ADSL: The Best Choice for Fast Internet Access

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ABSTRACT

There is a real need for the increased bandwidth at a lower cost provided by ADSL (Asymmetric Digital Subscriber Line). The time is ripe for deployment due to the current competitive environment, and both ADSL transport providers as well as ISP's may achieve acceptable returns on investment when offering the service. Due to new applications and a more pervasive use of the Internet, demand will only grow. This, combined with a growth in the number of providers that encourages price competition, will further help generate demand.

SINOPSIS

Este artículo describe los conceptos básicos relacionados con la implementación de la tecnología conocida como ADSL (Asymmetric Digital Subscriber Line). En el mismo se describe qué compone esta tecnología y las alternativas a la misma.

Se presentan los conceptos básicos sobre la infraestructura de ADSL y los diferentes sistemas que se necesitan para implementar esta tecnología.

I- INTRODUCTION

The growth of the Internet has been phenomenal. The backbone capacity in the United States alone has grown from single T-1 (1.54 Mbps) to OC-48 (2.4 Gbps): a 10.000 percent increase. In the same timeframe, applications have evolved from simple (and sometimes unreliable) email and FTP connectivity, to the WEB, e-commerce, Internet telephony and video streaming.

Access bandwidth has not kept pace, except for dedicated corporate access, which has, more or less, followed the backbone bandwidth curve. The bandwidth available to the typical residential user or even telecommuter has grown from 1200 bps to 56 Kbps, or in some cases ISDN at 128 Kbps: a paltry 1000 present increase. Thus, a disconnect in Internet's ability to support high bandwidth content and the average user's ability to take advantage of it.

Only in the last year has this situation changed, with the introduction of the Digital Subscriber Line (DSL) and cable modems. These two technologies deliver, for the first time, megabit connectivity to the masses at an acceptable price point. This last point is critical, since nothing actually precluded running an OC-3 ATM connection to the house down the street.

ADSL is the most relevant flavor for casual Internet users and telecommuters. ADSL is quickly growing in popularity, as evidenced by the number of users applying to local and the ISP's signing on support the service.

The availability of megabit connectivity to the average household opens up a wealth of new services and enables true convergence between Internet content and media. For the first time, high quality video streaming becomes a reality, and the worldwide waiting experienced when browsing graphic-intensive catalogs or auction sites is a thing of the past. For the telecommuter, ADSL delivers on the promise of productivity.

ADSL is, therefore, an important technology to understand in terms of both standardization and, more importantly, forming a basis for high speed Internet Services.

II- INTRODUCTORY CONCEPTS

Before beginning with the discussion about ADSL, the reader should be familiarized with the following concepts.

A- Digital Subscriber Line

Digital Subscriber Line or DSL is the generic name for a family of evolving digital services to be provided by local telephone companies to their subscribers. Such services go by different names and acronyms - ADSL, HDSL, HDSL2, SDSL, IDSL, RADSL and VDSL.

1- ***HDSL*** - High bit rate Digital Subscriber Line [1]. The most mature of the xDSL technologies. HDSL allows the provisioning of T-1/E-1 local loop circuits much more quickly and at much lower cost than through conventional means. In the U.S., HDSL delivers T-1 (1.536 Mbps usable bandwidth) over a four wire loop of two pairs. E-1 capacity of 2.048 Mbps requires three pairs. Unlike ADSL, HDSL bandwidth is symmetric, as equal bandwidth is provided in each direction.

The traditional approach of provisioning T-1/E-access loops on copper wires requires specially conditioned UTP (Unshielded Twisted Pair), with repeaters spaced every 6,000 feet in order to compensate for signal attenuation at the high carrier frequencies required. Each pair supports simplex (one way) transmission at 1.544 Mbps, of which 1.536 Mbps is usable for data transmission; in combination, the two simplex circuits yield a full duplex circuit.

HDSL, which involves special electronics at both the Center Office (CO) and the customer premise, delivers the same transmission capacity over standard UTP at distances up to 12,000 feet without the requirement for repeaters.

A proposal for a new variation on the HDSL theme was recently proposed as a standard. HDSL2, based on technology from Adtran Inc., provides the same capacity over a single pair, although the local loop length is limited to about 10,000 feet. This technology is also known as SDSL (Single line DSL). Speeds of up to one megabit per second are possible both ways (thus symmetrical).

2- ***IDSL*** - Integrated Digital Subscriber Line [1] is a developing xDSL technology, which uses ISDN technology to deliver transmission speeds of 128 Kbps on copper loops as long as 18,000 feet. IDSL is a dedicated service for data communication applications only; whereas ISDN is a circuit-switched service technology for voice, data, video and multimedia applications.

3- ***RADSL*** - Rate Adaptive Digital Subscriber Line [1]. Transmission technology that supports both asymmetric and symmetric applications on a single twisted pair telephone line and allows adaptive data rates. RADSL employs intelligent ADSL modems, which can sense the performance of the copper loop and adjust the transmission speed accordingly.

4- ***VDSL*** - Very high data rate Digital Subscriber Line [1]. A technology in the very early stages of definition. Initial VDSL implementation will likely be in asymmetric form, essentially being very high speed variations on the ADSL theme. Goals are stated in terms of submultiples of the SONET and SDH principal speed of 155 Mbps.

The application for VDSL is in a hybrid local loop scenario, with FTTN (Fiber To The Neighborhood) providing distribution from the CO to the neighborhood, and with VDSL over UTP (Unshielded Twisted Pair) carrying the signal the last leg to the residential premise. Clearly, the specific application is for highly bandwidth-intensive information streams such as those required for the support of HDTV and Video on Demand.

5- ***ADSL*** - Asymmetric Digital Subscriber Line [1] is an evolving high speed transmission technology. ADSL: (a) uses existing UTP copper wires from the telephone company central office to the subscriber's premises, (b) involves electronic equipment in the form of ADSL modems at both the central office and the subscriber's premises, (c) sends high speed digital signals up and down those copper wires, and (d) sends more information one way than the other - hence the term "asymmetric". The original speed specs for ADSL was T-1 (1.536 Mbps) downstream from the carrier to the subscriber's premises and 16 Kbps upstream. While still in field trial status, ADSL is available in a variety of configurations.

6- ***SDH*** - Synchronous Digital Hierarchy [1] is a set of standard fiber optic based serial standards planned for use with Sonet and ATM in Europe. Some of the SDH and Sonet standards are identical.

7- ***OC-3*** - Optical Carrier 3 [1] is a Sonet channel equal to three DS-3, which is equal to 155.52 Mega bits per second.

8- ***OC-192*** - Optical Carrier level 192 [1] is a Sonet channel of 9.953 Giga bits per second.

9- ***DWDM*** - Dense Wavelength Division Multiplexing is the higher capacity version of WDM (Wavelength Division Multiplexing), which is a means of increasing the capacity of fiber optic data transmission systems through the multiplexing of multiple wavelengths of light.

10- ***L2TP/L2F*** - Layer 2 Tunneling Protocol [1] providing secure, high priority and temporary path through the Internet.

11- ***ATM*** - Asynchronous Transfer Mode [2] is a technology designed to preserve the Quality of Service (QoS) requirements of multiple traffic types carried over a single link or network. ATM accomplishes this by segmenting all traffic types into 53 bytes entities known as cells associated with a different QoS. Figure 1 describes how the ATM technology segments the different types of traffic. As you can see in this figure, ATM arranges the types of traffic depending of the traffics QoS. For example voice traffic does allow to be delayed or with interference while data traffic is more flexible, thus ATM gives priority to voice since its QoS requirements are more demanding.

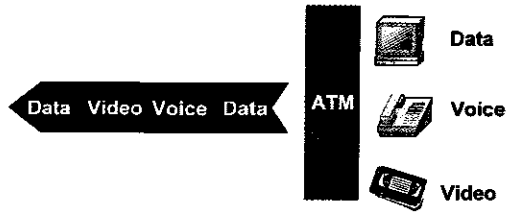

Figure 1: *How ATM Segments Traffic*

III- TECHNOLOGICAL BACKGROUND

A- Growth of the Internet

The demand for increasing bandwidth is insatiable [3]. As vendors roll out increasingly sophisticated software based on ever more powerful processors, as Web content grows in complexity and as IP telephony and video streaming enter the mainstream, Internet users demand higher speed connectivity.

Telecommuters and homeworkers seek increased efficiency, and branch offices wish to deploy new network centric services for subscribers but cannot afford bandwidth at traditional leased line pricing models. This is coupled with a change in expectations as the Internet takes on an increasingly important role in everyday life. Examples of this include e-mail connectivity, commerce and most recently, Internet telephony. This latter application along with its more sophisticated kin, videoconferencing, lends a case for permanent connectivity. A user is always reachable, able to receive incoming connections in addition to the traditional environment where only outgoing sessions are possible.

This demand for connectivity, however great on its own, is insufficient to guarantee the deployment of higher speed technologies at lower tariffs. The effect of ADSL on Internet connectivity and the perceived utility of its service are most evident when comparing a typical file download time for the different access technologies.

B- The New Internet Infrastructure

The Internet infrastructure [3] was composed of a backbone infrastructure, based mainly on T-3 and OC-3 links. Access methods to the Internet include leased lines and Frame Relay lines up to T-1 or T-3 modem or ISDN connectivity.

The new infrastructure is based on multiple fiber links in the backbone supporting ATM, SONET or DWDM transmissions and speed from OC-3 to OC-48 and even OC-192. The IP protocol may be carried over an ATM infrastructure or layered directly over SONET or DWDM. At the same time, high speed access technologies such as HFC supporting cable modems, high speed leased lines, DSL and wireless are emerging or are being deployed.

C- The Customer Premises

Within an ADSL deployment, the customer premises, either business or home, may at times be almost as complex as the Central Office. This environment contains the user's PC also know as Terminal Equipment in the parlance of the ADSL forum. These devices connect to a Premises Distribution Network (PDN) over which the data access the ADSL modem. This then connects to a POTS/ISDN splitter and finally to the local loop. The ADSL Forum formalizes this into a Customer Premises Equipment (CPE) reference model consisting of a set of logical entities and interfaces.

D- Premises Distribution Network

Within the context of the ADSL reference model, the Premises Distribution Network (PDN) is the technology connecting the user's terminal equipment (PC) with the ADSL modem including Ethernet, ATM and USB. The choice will depend on the user's mix of services and the choice of interfaces.

E- ISP / Corporate Gateways

After traversing the core network, the user's data finally arrives at the ISP or corporate gateway. This device terminates any ATM, PPP sessions or L2TP/ L2F tunnels, passing the traffic into the provider's core or corporation's Intranet. User authentication commonly occurs at this boundary. The actual hardware device performing this session termination function is commonly known as a home gateway

(HGW), or in the L2TP tunneling space an L2TP Network Server (LNS). When terminating PPP, this device must have the scalability to handle a large number of user PPP sessions. Unlike the customer, connected to the network via ADSL, the HGW will connect natively to an ATM or packet core.

IV- THE ADSL ARCHITECTURE

The ADSL concept can be represented using a layering model [3, 4, 5]. This model is divided in seven layers, which are as follow:

1- ***Physical Layer*** [3] - The Physical Layer provides the physical infrastructure for all the other layers. It consists of the actual transmission systems along with the necessary glue to allow the ATM cells to be carried over the system in question. This layer provides the actual connectivity for the higher layer ATM traffic, with options including fiber, copper, and wireless.

2- ***Link Layer*** [3] - The Link Layer provides controlled access to the physical layer. The best examples of a link layer are Ethernet and ATM.

3- ***Network Layer*** [3] - The Network Layer provides end to end connectivity through addressing and routing. The network layer uses the IP protocol; this protocol contains the necessary information to allow a data packet to be routed across the Internet. The IP protocol has the ability to multicast data from a single source to multiple destinations. Figure 2 describes what data multicasting does.

4- ***Transport Layer*** [3] - The Transport Layer consist of several protocols associated with IP. An example of one of these protocols is the transport control protocol (TCP). This protocol controls the flow of data and contains the mechanism for backing off data transmission in times of congestions and also is capable of retransmitting the data in case that some or the entire packet is lost during the transmission.

5, 6- ***Presentation and Session Layers*** [3] - Session and Presentation Layers, respectively, are hidden from the end user, as their functions are normally within a given application.

7- ***Application Layer*** [3] - The Application Layer is the one layer with which the user interacts.

Each of the seven layers wraps the original data, or packet, with a header information necessary to perform its required function.

V- ENCODING METHODS

The physical layer handles the basic ADSL encoding, including the standards, data rates, and the compatibilities with other technologies [4]. The most used encoding standards are Discrete Multi Tone

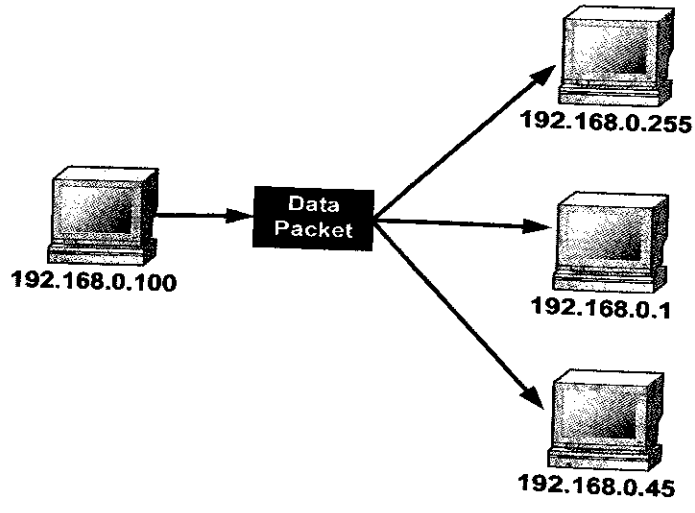

Figure 2: *Data Multicasting*

(DMT) and Carrierless Amplitude and Phase (CAP). The theory behind these two techniques is beyond the scope of this paper. Table 1 summarizes the different performances of these two methods.

Table 1: *Performance of DMT & CAP [4]*

	DMT	CAP
Downstream Max	6.1 Mbps 8 Mbps (short dist.)	7.168 Mbps
Downstream Typical	1.5 Mbps	1.5 Mbps
Downstream Min	384 Kbps	640 Kbps
Upstream Max	224 Kbps 768 Kbps (short dist.)	1.088 Mbps
Upstream Typical	384 Kbps	256 Kbps
Upstream Min	128 Kbps	90.6 Kbps
Distance	12,000 ft	18,000 ft

The actual performance of these technologies (DMT & CAP) ultimately depends on distance, line interference and noise and the quality of the actual copper cables.

VI- THE ADSL INFRASTRUCTURE

Figure 3 describes the infrastructure of ADSL from a home user perspective.

In order to implement ADSL, the home user needs only an ADSL modem and a splitter. The ADSL Modem provides the digital connection at one end (in the users home, the other end would be the service provider) and the splitter divides the traffic in data and voice.

Upon leaving the home premises, the first equipment encountered at the central office is the Main Distribution Frame (MDF). The MDF slits the ADSL signal into data and voice. The voice traffic is carried to the existing circuit switch, while the data enters the ADSL modem rack, known as the Digital Subscriber Line Access Multiplexer (DSLAM). This DSLAM multiplexes the data onto an ATM trunk, presenting it to a local aggregation function, or to an upstream aggregator reachable across an ATM network.

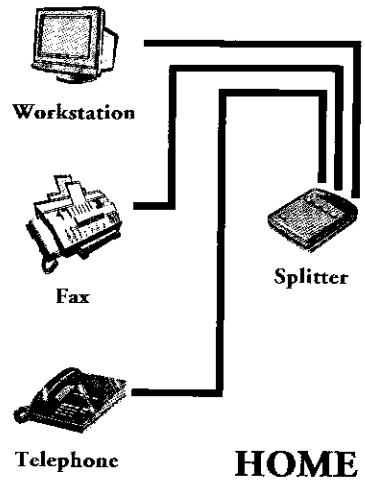

Figure 3: *ADSL Infrastructure*

VII- ALTERNATIVES TO ADSL

This section describes the different technologies that are available as an alternative to ADSL.

A- LMDS

LMDS [3] (Local Multipoint Distribution Service) is a broadband wireless point to multipoint communication system operating above 20 GHz (depending on country of licensing) that can be used to provide digital two way voice, data, Internet, and video services (see Figure 4). This technology offers a downstream scale of 155 Mbps. These 155 Mbps contents are within 40 MHz local channels.

The acronym LMDS is derived from the following:

1- ***L (local)*** - denotes that the propagation characteristics of the signals in this frequency range limit the potential coverage area of a single cell site; ongoing field trials conducted in metropolitan centers place the range of an LMDS transmitter at up to 5 miles.

2- ***M (multipoint)*** - indicates that signals are transmitted in a point to multipoint or broadcast method; the wireless return path, from subscriber to the base station, is a point to point transmission.

3- ***D (distribution)*** - refers to the distribution of signals, which may consist of simultaneous voice, data, Internet, and video traffic.

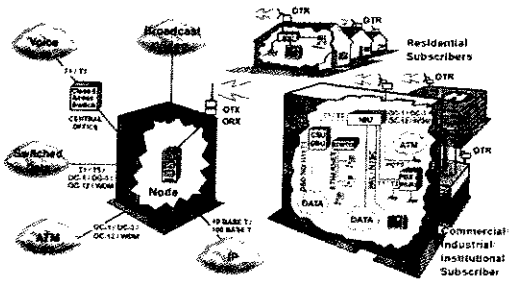

Figure 4: LMDS

4- ***S (service)*** - implies the subscriber nature of the relationship between the operator and the customer; the services offered through an LMDS network are entirely dependent on the operator's choice of business.

As a result of the propagation characteristics of the signals in this frequency range, LMDS systems uses a cellular like network architecture, though services provided are fixed, not mobile. In the United States, 1.3 MHz of bandwidth (27.5 B, 28.35 GHz; 29.1 B, 29.25 GHz; 31.075 B, 31.225 GHz; 31 B, 31.075 GHz; and 31.225 B, 31.3 GHz) has been allocated for LMDS to deliver broadband services in a point to point or point to multipoint configuration to residential and commercial customers.

B- MLDS

MLDS [3] (Multichannel Multipoint Distribution Service) operates in a different frequency with a more ample hub space. This high speed service serves a radius of 40 to 50 miles, covering approximately 100 to 300 subscribers. This technology operates a 2.5GHz bandwidth, 198MHz spectrum. This type of Technology operates at 2.5GHz, whereas the uplink serves 2.15 to 2.16 GHz. This downstream bandwidth is QAM encoded while upstream data depends on QPSK encoding.

The typical setup of an MMDS system is shown in Figure 5. The wireless system consists of head end equipment (satellite signal reception equipment, radio transmitter, other broadcast equipment, and transmission antenna) and reception equipment at each subscriber location (antenna, frequency conversion device, and set-top device).

C- Cable Modem

A cable modem [3] is a device that sits between a PC and a cable TV network and allows the PC to send and receive data in a similar manner to a traditional analog modem. To offer high speed Internet services, a cable operator creates a data network that operates over its Hybrid Fiber/Coax (HFC) plant. The cable modem speeds varies widely, depending on the cable modem system, traffic load and cable network. The downstream direction (from the network to the computer) speeds can be anywhere up to 27 Mbps, and the upstream direction (from computer to network) speeds can be up to 10Mbps.

VIII- CONCLUSION

With the rapid growth of the Internet and new users joining by the thousands everyday, a new

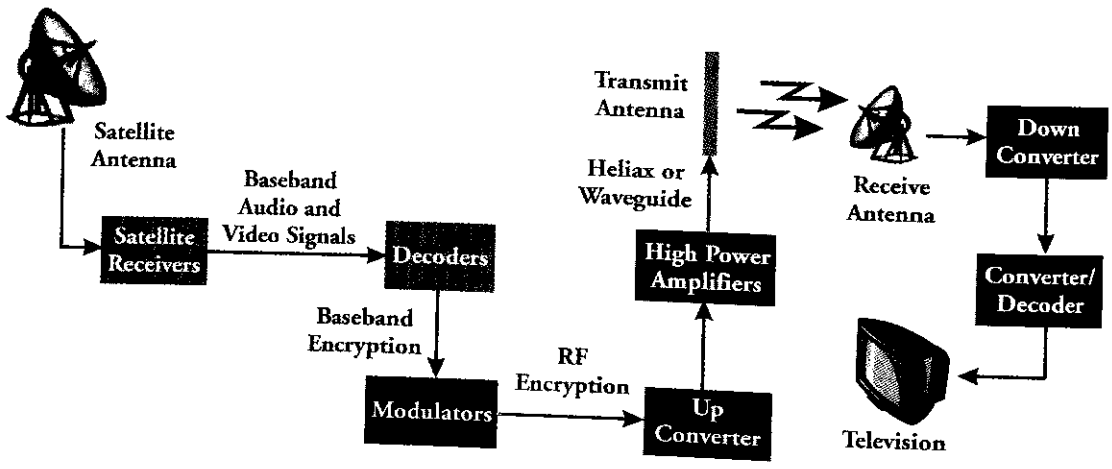

Figure 5: MMDS

technology is needed to help these users achieve their daily tasks more rapidly.

By using ADSL as an alternative to dial up connections, users will be indeed able to connect to the Internet, and access all the resources available, faster than ever. Business will also benefit from this because they will be able to offer new and improved services to their customers and, also, deliver live multimedia events from any place in the world.

Of all the available technologies for doing this, ADSL is better suited to perform the job since it can use the existent phone lines, and gives the user a dedicated exclusive connection to the Internet for a reasonable cost.

The implementation of high speed connections to the Internet will bring new companies and markets, since new services and products will be available for customers. This will also help the Internet to continue growing at its enormous rate.

IX- REFERENCES

[1] Harry Newton, "Newton's Telecom Dictionary", 15th edition, Miller Freeman Inc., 1999

[2] ATM Forum, ATM Forum Traffic Management Specification Ver. 4.0, AF-TM-0056, ATM Forum, April 1996

[3] David Ginsburg, "Implementing ADSL", Addison Wesley Logan Inc., 1999.

[4] ADSL Forum, Framing and Encapsulation Standards for ADSL: Packet Mode, ADSL Forum TR-003, June 1997

[5] ADSL Forum, An End to End Packet Mode Architecture with Tunneling and Service Selection, ADSL Forum TR-011, June 1998.