Digital Communication Systems

Asymmetric Digital Subscriber Line (ADSL)

Gavin Cameron

MSc/PGD Electronics and Communication Engineering

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ABSTRACT

This report contains an overview of the new technology of Asymmetric Digital Subscriber Line (ADSL) where broadband information can be transmitted into homes down standard telephone cable. It looks at the two competing standards and gives an overview of the problems faced delivering this technology.

INTRODUCTION

Asymmetric Digital Subscriber Line (ADSL) is a relatively new technology. It’s aim is to provide high speed data transmission rates over standard telephony cables.

Telephone cables installed into homes are usually copper twisted pair wire connected to telephonic equipment with a bandwidth limited to around 300Hz to 3.4kHz, this was the requirement for speech transmission. However, nowadays the demand for high speed Internet access has driven the investment in new technologies such as V90 modems to allow download rates of up to 56kBaud and ADSL which can allow up to 8MBaud download rates.

STRATEGY OF ADSL

For the last 15 years, cable and telephone operators have been trying to introduce broadband services directly into homes, primarily for high quality, on-demand video by developing Gigabit and fibre based systems. These technologies would have required removing existing infrastructures and installing more up to date equipment. However operators have discovered that the customer does not require this sort of throughput, in fact hundreds of kilobits to a few megabits would be adequate. More significant is the fact that this sort of bandwidth can be realized using some of the existing telecoms infrastructure.

The backbones of the networks requires to be upgraded, however this would always be the case. The significant saving comes through the fact that the twisted copper pair wires installed into almost every home in the developed world are adequate to carry this sort of bandwidth.

Bandwidth is not the only problem with the current system. Users nowadays are not just logging on to a server, transferring a few files and then hanging up their modems as was the case of the Bulletin Board era. With the growth of the Internet in the last few years, there is an ever increasing amount of information and entertainment available from all over the world. The average household (that is on-line) spends 6 hours per week on the Internet, but very few spend that long on voice calls. All of these users logged on for all of this time clogs up the telephone network as every call has it's own dedicated, permanent "connection" (for the duration of the call) over the digital network.

Integrated Services Digital Network (ISDN) was introduced as a pure digital-to-end-user solution. However it still uses the modern digital Public Telephone Subscriber Network (PTSN) or Plain Old Telephone System (POTS) as the voiced calls. The end user has greater bandwidth (2 x 64kb/s and 1 16kb/s channels) however the POTS network is still clogged up. The main problem with ISDN is availability: any end user must be connected to a digital exchange and that digital exchange must be able to cope with ISDN - a plug in addition to the digital switch. Due to the cost of installing this equipment, the uptake has not been worth the investment, but investment is required for availability (a chicken and the egg scenario). The cost to transmit the data depends on the amount of time the line is active for.

This is why Digital Subscriber Lines (DSL) has come about. It is a sophisticated technology which can meet the demands of the consumer with regard to bandwidth, it can strip any Internet related traffic off the POTS network routing it on high speed packet switched networks and be delivered at a reasonable cost to the consumer. Because the high speed network is a packet switched network, the length of the call is not an issue as the bandwidth from the exchange is only used as and when required. This has led to the philosophy of being on-line 24 hours a day, 7 days a week. However, in this country there is still availability problems - only 20% of the population have access to this technology.

Regulatory boards in this country have actually slowed down the penetration of ADSL services. Telecoms companies (like British Telecom) have had the technology waiting and were ready to equip the whole country with broadband, but it would only be worth it if they were able to broadcast television on these networks. The regulators waited until cable television companies were well established in the telecoms market before allowing this. This is acceptable in areas of mass population where cable services are abundant, however, the more rural communities have suffered because of this.

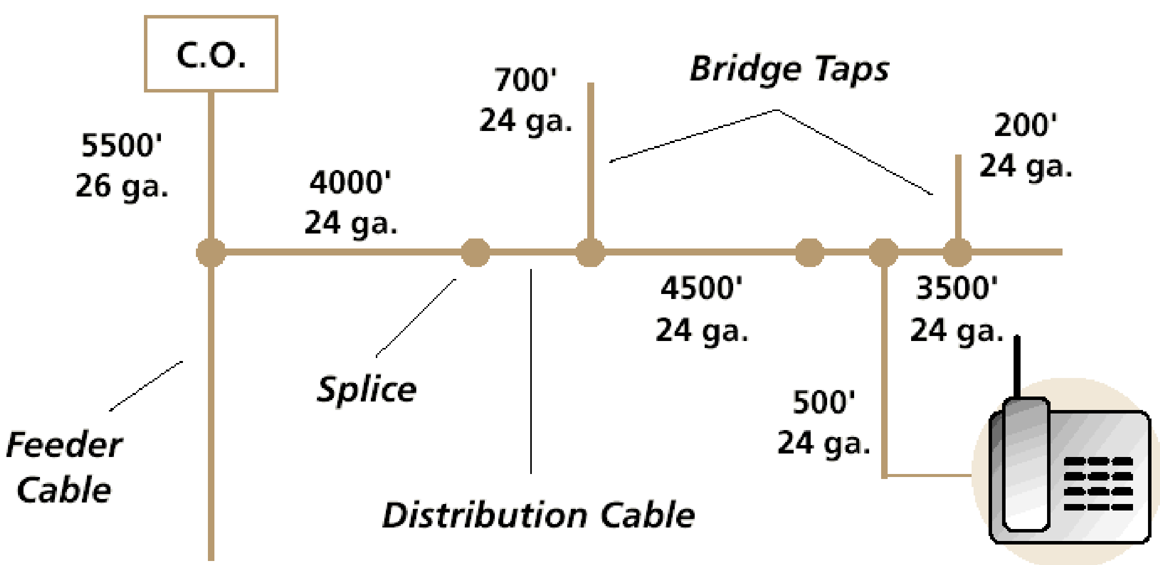
PROBLEMS TO OVERCOME

The advantage of this technology is the main problem with it, that of using the twisted pair wire. This wire may run for several miles between a home and the telephone exchange. During it's journey, a signal on the wire may pick up noise from any number of sources: car ignition systems, hair dryers, street lights etc. All of these noises degrade the signal quality by the time it arrives at the exchange.

Another contributing factor is the age of some of the cables: as the insulation deteriorates over time, moisture leaks in and oxidizes the wire. Also, a whole street's twisted pairs will run beside each other in a single outer sheath, this introduces the problem of crosstalk between pairs. On it's route, the wires may be spliced with other wire, possibly of a different gauge or material. These cause changes in the impedance of the wire and hence reflections back to the source of the signal.

Figure 1 below shows a typical scenario for the local loop between the exchange and a home:

Figure 1 - Typical Local Loop

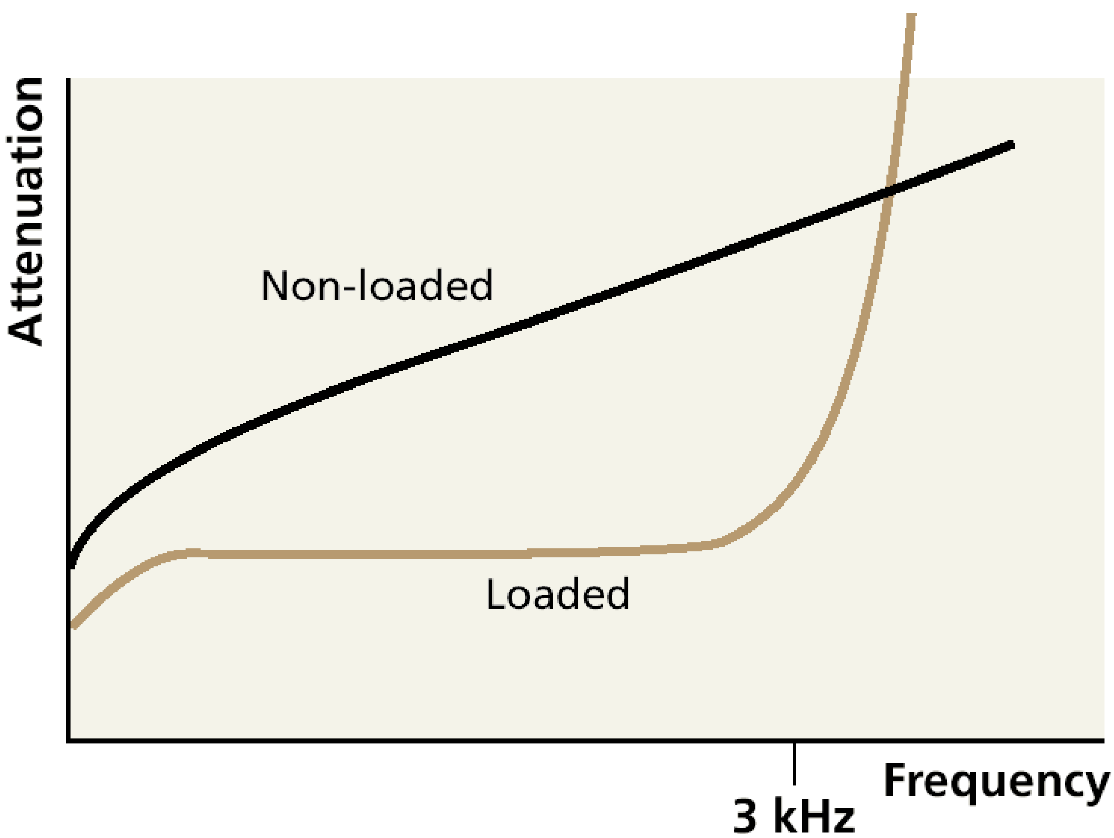


Typically, on a single wire pair, a feeder cable will leave from the exchange (or Central Office). These feeder cables contain many pairs and are laid in major "corridors." Periodically, a certain number of pairs are dropped to a distribution frame and connected to distribution cables, which actually deliver service to the subscriber. The distribution cables travel along each street and outside every house, a drop wire is attached.

An important note is that the wire pairs in the distribution cable are never cut, instead the drop wire is bridged onto the cable. This is handy from the point of view of subscribers leaving and the drop wire being removed: the pair could be used else where along the distribution cable. However, due to this every twisted pair will have an unterminated stub for the length of the rest of the distribution cable. If a single pair is subject to many subscribers joining and leaving, there could be a case where some of the drop wires have not been removed, creating more stubs. This is acceptable within the voice band, but during high frequency transmissions, these stubs cause reflections and can severely hamper the signal quality.

Another problem on these lines is loading coils. To band limit the wires on long runs small coils are periodically placed in series with the wire. Together with the mutual capacitance of the wire form a tuned low pass circuit. The reason for these was to increase the usable range of a wire pair by quenching any high frequency components picked up as noise. Figure 2 shows the difference the loading coils can make to a lines attenuation:

Figure 2 - Line Loading



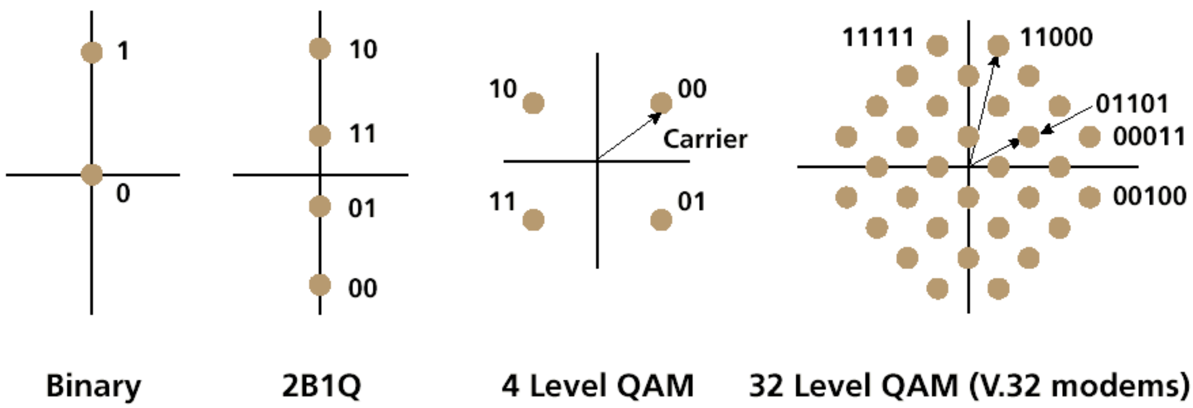
This is another example of telephony technology specifically targeted at voice calls. If a line has too many of these coils in it then DSL communications may not be possible.

HOW DOES ADSL WORK?

There are two different standards of ADSL on the market: Carrierless Amplitude Phase (CAP) and Discrete Multi-Tone (DMT). Both use similar techniques, but are completely incompatible. However, they both allow simultaneous transmission of voice data over the transport medium.

Both modulation schemes use phase (quadrature) and / or amplitude modulation where any number of bits are represented as symbols, e.g. 5 bits representing 1 symbol, hence 32 symbols. Each symbol has a different amplitude and / or phase shift. Figure 3 below shows various type of modulation schemes.

Figure 3 - Modulation Constellations



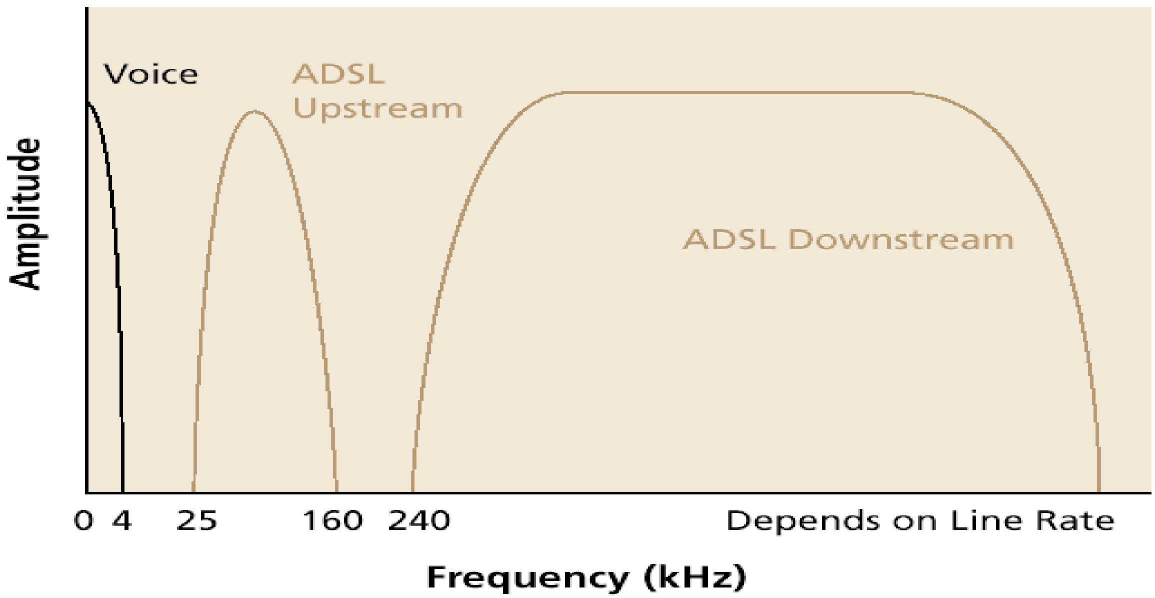
This shows how the symbols are distributed throughout the amplitude and quadrature axis. Binary involved no change in phase with 2 amplitudes. 2B1Q as used in ISDN is a 4 level amplitude modulation with a single phase. 4 level Quadrature Amplitude Modulation (QAM) has the same 4 symbols but 2 amplitudes and 2 phases. Finally the 32 level QAM, as used in V.32 modems has 32 symbols each with different phase and amplitudes.

The more symbols present, the more difficult it is for receiving modems to differentiate between different symbols with line noise present on the line which can distort the signal.

Carrierless Amplitude Phase (CAP)

The CAP system uses two carrier waves, well above the voice band limit of 4kHz, one shifted by 90°. Both carriers are multi-level amplitude modulated similar to 2B1Q, but with more levels. The summation of these two carriers is similar in appearance to the 32 level QAM. The carrier signal is suppressed before transmission as it contains no information and is reassembled at the receiving modem (hence the words "carrierless" in CAP). A lower carrier frequency is used for the upstream traffic as this has the lowest bandwidth. The width of the downstream channel is dependant on data content, i.e. speed of the connection: the higher the speed, the more symbols. Figure 4 shows the frequency spectrum of a CAP based ADSL system.

Figure 4 - CAP ADSL Spectrum



At start-up CAP tests the quality of the line and implements the most efficient version of QAM for the line at that time.

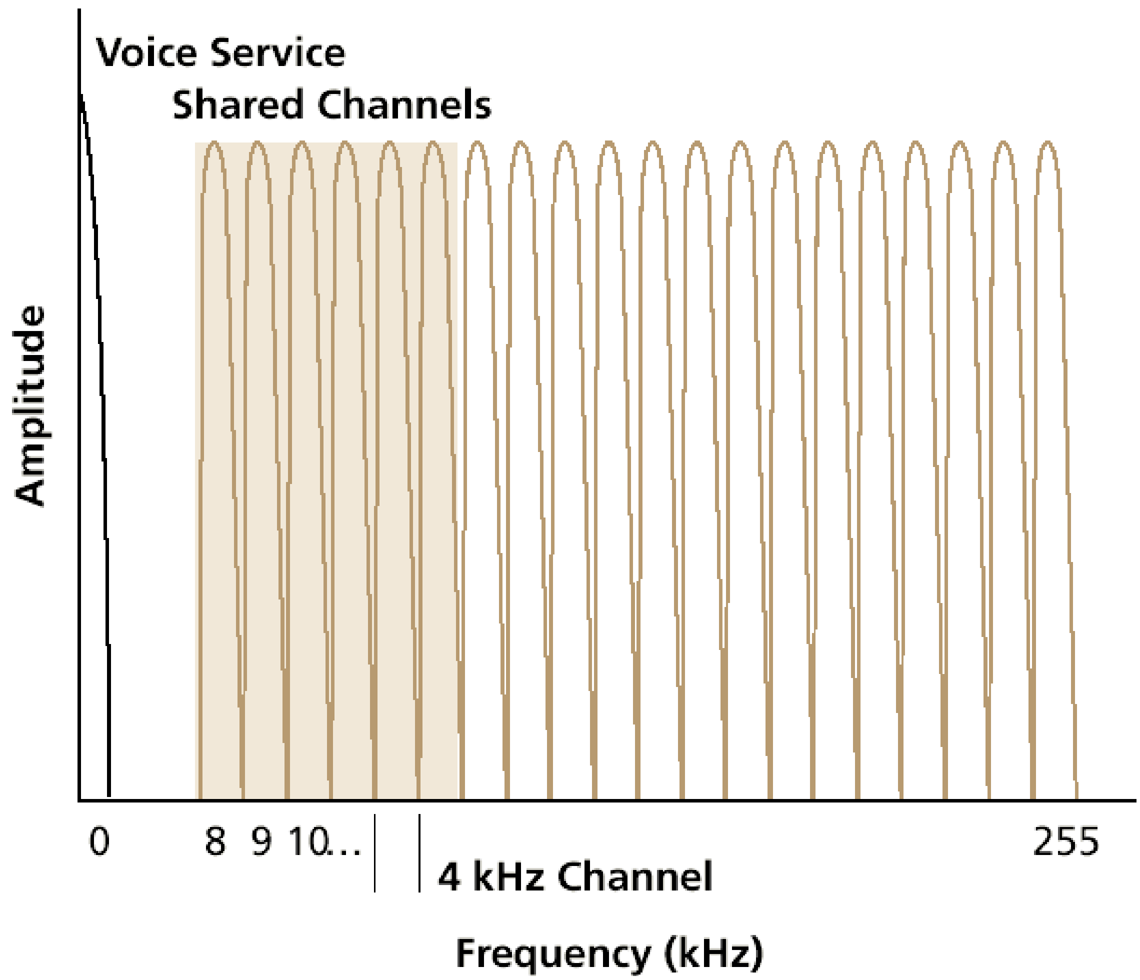
It advantages are that it is available at 1.544Mb/s speeds and it is low on cost due to it simplicity. It's disadvantage is that it is not a bona fide American National Standards Institute (ANSI) or European Telecom Standards Institute (ETSI) standard and as such equipment vendors are free to have variations on the CAP standard such that inter-operability between manufacturers is unlikely. Both ends of the local loop must be the same manufacturer.

Discrete Multi-Tone (DMT)

DMT offers a multi carrier alternative to QAM. Because high frequency signals on copper lines suffer more loss in the presence of noise, DMT discretely divides the available frequencies into 256 subchannels, or tones, each channel is 4kHz wide.

The reason for this approach is that the data is effectively split up into 247 discrete channels spread throughout the spectrum. Each channel is monitored for signal-to-noise levels and if a channel is found to be too noisy, some or all data bits are moved from that channel and placed elsewhere. DMT is capable of compressing up to 15 bits per symbol into a single channel. This constant monitoring allows DMT to constantly adapt to changes in line quality and always optimize the data throughout the spectrum. Figure 5 shows the spectrum of a DMT system.

Figure 5 - DMT Spectrum



If there are not enough channels to fit the required information in, then the DMT scheme will automatically reduce the data rate to match the number of good channels.

The system uses the lower channels as bi-directional channels for upstream and downstream, hence these channels require echo cancellers.

DMT's main advantages is that it is an ANSI, ETSI and ITU standard and as such inter-operability between manufacturers *should* be guaranteed. Also, it is much faster than CAP, able to deliver downstream data at up to 8Mb/s, and it's adaptive features make it very efficient. However, it's disadvantage over the CAP system is the signal processing required to continuously monitor 256 discrete channels, adapt bits per channel, adapt data rate and echo cancel the lower channels are expensive with regards cost and power usage.

CONCLUSION

ADSL has the potential to provide most Internet users in this country with a fast, reliable, relatively cheap gateway to the web. In order to do this, BT and service providers must invest in the project to upgrade the networks or this technology will go the way of ISDN.

The technology itself must be clearly standardized as V.90 modems are now, where previously there were two competing protocols: the k56 and the x2. After ratification by the ITU, any make of V.90 modem will communicate with any make of V.90 downstream modem.

Obviously DMT is the most sophisticated and advanced technology. Over the next couple of years the cost of manufacturing DMT compatible hardware will come down. Even now complete System On A Chip (SOC) solutions are available.

Future broadband requirements may include high definition TV, 3-dimensional TV (currently under development) or any other high bandwidth technology. Ultimately, the twisted pair copper wire will have to be replaced to facilitate these, but for the present, ADSL will do.

REFERENCES

1. Personal broadband: DSL and ATM, Virata: http://www.virata.com/Docs/virata_dsl2.pdf

2. DSL Forum home page: http://www.adsl.com/dsl_forum.html

3. xDSL Local Loop Access Technology:
http://www.3com.com/technology/tech_net/white_papers/pdf/500624.pdf