Extracting More Bandwidth Out of Twisted Pairs of Copper Wires

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INTRODUCTION

Since the inception of the plain old telephone system (POTS) in the 1880s, it has formed the backbone of the communications world. Reliant on twisted pairs of copper wires bundled together for its operation, there has not really been any quantum jump in its transmission mode, except for its transition from analogue to digital at the end of the 1970s.

Of the total bandwidth available on the copper wires, the voice portion, including the dial tone and ringing sound, occupies about 0.3 %—that is, the remaining 97.7 % is unutilized This seems to be poor resource management as prior to the advent of the Internet, telecommunication companies (telcos) have not really sought to explore better utilization of the bandwidth through technological enhancements—for example, promoting better voice quality and reducing wiring by routing two neighboring houses on the same line before splitting the last few meters. Two possible reasons could be cited for this. Advances in microelectronics and signal processing necessary for the efficient and cost-effective interlinking of computers to the telecommunications network have been rather slow (Reusens, van Bruyssel, Sevenhans, van Den Bergh, van Nimmen, & Spruyt, 2001). Also, up to about the 1990s, telcos were basically state-run behemoths which had little incentive to come out with innovative services and applications. With deregulation and liberalization of the telecommunication sector introduced in the 1990s, the entire landscape underwent a radical change that saw telcos instituting a slew of services, enhancements, innovations, and applications; in parallel, there was a surge in technological developments facilitating these.

Prior to the advent of the Internet, POTS was used mainly for the transmission of voice, text, and low resolution graphics—the latter two are in relation to facsimile machines which became popular in the late 1980s. The POTS network is, however, not able to support high bandwidth applications such as multimedia and video transmission. Because of the ubiquity of POTS, it makes sense to leverage on it for upgrading purposes in order to support high bandwidth applications rather than deploy totally new networks which would need heavy investments. In recent times, asymmetric digital subscriber line (ADSL) has emerged as a technology that is revolutionizing telecommunications and is fast emerging as the prime candidate for broadband access to the Internet (Tan & Subramaniam, 2005). It allows for the transmission of large amounts of digital information rapidly on the POTS.

BACKGROUND

Attempts by telcos to enter the cable television market led to the beginnings of ADSL (Reusens et al., 2001). They were looking for a way to send television signals over the ubiquitous phone line so that subscribers could use this line for receiving video. An observation made by Joseph Leichleder, a scientist working at Bellcore, that there are a plethora of applications and services for which faster transmission rates are needed from the telephone exchange to the subscriber's location rather than for the other way around (Leichleider, 1989), led to the foundations of ADSL. Telcos working on the video-on-demand market soon recognized the potential of ADSL for sending video signals on the phone line. The video-on-demand market, however, did not take off for various reasons: telcos were reluctant to invest in the necessary video architecture as well as upgrade their networks for the transmission of video signals, the quality of the MPEG video stream was rather poor, and there was competition from video rental stores that were proliferating in many countries and leasing out the videos inexpensively (Reusens et al., 2001). Moreover, the hybrid fiber coaxial (HFC) architecture for cable television, launched in 1993, posed serious competition. At about this time, the Internet was becoming a buzzword, and telcos were quick to realize the potential of ADSL for fast Internet access. Field trials began in 1996, and in 1998, ADSL started to be deployed in several countries.

Excessive interest by telcos towards ADSL has more to do with the fact that the technology offers speedy access to the Internet as well as provides scope for delivering a range of applications and services while offering competition to cable television companies entering the Internet access market. Obviously, this means multiple revenue streams for telcos and maximizing shareholder value.

Since 1989, there have been rapid technological enhancements in relation to ADSL; the evolution of standards for its use has also begun to fuel its large-scale deployment for Internet access (Chen, 1999). It is a good example of a technology that went from the ideation stage to the implementation stage within a decade (Starr, Cioffi, & Silverman, 1999). The purpose of this article is to provide an overview of ADSL.

ADSL TECHNOLOGY

The frequency band for voice transmission over the phone line occupies about 3 KHz (200 Hz to 3300 Hz), while the actual bandwidth of the twisted pairs of copper wires constituting the phone line is more than 1 MHz (Hamill, Delaney, Furlong, Gantley, & Gardiner 1999; Hawley, 1999). ADSL leverages on the unused bandwidth outside the voice portion of the phone line to transmit information at high rates. A high frequency (above 4,000 KHz) is used because more information can then be transmitted at faster rates; a disadvantage is that the signals undergo attenuation with distance, which restricts the reach of ADSL.

There are four key technologies that constitute ADSL:

a. **Signal modulation:** The process of sending information on a phone wire after encoding it electrically is called modulation. Initially, carrierless amplitude phase (CAP) modulation was used to modulate signals over the ADSL line. CAP works by splitting the line into three bands—one each for voice, upstream access, and downstream access, with the three bands sufficiently separated so as to avoid interference from each other. It has since been largely superseded by a superior technique called discrete multitone (DMT) technology, which is a signal coding technique invented by John Cioffi of Stanford University (Cioffi, Starr, & Silverman, 1998; Ruiz, Cioffi, & Kasturia, 1992). He demonstrated its use by transmitting 8 megabytes of information in one second across a phone line 1.6 km long. DMT is superior to CAP when it comes to speed of data transfer and efficiency of bandwidth allocation but not in terms of power consumption and cost since complex signal processing techniques involving sophisticated algorithms and hardware designs are involved. The former reasons have been key considerations in the widespread adoption of DMT by telcos.
b. **Frequency division multiplexing:** In DMT, the bandwidth of the phone line is divided into 256 narrow band channels through a process called frequency division multiplexing (FDM) (Figure 1) (Kwok, 1999). Each narrow band channel occupies a bandwidth of 4.3125 KHz and is spaced 4.3125 KHz apart from the others. For sending data across each narrow band channel, the technique of quadrature amplitude modulation (QAM) is used. Two sinusoidal carriers of the same frequency but which have a phase difference of 90 degrees constitute the QAM signal. The number of bits allocated for each narrow band channel varies from 2 to 16—the higher bits are carried on narrow band channels in the lower frequencies, while the lower bits are carried on narrow band channels in the higher frequencies.
The following theoretical rates apply:

Downstream access: 256 carriers x 8 bits x 4 KHz = 8.1 Mbps
Upstream access: 20 carriers x 8 bits x 4 KHz = 640 Kbps

From a practical standpoint, the data rates achieved are much less owing to inadequate line quality, long length of line, crosstalk, and noise (Cook,