gbps) and OC-3072 (160 Gbps). The major problem with using a high speed IP router over an ATM switch is the lack of control for ISP managers. ATM provides great control and assessment capabilities through virtual channel and virtual path connections. Without these ATM connections, ISPs will no longer have the ability to measure traffic, allocate bandwidth, and direct traffic all within a single infrastructure; asynchronous transfer mode allows for this level of control. "By contrast, today's IP routing protocols such as OSPF and EIGRP, as well as the IS-IS and BGP4 protocols used by many service providers, perform destination-based forwarding that may not always pick the path intended by network designers; router protocols may select a shorter congested route instead of a longer uncongested route." [PASSMORE98] It is more than reasonable to state that ATM has quite a few advantages over IP.

The combination of ATM and SONET provide an even stronger network solution over that of IP. "ATM is a richer protocol than IP for built-in and proactive maintenance testing features, and so is SONET." [AMERICA'S96] With SONET, monitoring of transmission is granular down to a multiplexer section of the transmission, and this is not possible with IP. The ability to regulate the ATM connection has already been illustrated, and the two in conjunction provide a powerful means for controlling network data flow. The use of ATM and SONET together provides other testing and maintenance capabilities absent in IP, like the ability to discover the locations of line failures. Finally, ATM and SONET have proven to be the best means of transmitting voice. "There is no debate that, even at their best IP or frame will not handle voice better" than ATM and SONET. [NOLLE97] Though Internet Protocol does indeed have its advantages over certain network technologies, ATM and SONET have proven to be a better solution.

FDDI

Fiber distributed data interface (FDDI) is a LAN transmission mechanism that maintains a data rate of 100 Mbps across a fiber optic transmission medium. ATM provides a number of advantages over FDDI. The definition alone demonstrates one weakness in FDDI, its limitation to one data rate versus ATM's multiple port speeds. Additionally, the need for multiple data forms like video, voice and file data is not met by FDDI. Bay Networks' Julie Ford notes that "fiber distributed data interface networks [are] migrating to ATM . . . for not only bandwidth intensive applications but voice, video and data." [CUPITO97] Bo Nyein, ATM manager at Cisco Systems, Inc. further corroborates the inability of FDDI to handle the necessary network management tasks for transmitting data in numerous forms, especially at varying rates. Additionally, voice and video transmissions are more reliable and are of a higher quality due to the difference in the 53-byte ATM cell length and the 4,500-byte FDDI frame size. "Inherently low transmission delays guarantee real-time delivery of collaborated image and voice data for dynamic resolution and sound quality." [BERNHARD97] Finally, the cost to implement a FDDI network solution is greater than that of ATM, making it even less desirable of a choice. Dr. John McQuillan, chair of the annual Next Generation Networks conference, feels that "ATM is a solid answer . . . especially for customers who have outgrown FDDI or want to leapfrog it entirely." [MCQUILLAN97] Once again, the advantages of using ATM over another technology, in this case FDDI, are significant and convincing.

Frame Relay

Frame relay and ATM are quite similar in that they are both types of packet-switching, they operate at multiple port speeds, and much of their design is aimed at high performance and throughput. Frame relay, however, uses frames of changing length, and it does not utilize the network layer of the OSI model. The advantages of ATM over frame relay are higher speeds, interoperability with SONET, traffic management, scalability, and more defined classes of QOS. Even with these advantages, frame relay has a much greater hold on the market, giving it an advantage over ATM due to its presence and public awareness.

ATM has a number of benefits that distinguish it from frame relay. Frame relay is capable of reaching speeds over T1, while ATM exceeds the fastest frame relay speed by a significant amount. The speeds that frame relay does operate with are incompatible with SONET networks, and ATM works quite well with SONET. Additionally, "large frame relay networks become unmanageable because they lack the kind of advanced traffic management that ATM provides." [MCQUILLAN97] The more frame relay nodes that are implemented into a network, the more complex and costly it becomes; ATM is a much more scalable solution. Finally, frame relay introduced certain levels of Quality of Service into its architecture, but they are not nearly as defined or intended as those within ATM. Asynchronous transfer mode delivers this assortment of benefits over and above what frame relay supplies.

Other Packet Technologies

A final examination of ATM's capabilities versus competing technologies reveals that it has important advantages over other packet transmission technologies in general. First, disparate types of data are transmitted through an ATM network. Next, cell length is constant at 53 bytes allowing for more efficient and more accurate control and management. In addition, ATM is capable of handling both circuit and packet data flows. Asynchronous transfer mode is more scalable such that the growth in network traffic requirements is easily met. Finally, public carriers can easily recognize the benefits of using ATM. "For the first time, they [have] a technology that could be applied to building a seamless data network using internationally accepted protocols. This advantage translated into products that worked together using high-level protocols." [AMERICA'S98] In short, ATM holds many advantages over the majority of competing technologies, save SONET which truly complements ATM and makes it more robust.

V. Conclusion

In summary, Asynchronous transfer mode is a powerful transmission protocol, capable of high-performance, high-speed transport of numerous data forms. This paper set upon defining and characterizing the technology, while illustrating examples of its use in the relative market and summarizing its advantages and disadvantages versus competing technologies. ATM's usage and proliferation into the enterprise will only increase in the future "because it meets emerging requirements for scalable transport of myriad end user services, including voice, video and data." [MCINERNEY97] In conclusion, ATM provides for a flexible network architecture, capable of servicing end user applications quickly, reliably and simply.

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