

Florida Public Service Commission

White Paper
on

Network Access Technologies

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1. Introduction

Historically, access to various networks has been the driving force behind economic and social development. An early example of the economic force behind increased access to networks is the growth associated with the nineteenth century railroad system. It is quite easy to track the development and growth of cities along the railroad networks. As these railroad networks grew, access to goods and services increased and the industrial economy boomed. Today, the economy has completed the transition from an industrial base to an information base. Out of this information based economy, the Internet has become the modern day railroad system. With the advent of e-commerce, on-line government services, and real time data transfer capabilities, we are experiencing another leap in social and economic development. Just as the railroad brought change to the business practices of the nineteenth century, today's Internet promises to not only redefine the current business model but also increase access to information and facilitate true instantaneous worldwide communication. There are, however, limitations to the development of this new paradigm. One of the most pressing issues revolves around the connection speeds in which the Internet is able to be accessed.

There are two main market forces which are driving the demand for this increased access to the Internet: consumer "edutainment" (combination of education and entertainment) and business applications. Moreover, the business forces are driving the demand for higher access speeds through the changing nature of the workplace (i.e. telecommunicating), globalization of facilities (i.e. streaming video for conferences), and increased competition for the best workers. Also, this need for speed is being driven by the actual Web applications and multimedia developments which are being created to meet specific data transfer demands. "These demands are accelerating as Java-based applets, real-time video and audio features, and data warehousing become commonplace."¹

Some of the forward looking technologies which are addressing the need for increased data transfer speed (broadband) include Digital Subscriber Line (DSL), cable modems and fixed wireless systems. This paper is intended to give an overview of these technologies which are emerging to address these increased

¹Remote Network Access Technologies: Addressing the Need for Higher Speeds; Gartner Group Strategic Analysis Report; 16 November 1998.

bandwidth concerns. This paper will also provide an understanding of technologies that make up the infrastructure that provides voice, data and multimedia services over the same backbone network.

2. Network Access Market Comparison

With the advent of the modulator/demodulator (modem) in 1979, it was possible to send and receive data from one computer to another via voice grade analog telephone lines. This new modem technology gave the personal computer (PC) the communication potential which soon equaled that of the telephone. The transmission speed (baud rate) which data was transmitted over this analog modem was initially much less than the maximum capacity of the telephone lines. However, in a short period of time, revolutionary PC advancement allowed computers to process much more data at much faster speeds, and on-line services provided access to graphics, video and large databases. "These capabilities outdistanced the telephone modem, which was unable to handle data at the speeds people wanted. On the information superhighway, the telephone modem became a speed bump that slowed traffic and frustrated people."² The main problem with using voice-grade telephone lines, for the high-speed Internet applications discussed above, is the relatively narrow bandwidth of the channel. A standard voice-grade channel is one kilohertz (KHz) and is restricted to carrying a small amount of data at a time. Currently, the fastest analog modem can send and receive data at only 56,000 bits per second (56 kbps). Telephone companies are introducing faster services using higher bandwidth, such as DSL. This is being done to satisfy the increasing demand for high-speed service and to compete with other broadband access alternatives such as cable modems.

2.1 Analog Modems

The most common form of connecting to the Internet is through an analog modem. An analog modem must dial into an Internet Service Provider (ISP) through a conventional phone jack to connect to the Internet. Accordingly, a modem modulates outgoing digital signals from a digital device (such as a computer) to analog signals which are carried over the traditional copper twisted-pair phone line. In reverse, signals sent to the modem from the

²Jones Telecommunications & Multimedia Encyclopedia;
<http://www.digitalcentury.com>

telephone company's central office are demodulated from analog to digital to be read by the digital device. Currently, analog modems' transmission rates are limited by the Federal Communications Commission to 56 Kbps, but local loop limitations dictate most users are not able to reach this speed.

Analog modems are the most reliable, inexpensive, and wide spread Internet connection method, making it the choice of the majority of Internet users. Other telephone line connection methods, such as Integrated Services Digital Network (ISDN) and DSL, are capable of additional features and far greater transmission speeds, as well as an "always on" connection.

2.2 Digital Subscriber Line (DSL):

DSL has been developing in some form since the early 80's. It is a Local Access Network (LAN) Technology meaning it connects from the central office to the service user. To understand the development and usage of DSL compared to standard analog modems, a short description relating the technology involved is required. As previously mentioned, analog modems, fax modems, and private line modems use the readily available phone line. This is a twisted pair of copper lines limited to the voice-grade frequency spectrum range of 0 to 3,400 Hertz (Hz). The highest information rate on the 3,400 Hz frequency spectrum is less than 56 kilobits per second (kbps). One line of the copper pair is used for sending information, while the other is used for receiving information.

DSL offers information rates between 200 kbps and 8 millions of bits per second (Mbps) on the same type of twisted copper pair lines. This is possible because DSL eliminates the 3,400 Hz frequency spectrum boundary, allowing higher frequency usage corresponding to higher information rates and, in some cases, allowing the same line to support voice calls. To use a higher frequency spectrum on the twisted pair phone line, a few changes must be made. These include:

- A Digital Subscriber Line Access Multiplexer (DSLAM) must be installed at the Central Office (CO).³ The DSLAM converts analog and digital signals to allow the DSL signal to travel along the existing phone line to the DSL modem. Currently,

³ A DSLAM must be installed at the DLC remote terminal if fiber optic or T1/E1 line is used for transmission from the CO.

DSL is not compatible with Digital Loop Carriers (DLCs).⁴

- Loading coils must be removed from the phone line. The frequency signal transmitted over the metallic loop attenuates energy, and the higher the frequency means the higher the attenuation. This signal degradation requires loading coils to magnify the voice line signals below 3,400 Hz when the lines are longer than 18,000 feet. Without the ability to amplify its signal, DSL is currently limited to within 18,000 feet of its DSLAM. DSL uses a much higher frequency spectrum. The loading coils amplify noise which interferes with the DSL signal and causes disconnection.

Two types of DSL services are available today: symmetric and asymmetric. Symmetric is generally used in office settings where the data downstream and upstream speeds are the same. Asymmetric, on the other hand, is mostly for personal home use. Sending and receiving information has similar importance in business applications, while residential and small business users have a greater emphasis on downloading or obtaining information. Residential and small business users also can avoid the additional investment required for symmetric transmissions. The following are the different types of DSL services (DSL) in chronological order of their creation, with a brief description of their advantages and differences.

ISDN created in the early 1980's is the first type of DSL. This symmetric transmission service is able to offer two lines at 64 kbps (for voice, data, or voice and data), or the two lines can be combined at 128 kbps for data service. This form utilizes the 0 to 80,000 Hz frequency range and, therefore, requires an ISDN interface on either end of the line, a special configuration based on the type of ISDN service needed, and a premium installation price. As the different types of high-speed services have evolved at higher speeds and less expensive installation costs, ISDN's growth opportunities have diminished.

In the early 1990's, High bit rate DSL (HDSL) was created for

⁴ A DLC remote terminal is required to convert the analog signal received from the "last mile" of copper twisted pair phone line when fiber optic or T1/E1 line is used from the CO. In this situation, a DSLAM would not be able to transmit the DSL signal over the fiber or T1/E1 line, but the DSLAM could be placed in the DLC to receive and convert the DSL signal for the DLC.

use with the T1⁵ lines. This symmetric transmission service uses the T1 service speed ability, without repeaters, of 1.544 Mbps and splits it into two pairs of copper wires (four wires) running at 784 kbps. Without repeaters, HDSL is capable of being implemented on a loop up to 12,000 feet. A multiplexer "at the street" (where the service user's dedicated line converges with other dedicated lines to connect with the main phone line) separates the voice and data service.

Symmetric DSL or Single-line DSL (SDSL) is essentially the same type of symmetric transmission service as HDSL using T1 service ability, but uses only one pair of copper wires. The trade-off between the 4 wire and 2 wire systems is that HDSL can operate at lower frequencies and, therefore, has a loop distance advantage. SDSL uses only two wires to support the T1 connection and has a loop reach of approximately 11,000 feet instead of HDSL's 12,000 feet. With a relatively small difference in loop ability, SDSL has the advantage over HDSL of lower cost to connect to the T1 service.

Asymmetric DSL (ADSL) is an asymmetric transmission form of DSL that commits a large part of its bandwidth to the downstream direction toward the end user. This takes advantage of the decreased reliability of transmitted signals from the service user to the CO by increasing the downstream speed and decreasing upstream speed from the user. Downstream speeds vary from 1.544 to 6.1 Mbps, and upstream rates vary from 16 to 640 Kbps. Designed for copper twisted-pair lines, it is not compatible with fiber optic or T1 lines at this time. DSLAMs are placed in the CO or DLC remote terminal to concentrate the DSL signal from the DSL modem at the service user. ADSL is intended for mostly private or small business use, competing for the same clientele as cable modems.

Advancements in technology brought along Rate Adaptive DSL (RADSL), a symmetric or asymmetric transmission type of DSL allowing the service provider the option to reduce or optimize the line speed. This allows flexibility in the line length requirement and adjustments in line speed to adapt for line degradation. RADSL is capable of being manually or automatically adjusted between line speeds of 640 Kbps to 2.2 Mbps downstream and 272 Kbps to 1.088 Mbps upstream. The development of RADSL allows a system to support

⁵ T1 lines (24 channels of 64 Kbps) are dedicated connections capable of supporting data speeds of 1.544 Mbps. The channels can be configured for voice or data traffic.

a variety of services on the same product which minimizes costs, service, and equipment.

Very High Speed DSL (VDSL) is the latest form of DSL. This asymmetric type of transmission is capable of extremely high downstream (12.9 to 52.8 Mbps) rates and relatively high upstream (1.5 to 2.3 Mbps) rates. The difference in rates is dependent upon the distance to the end user, with a traveling capacity of up to 4,500 feet.

Digital Subscriber Line service has come a long way since its introduction in the 1980's. At its introduction, ISDSL (ISDN DSL) consisted of two lines supporting 64 Kbps that could be combined or separated for voice or data transmission. High expense and line conditioning was required for the system to run correctly, with only slightly higher speeds than standard phone modems. Presently, multiple variations of DSL exist dependent upon the service user's requirements, infrastructure, and location in relation to the central office or remote terminal. Options now exist such as Very High Speed DSL (VDSL) that uses downstream speeds that reach 52.8 Mbps when within 1000 feet of a remote terminal. Inexpensive Asymmetric DSL (ADSL) can reach residential homes within 18,000 feet of a central office at rates up to 6.1 Mbps downstream. DSL technology has allowed telephone companies to compete with cable and fixed wireless companies as the provider of high speed access to the Internet and will continue to compete with these other broadband technologies as new innovations emerge.

2.3 Cable Modems:

A cable modem is an electronic device that enables a personal computer (PC) to connect to a high-speed data network and send and receive data over the coaxial cable used in cable

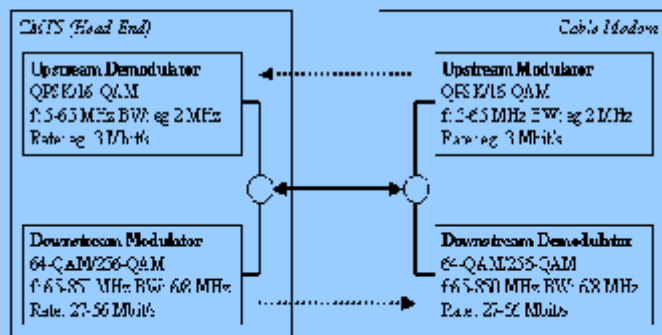
television (CATV) systems.⁶

As shown in the previous diagrams⁷, a cable modem is essentially a device which is able to convert the digital output of a PC into analog signals which can be sent (upstream) through existing analog cable and converts the downstream data into digital input for the PC. This cable modem accesses a specific frequency or channel, over the existing cable lines, which the cable operator has set aside for data transmission purposes. There are several characteristics which define the market for cable modems, these include:⁸

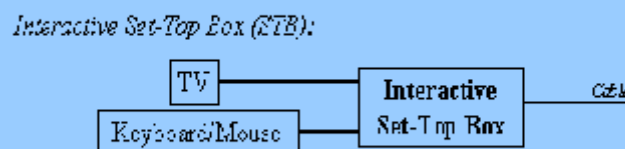
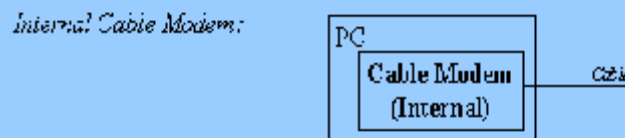
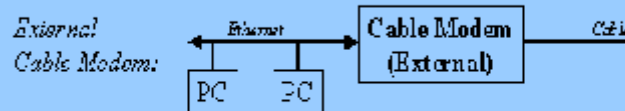
- First, the transmission medium of cable plant is broadband coaxial cable and fiber optics, supporting much higher data rates than the copper lines of telephone companies.
- Second, the broadband capacity is operated as shared Ethernet; all subscribers on an Ethernet segment share the broadband capacity. (With the telephone companies' approach, a subscriber has a defined rate dedicated to that subscriber.)

What does Cable Modem mean?

- "CABLE" is short for Cable TV (CATV) Network
- "MODEM" is MOdulator-DEModulator
- Actually more like a network adapter than a modem



Cable Modem types



⁶Ibid.

⁷Diagrams taken from, Cable-Modems Org. <http://www.cable-modems.org>

⁸Characteristics taken from Gartner Group Strategic Analysis Report; 16 November 1998.

- Third, the cable operator typically provides direct access to the Internet effectively acting as an ISP. The telephone companies typically offer access to ISPs and corporate networks.
- Fourth, standard telephone service using the cable approach requires a separate telephone line (with DSL, the same telephone line is used for data and voice); however, it is expected that cable companies will, over time, offer IP telephony services.

It is the first and second characteristics which confine the cable broadband market almost exclusively to residential and not business usage. Since the cable companies have experience with streaming audio and video, it is likely that the faster download speeds of the cable approach will lend themselves to the kind of pay-per-view model currently utilized by the cable companies.

Cable vendors and service providers have the advantage of mature technologies and less standards churn than the DSL marketplace. However, cable companies are selling into a market where the majority of buyers are interested in entertainment solutions, often viewing data access as a new toy for children. To develop new revenue streams, cable operators will do what they do best, which is pursue incremental revenue that can be tied to pay-per-view and pay-per-use.⁹

It is for mainly this "edutainment" (combination of education and entertainment) purpose which the higher speeds of the cable technology will be utilized. On the other hand, the second characteristic of the cable approach will be rather unattractive to most business users. For commercial usage, broadband access will require a dedicated line with guaranteed speeds and reliability. The cable broadband approach requires that end users be connected through an Ethernet system. The main disadvantage of this system is that the speeds are reduced as more users are added to the network. This problem of shared resources can be averted through the use of DSL telephone technology. In the DSL approach, each

⁹Remote Network Access Technologies: Addressing the Need for Higher Speeds; Gartner Group Strategic Analysis Report; 16 November 1998.

user has a dedicated bandwidth at all times thus securing both speed and reliability. Obviously, this approach would be more appropriate for commercial usage.

2.4 Telephone Company vs. Cable Company Approach:

Even though the telephone and cable companies are basically addressing the same market, their strengths and technological characteristics tend to favor distinct market classifications. The markets for cable companies favor consumers while the telephone companies favor business consumers. However, even though the two approaches seem to favor distinct market participants, it is important to realize that the nascent competition in the market for broadband services will allow, and even mandate, drastic changes through technological developments and effectual demand. This situation sets up a clash between the telephone and cable companies for broadband subscribers.

It was once viewed that telephone and cable companies would compete in each other's markets. Telephone companies would be able to justify fiber optic lines to the end user through the offering of additional video-on-demand services, much like the cable company's pay-per-view system. Conversely, cable companies were expected to offer residential telephone service. Though these services did not materialize, what did come about was competition for high-speed Internet access services. Cable Internet service, as a shared Ethernet, is more suitable for residential usage than for business. The shared Ethernet raises quality of service as well as security issues. At the end of 1999, 1.45 million customers were using cable modems compared to 560,000 customers using DSL alternatives.¹⁰ This can be misleading, as DSL has just recently become a factor in the competition for residential Internet access services with only about 50,000 customers at the end of 1998. Fearing the loss of revenue from second phone lines for Internet service, telephone companies were able to develop Asymmetric DSL (ADSL). This service is capable of sharing the same phone line as voice service, allowing telephone companies to market and deploy this new technology as an alternative to the high speed cable Internet access.

The penetration of ADSL into the residential market was further bolstered with the FCC's decision to force incumbent local

¹⁰The State of Broadband Competition, Kagan Media Appraisals for the National Cable Television Association.

exchange carriers (ILECs) to share their phone lines with competitive local exchange carriers (CLECs), and the DSL providers' decision to cut prices to be closer to cable. Cable modems presently have downstream speeds in excess of 10 Mbps and are not limited by distance from its signal origination point. Alternatively, ADSLs 200 Kbps to 6 Mbps speed is dependent on the type of equipment used and distance from the telephone central office (to a maximum of 18,000 feet).

Cable and DSL broadband services are providing the same basic service through different access types. Each type of service has its own limitations and advantages. As technology continues to evolve, this competition for residential high speed Internet service will only continue to heat up.

2.5 Looking Toward the Future: Fixed Wireless Broadband Access

"Broadband service can also be ground based and wireless, and indeed those are the distinguishing characteristics of a diverse set of technologies being explored for the consumer (and commercial) marketplace."¹¹ One of the basic premises behind these wireless networks is that the major expense of creating any broadband network based on cable or fiber is not the actual materials, but the labor needed for installation. Thus, if you are able to bypass the fiber or cable link, the cost of implementing such a "wireless" broadband network will be economically feasible even after considering the level of advanced technology. In the past, a telecommunications providers' first step was to build a network. Only when they had deployed a significant portion of the network did they market a list of standard services. Point-to-point and point-to-multipoint wireless technologies allow this paradigm to be turned around. Customers can now come first, and based upon a business' telecommunications requirements, the local loop network can be built incrementally (thus eliminating the need for a large initial footprint). This flexibility to deploy new network connections quickly gives wireless providers a marketing advantage over the wireline competition. In addition to the rapid deployment and low operating costs, fixed wireless broadband access also allows incremental capital investment more attuned to the number of subscribers.

Some of the characteristics and trends of the marketplace for

¹¹Scientific American; Clark, David D. "High-Speed Data Races Home." October 1999

fixed wireless services include:¹²

- Data Rates: Terrestrial: 44kbps to 2 Mbps, depending on mobility
Satellite: 2Mbps upstream, 16Mbps downstream
- Price: Equipment: Terrestrial \$250 - \$700; satellites under \$1,000
Network: Terrestrial 20-60 cents per Kbyte, \$60 per month
Satellite: Typically \$100 per month
- Markets: Embryonic but poised for high growth
Expected future higher data rate systems
Hardware and service costs expected to drop by over 30%
- Vendors: Nortel Networks, Lucent Technologies, Alcatel, Newbridge Networks, Bosch Telecom, and Hughes Network Systems

On the forefront of these wireless technologies is Local Multipoint Distribution Services (LMDS). Local Multipoint Distribution Service is a regulatory designation for broadband fixed wireless systems that operate in the 28 gigahertz (Ghz) band and offer up to several gigahertz of licensed spectrum (1.3 Ghz in the US). LMDS, one of several stationary broadband wireless access technologies designed for a mass subscriber marketplace, is designed for a line-of-sight coverage over a range of 3 to 5 kilometers with the capacity to provide data and telephony services for up to 80,000 customers from a single node. "Broadband wireless services called LMDS, which Gartner Group refers to as wireless fiber, will become a valuable service offering that finally enables many of the intentions of the Telecommunications Act of 1996 - namely, new technology, competition and reductions in service cost."¹³ However, fixed wireless broadband access through LMDS is not without some potential drawbacks. The very high frequency of LMDS imposes some limitations because the radio waves travel only in straight lines and are therefore blocked by buildings and other

¹²Remote Network Access Technologies: Addressing the Need for Higher Speeds; Gartner Group Strategic Analysis Report; 16 November 1998.

¹³Ibid.

obstacles. Even more problematic, they cannot penetrate moisture and therefore do not work well in areas of heavy foliage. Nevertheless, the large bandwidth allocation (1.3 Ghz) allows for the potential creation of very high speed data services.

A fixed-wireless system generally works this way: An antenna is placed on the user's premises--generally either on the roof or in a window. The antenna is connected by a cable to an adapter inside the user's office. The adapter, in turn, is attached to the user's PC or LAN by another cable, and its power cord is plugged into an electrical outlet. When the user sends data from a PC, the data is converted into signals by the adapter. The signals then travel through the first cable and are picked up by the user's antenna. That antenna relays the signals to the wireless provider's "base-station" antenna, which is also gathering signals from other nearby antennae. The base-station antenna transmits the collection of signals to a switching center via a high-speed, land-based fiber-optic cable. (With some providers, the user's signals are relayed directly to a satellite in the sky, which then transmits them to a switching center via a land-based cable.) Finally, at the switching center, the traffic is handed off to the appropriate network--either plain old telephone service (POTS) or the Internet. The reverse occurs when the user receives data: the adapter converts the signals picked up by the antenna into data so that they can be fed into the PC or LAN. Unlike DSL, a fixed-wireless system has no distance restriction and requires just one vendor for both setup and service. As long as the user's antenna is positioned on a clear line of sight with the provider's antenna, service can be established.¹⁴

The future of fixed-wireless broadband access was

¹⁴"Rapid Transit" Technology Magazine, Vol. 21, Issue 13, p121. September 14, 1999

characterized by Volpe Brown Whelan & Co. (VBW), a leading investment bank for the technology sector, in a comprehensive broadband industry report in December 1999. This report indicated that the unprecedented growth of Internet traffic offered "a tremendous opportunity for broadband use to take off and investors to profit." This VBW report projected explosive growth for fixed wireless as perhaps the most important means of broadband access in the near future, one which will significantly expand the availability of broadband availability for commercial usage. Although this technology is currently in an infant state, the potential for rapid growth and business applications make fixed wireless a market player restricted only by the amount of capital which will be invested. Nevertheless, fixed wireless seems poised to dominate a niche market comprised of business consumers who demand both speed and bandwidth.

3. BACKBONE OF TECHNOLOGIES

The post-U.S. Telecom Act of 1996 landscape for telecommunications service-provider is going through significant restructuring. Technology advances in software, transport, and interconnection are creating the so-called converged service offerings. This converged service involves the packaging of disparate services such as local, cellular, and long distance telephony with data and Internet access service into one service bundle transmitted over the network. A truly converged infrastructure provides voice, data and multimedia services over the same network using packet-based technologies in backbone networks. An integrated service digital network provides a single network that can handle these services, Asynchronous-Transfer-Mode (ATM) serves as multiplexer, aggregator, concentrator and router for the network, while SONET (Synchronous Optical Network) provides the necessary bandwidth to transport information from one ATM switch to another.

The bulk of the current Public Switched Telecommunications Network (PSTN) infrastructure consists of a variety of different networks, technologies, and systems, most of which is still based on the wireline circuit-switched infrastructure. The direction that the industry is taking in conceiving and building next-generation networks is largely premised on replacing much of the Time-Division Multiplexing (TDM) - based circuit-switched infrastructure with an ATM-based packet-switched infrastructure. ATM is used to provide end-to-end networking solutions based on packet-switching technology using virtual channels or circuits.

3.1 Asynchronous Transfer Mode (ATM)

The bandwidth limitations of a fiber system are not due to the intrinsic properties of the fiber, but the limitations of the switching, multiplexing, and transmission equipment connected to the fiber. New services such as High speed packet-switched services, LAN transport, and High Definition Television (HDTV) are examples of broadband services that utilizes large bandwidth. These broadband services require a network that combines speed with system reliability and integrity.

ATM is a statistical time division multiplexed (STDM) form of traffic that organizes digital data into 53-byte cell units and transmits them over a physical medium using digital signal technology. These fixed length cells that are transmitted by ATM are transported to and are reassembled at specific location. Each ATM cell is made up of 53-bytes, of these, 48-bytes make up the payload (user-information field) and 5-bytes make up the header. The cell header identifies the virtual path to be used in routing cells through the network. Individually, a cell is processed asynchronously relative to other related cells and is queued before being multiplexed over the transmission path. While ATM cells are transmitted synchronously to maintain clock between sender and receiver, the sender is not limited to sending data every, say, 24th. cell. Rather, the sender transmits when it has something to send and, when idle, sends empty cells synchronously. So, in short, data is sent asynchronously, cells are sent synchronously.

ATM uses packet-switching technology to provide end-to-end networking solutions with virtual circuits or paths. Packet switching is a store and forward switching technology where users' messages are broken down into smaller pieces called packets. Between source and destination, each of these packets traverse communication links and packet switches (routers), and each switch must receive the entire packet before it can begin to transmit the first bit of packet onto the outbound link.

In ATM, packets are routed according to virtual circuit numbers. ATM service provides flexible connectivity using virtual connections implemented over fiber optics cable operating at transmission speeds between 1.536 Mbps to 599.04 Mbps. This service provides for the switching of symmetrical duplex transmission of fixed length ATM cells, utilizing virtual circuits (VC). ATM supports the establishment of both permanent VCs and

switched virtual circuits. Permanent VCs (PVC) are established between customer sites via a switch, and once established, these connections are available at all times, hence, when there is no traffic, the network carries empty (idle) cells.

3.2 ATM Protocol

ATM protocol consists of three layers: the ATM adaptation layer (AAL), the ATM layer, and the ATM physical layer.

ATM adaptation Layer (AAL)
ATM Layer
ATM Physical Layer

The purpose of the AAL is to allow existing protocols (e.g., Internet Protocol (IP)) and applications (e.g., constant-bit-rate video) to run on top of ATM. AAL is implemented in the ATM end systems (i.e., entry and exit routers) and not in the immediate ATM switches. Thus, the AAL is analogous in this respect to the transport layer in the IP stack. AAL has two sublayers: the Segmentation and Reassembly (SAR) Sublayer and the Convergence Sublayer (CS). The user data is first encapsulated in the CS, and then segmented at the ATM source and reassembled at the ATM destination. The SAR sublayer which sits above the ATM layer, segments and adds AAL header and trailer bits to form the payloads of the ATM cells.

The ATM layer forms the core of the ATM standard and defines the structure of the ATM cell (i.e., the 53-bytes in a fixed cell) and the meaning of the fields within the structure. The first 5-bytes of the cell constitute the ATM header. The cell header identifies the virtual path to be used in routing a cell through the network while the virtual path defines the connection through which the cell is routed to reach its destination. The remaining 48-bytes constitute the payload which is the portion that carries the actual user information.

ATM physical layer is concerned with sending an ATM cell over a single physical link. It deals with voltages, bit timings, and framing on the physical medium. The physical layer has two sublayers: the Physical Medium Dependent (PMD) Sublayer and the Transmission Convergence (TC) Sublayer. The PMD sublayer is at the very bottom of an ATM protocol stack and it is specified

differently for different physical media (fiber, copper, etc.). PMD sublayer specifies the medium itself and is also responsible for generating and delineating bits. Some possible examples of PMD sublayers include: SONET over single-mode fiber, and T1/T3 frames over fiber, microwave, and copper. The TC sublayer sits on top of the PMD sublayer and just below the ATM layer. On the transmission side, the TC sublayer places ATM cells into the bit and transmission frame structure of the PMD sublayer. On the receiving side, it extracts ATM cells from the bit and transmission frame structure of the PMD sublayer.

In conclusion, ATM has the following characteristics:

- ▶ ATM defines a full array of communication protocols, from the transport layer through the physical layer.
- ▶ It uses packet switching with fixed length cells of 53-bytes. Each cell has 5-bytes of header and 48-bytes of payload which facilitated high-speed switching. Packet switching is a store and forward switching technology where users' messages are broken down into smaller pieces (cells). Store and forward transmission means that the switch must receive the entire packet before it can begin to transmit the first bit of the packet onto the outbound link.
- ▶ ATM uses virtual circuits (VCs) and supports both the Private VC and SVC. Packet switches use the virtual channel identifier (assigned by the ATM header to the VC) to route cells toward their destinations.
- ▶ ATM provides congestion control on an end-to-end basis. That is, the transmission of ATM cells is not directly regulated by the switches in times of congestion. However, the network switches themselves do provide feedback to a sending end system to help it regulate its transmission rate when the network becomes congested.
- ▶ ATM can run over any physical layer. However, it often runs over fiber optics using the SONET standard at speeds of 155.52Mbps, 622Mbps and higher.

3.3 Synchronous Optical Network (SONET)

Synchronous Optical Network (SONET) is the U.S. standard for synchronous data transmission on optical media. It provides the necessary bandwidth to transport information from one bandwidth switch (such as ATM) to another. It serves as the transport layer for cell-based traffic. The standard was initiated for the following key purposes:

- ! To achieve compatibility of equipment by all manufacturers
 - ! To achieve synchronous networking
 - ! To achieve enhanced operations, administration, maintenance, and provisioning (OAM&P)
 - ! To achieve more efficient add/drop multiplexing (ADM)
- SONET defines Optical Carrier (OC) levels and electrically equivalent Synchronous Transport Signals (STSs) for the fiber-optic-based transmission hierarchy. The standard SONET rates and its multiples are shown below:

Optical Carrier Level	Electrical Equivalent	Line Rate Mbps
OC-1	STS-1	51.84
OC-3	STS-3	155.52
OC-12	STS-12	622.08
OC-24	STS-24	1244.16
OC-48	STS-48	2488.32
OC-192	STS-192	9953.28

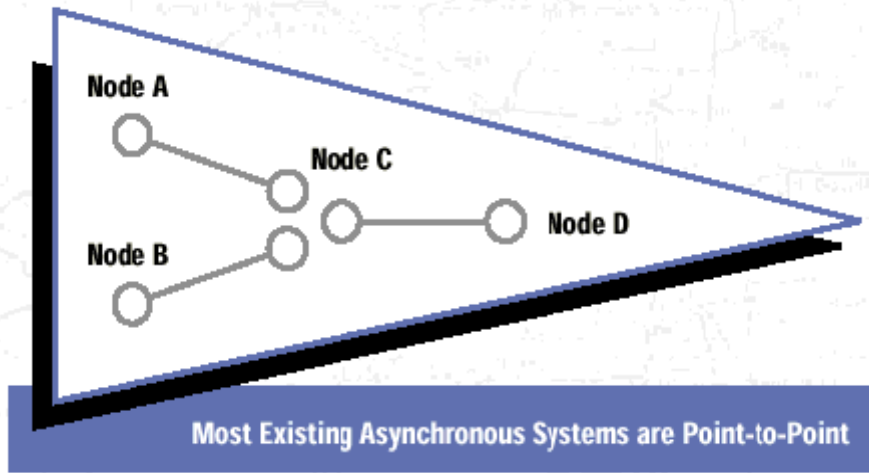
Note: The higher line rates are integer multiples of the base rate of 51.84 Mbps.

For example $OC-12 = 12 \times 51.84 \text{ Mbps} = 622.08 \text{ Mbps}$.

An integrated service that handles voice, data, and video consists of broadband switches and terminals that tie high speed local area networks (LANs), digital TV and other video services, data communication devices, telemetry equipment and voice into one digital network. SONET provides the necessary bandwidth to transport information from one integrated service network switch (or terminal) to another. For example, an OC-3 (155 Mbps) rate may be used to transport an H4 digital broadband channel carrying a broadcast quality TV.

The transport network using SONET as the backbone provides much more powerful networking capabilities than existing asynchronous systems. Synchronous systems such as SONET allows for a hub configured network. While ATM provides for only point-to-point configuration, SONET supports a multi-point or hub configuration. A hub is an intermediate site from which traffic is distributed to three or more spurs. The hub allows the four nodes or sites to communicate as a single network instead of three separate systems. This set-up reduces requirements for back-to-

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and send it to the appropriate nodes without using back-to-back configuration, back-hauling or manual separation. SONET provides a grooming function that can either consolidate or segregate traffic and make more efficient use of the network. For example, at an interconnect point, an incoming SONET line may contain different types of traffic, such as switched voice, data, or video. A SONET can conveniently segregate the switched and non-switched traffic (see figure 3.2 below)

Point-to-Point Versus Multi-Point and Grooming¹⁵

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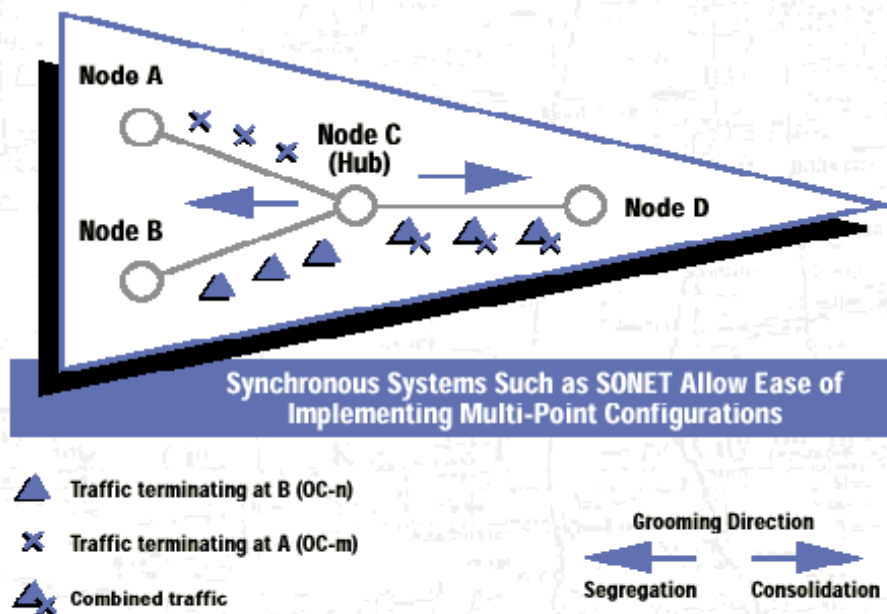


Figure 3-2 • Point-to-Point Versus Multi-Point and Grooming

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in the ATM physical layer protocol. SONET provides service flexibility and broadband capability to support broadband services. High speed packet-switched services, LAN transport, and high definition TV are examples of broadband services (services requiring 50-600 Mbps transport capacity) that may use ATM.

An ATM-based network is bandwidth transparent, which allows handling of a dynamically variable mixture of services at different

¹⁵http://www.nortelnetworks.com/products/01/sonet/collateral/sonet_101.pdf

bandwidths (see figure below), and provides transfer mode for broadband applications. Because of the bandwidth capacity that it offers, SONET is a logical carrier for ATM. SONET provides the necessary bandwidth to transport information from one ATM to another, and it offers sufficient payload flexibility that makes it suitable to be used as the underlying transport layer for ATM cells.

3.5 Multichannel Multipoint Distribution Service (MMDS)

MMDS is a broadband wireless technology that is used to deliver multiple service offerings (such as voice dial-up services, data, Internet access and video). MMDS serves as a delivery platform for the wireless local loop. While DSL, cable and wireless provides transmission technology for broadband services, MMDS provides service support ability function for fixed wireless service.

MMDS was originally conceived as, and used for, a delivery platform for video program content for entertainment and, in conjunction with educational institutions, to deliver video for distance learning activities. Most systems use analog transmission standard to deliver one video program per 6-MHz radio frequency (RF) channel. Two major changes occurred that propelled the MMDS industry to the fore front, one is the transition to digital video compression and transmission and, the other is the FCC ruling on two-way access.

The digital video enables compression of at least five video streams of similar resolution of analog video into one 6-MHz RF channel. With the spectral efficiencies of digital video compression, a few RF channels per MMDS system can be dedicated to provide broadband (>10Mbps) high-speed data service.

The second change occurred when Federal Communications Commission (FCC) ruled in 1998 that MMDS spectrum holders could operate two-way systems. That ruling made the technology platform an optimal last-mile option for addressing data networking and fast Internet access. Two-way access is necessary for delivering fast Internet service. The Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) modulation techniques on the MMDS allow for the bidirectional flow between the carrier and the end user. In many cases, a different upstream is required than the downstream and the ability to modulate differently compensated for this difference. For example, MMDS can provide coverage in

excess of 25-miles, with speeds of 10-Mbps downstream using a 2-MHz channel and 128-Kbps upstream.

MMDS solves the bandwidth shortage in the Metropolitan area network because it operates in the low frequency band - 2.1, 2.5, and 2.7-GHz, as compared with its sisters technology, Local Multipoint Distribution Service (LMDS), which operates at a higher frequency and has more available spectrums than MMDS. Typical microwave distances, bands, and operations are shown in the table below:

Frequency Band	Technology Platform	Distances	Use
2-6 GHz	MMDS	30-miles	WLL, TV
10-12 GHz	Digital Broadcasting	20-miles	DBS, TV
25-GHz and above	LMDS	3-5 miles	Business, bypass operation.

Wireless presents some challenges to the service providers. Inherent in wireless technology are some line of sight issues, in which the antenna must have a clear view of the site to where it is sending information. Microwave signals travel in straight lines, the receiver must have a direct and unobstructed view of the source in order to enjoy a reliable and good quality signal. To compensate for the line of sight limitation, delivery distance per transmitter is usually limited to a 20-mile radius, even though, theoretically, it can serve up to a 30-mile radius.

The primary network pieces constituting MMDS are as follows:

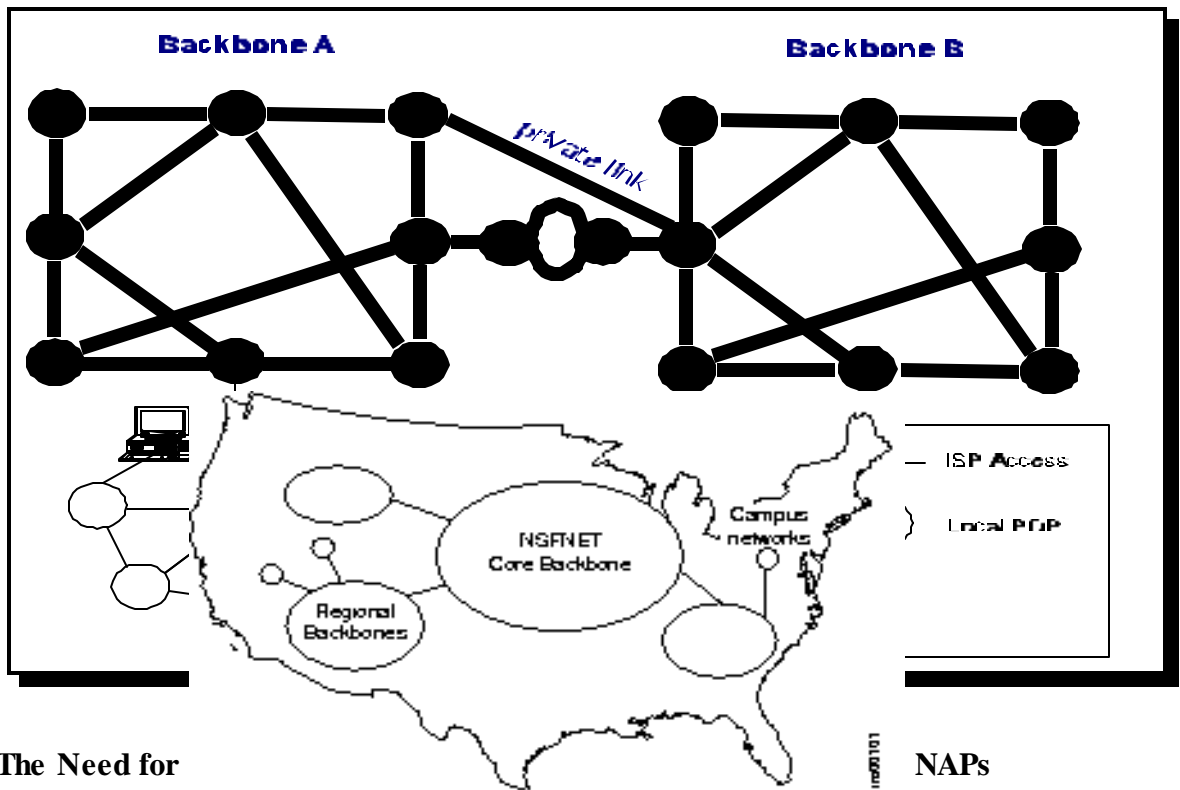
- ▶ The Network Operations Center (NOC) contains all the management functions that manage all the components of the infrastructure.
- ▶ The cable infrastructures (for LAN) are usually fiber based to connect the components of the MMDS to the private networks. The cabling consists of T1/T3 or OC-1, OC-3 or OC-12 connecting to the ATM and Internet backbones.
- ▶ The Base station is where the fiber-to-radio frequency conversion takes place; the modulation signal across the airwaves occurs at the base station also.
- ▶ The customer equipment, which varies from user to user.

The major players in MMDS are Sprint (set to be acquired by MCI Worldcom) and MCI Worldcom. The two companies have invested heavily and have acquired MMDS spectrum holders in an effort to gain technology that delivers broadband services (voice and data) directly to the customer, while bypassing the local networks. The two companies believe that MMDS offers advantage of (a) economies of scale and (b) rapid deployment over competing wireline technologies such as cable and DSL.

4. Network Access Points

A Network Access Point (NAP) is an interconnection point that serves to tie Internet access providers together through the use of high-speed links and switches. As a physical location, a NAP is literally the aggregation point of global network convergence. A NAP is the point where multiple information carriers hook up to swap information (also called peering). NAPs may be as simple as a FDDI (Fiber Distributed Data Interface) switch (100 Mbps) or an ATM switch (155 Mbps) passing traffic from one provider to the other. NAPs relay traffic from one ISP to another ISPs by transmitting this information through a SONET. A SONET is the transport mechanism for these ISPs to get to and from a NAP. Once the NAP receives the information packet from the ISP, it identifies the information packet by the Internet Protocol address (IP address) and sends it to the appropriate IP address location.

NAPs serve to tie all the ISPs together so that, for example, an AT&T user in Portland, Oregon can reach the Web site of a BellSouth customer in Miami, Florida. A NAP does absolutely no routing, as this job is completed by the routers managed by the ISPs that actually connect to the NAP. It should be noted that the Florida and regional traffic that travels through a NAP usually has to travel a vast distance. Therefore, not all Internet traffic travels through a NAP. In fact, it is common for Internet traffic to be handled using peering arrangements and interconnections within geographic regions. This type of regional peering is where each carrier connects at the closest possible point, instead of carrying traffic all the way to a NAP (See diagram below). Opponents of NAPs claim that some telecommunications carriers prefer this regional peering instead of using a NAP, due to the heavy congestion at the current NAPs.



4.1 The Need for

The structure and makeup of the Internet has adapted as the needs of its community have changed. Today's Internet serves the largest and most diverse community of network users in the computing world. With the constant need for speed, direct connections from the ISPs to NAPs are desirable because web pages, video, and voice connections all work faster, clearer, and more efficiently. See Attachment 1, Internet: The Big Picture, for an illustration that depicts the main pieces of the Internet from a User's PC all the way to the online contents.

To gain a better understanding of the demand for NAPs, we must go back to 1969 when the Internet was originally implemented by the Department of Defense to connect major universities and private companies for the purpose of research. Private networks from schools and governments connected to this original ARPANET, named for the project designers, Advanced Research Projects Agency, creating mass congestion. For this reason, the National Science Foundation (NSF) began to develop the National Science Foundation Network (NSFNET) to connect both campuses and research organizations to regional networks, and then to connect these regional networks to a major backbone that linked several super computer centers. (See figure below¹⁶)

¹⁶<http://www.cisco.com/cpress/cc/td/cpress/design/isp/lispint.htm>

Even in the early 1990's, this network was available solely for government, educational, and research applications, although the demand was rising for both commercial and general-purpose access. A new industry saw an opportunity to profit from this demand, thus the beginning of ISPs. As networks grew increasingly complex, the NSFNET appointed Sprint to connect backbone networks in the U.S. (including the Federal Internet eXchange (FIX) and the Commercial Internet eXchange (CIX)), as well as networks in Europe and Asia.

Due to the decommissioning of NSFNET in 1995, the Internet became less centralized. It transitioned from a government-financed and supported Internet to a commercially operated Internet, thus distributing operations to a number of commercial network service providers, such as Sprint and MCI. With all this information and all these different networks, the need for efficient interconnection was clear. NAPs fill this role and simplify data flow across the Internet.

4.2 NAP Implementing Strategy for Florida

In the *Florida 2000 Legislative Report* that was created by the Information Service Technology Development Task Force, it states that NAPs are “seen as the technological catalyst for sustained economic growth throughout the state, nationally, and in the continued effort to brand Florida as the gateway to Latin America,” and have capability to “attract huge investments in the latest and fastest technology from telecommunications carriers.” Other than the enormous economic growth created by a NAP, establishing a NAP in Florida should mean faster, more reliable service and possible lower Internet rates for the average Florida Internet user. The goal is to create a Florida NAP, preferably in the Miami area, that will motivate economic activity throughout Florida and increase national and international awareness of Florida as a state ideally suited for the successful advancement of the information technology business sector.

Some of the earlier NAPs were built with federal monies; however the proposed Florida NAP would be a private business initiative with state monies contributed to ensure that the state would have a stake of the Internet infrastructure to attract commerce and provide a gateway to Central and South America. Private NAPs, or P-NAPs, have begun to appear all over the country and across the world. P-NAPs are becoming more popular since Public NAPs are becoming extremely congested. Most P-NAPs have direct connectivity to several backbones to ensure the most optimal path, as well as for backup in case a backbone is down. An example of such a regional P-NAP is the Compaq Houston NAP created by Compaq in 1997. Compaq donates equipment and support, and Insync Internet Services runs the service to help the Houston community on a non-profit basis. Not all companies, in fact very few companies, donate such resources on a non-profit basis. Most companies creating NAPs see an extremely profitable opportunity. For

example, MCI WorldCom, the operators of the Metropolitan Area Exchange (MAE) East, have created six other P-NAPs across the country: the MAE West (located in San Jose, CA), the MAE Chicago, MAE Dallas, MAE Houston, MAE Houston, MAE Los Angeles, and the MAE New York.

Senate Bill 1334 (SB 1334), "Itflorida.com Act of 2000", was passed during the 2000 Florida Legislative Session. This bill directs the State Technology Office to report by July 1, 2000 on the feasibility of developing a NAP in Florida. It has been estimated that a Florida NAP may cost between \$100 million to \$300 million, spread over several years. In an effort to fund this, Florida is considering a tax incentive for firms who aid in developing the connection hub and routing center. In fact, SB 1334 was amended late in the session to include \$700,000 for the State Technology Office to carry out the Act. Six hundred thousand is to be used to reimburse eligible companies for sales tax payments made on equipment associated with the creation of a NAP. Enterprise Florida is also forming a study group to explore the feasibility of using state-employee pension funds to support investors that are either domiciled in Florida or regularly investing in technology companies headquartered in this state. Enterprise Florida, Inc., must submit a report on the findings of the study group to the Governor, the Speaker of the House of Representatives and the President of the Senate by October 1, 2000.

5. Conclusion

The nature of Internet use is changing rapidly and the need for Internet access is exploding. The need for bandwidth and speed serve as the driving forces for the emerging communications network that delivers broadband services. Various access options such as fiber, satellite, fixed wireless, DSL and cable are the prevailing transmission technologies that are needed to provide the capable bandwidth. The transport of these broadband services is provided by ATM and/or SONET for fiber, and MMDS and LMDS for the fixed wireless service. To take full advantage of the available bandwidth in the fiber optics cable, ATM and/or SONET remove the limitations imposed on the fiber by the switching, multiplexing and transmission equipments that are connected to the fibre. While ATM defines communication protocols from the transport layer through the physical layer using packet-switching technology with virtual circuits, SONET serves the physical transport layer for cell-based traffic. SONET provides the necessary bandwidth that facilitates the transport of information from one integrated service network switch to the other. As a result, SONET is normally used in ISPs and NAP network systems.

Given the wide range of systems and the technical requirements, it is tempting to speculate which broadband technology will emerge as the dominate one. However, technology may ultimately have little influence upon deployment. The various systems are all technically feasible

and have been demonstrated and installed in varying degrees. It seems that the real barrier to widespread broadband access is the cost of installation. Economics, market structure, and capital investment decisions are the main forces driving broadband deployment. Thus, the end mix of broadband technologies will have little to do with their technical merits and will mainly rely upon the various levels of marketing and investment.