

DSL : An overview

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Introduction

It is estimated that there are 500 million telephone lines enmeshing our planet. Obviously communication systems designers ignore it at their own risk. It remains the prime vehicle for any new communication system that wants to reach out globally. Digital subscriber technology (DSL) grew out of a need to get *all that is possible* from the humble telephone line, and switching equipment, snidely referred to by web-age technologists as POTS (plain old telephone services)

If Shannon is to be believed the 56K modem has brought us to the *end of the line* of the telephone line modem. However, breaking rules remains an enjoyable activity and communication engineers are no exception. The *breakthrough* of the DSL modems came about not out of any violation of Shannon's channel capacity theorem, but out of a realisation that the ubiquitous telephone line has a bandwidth of nearly 1 MHz. This is a huge expansion in available bandwidth in comparison to the 4 KHz voice bandwidth utilised by the voice band modems. Of course, this also meant that the exchange makers should handle the tsunami of multi-mega bit data rates instead of the gentle streams of 56K that they were used to. Once this was accepted, DSL's future was secured.

So what can DSL do ? In plain terms, you can connect to the internet at rates of 8 Mbps or more, while you can use your telephone simultaneously. It is 'personal broadband' at your disposal, over the old faithful telephone line. Also, it is often 'biased' in your favour ie; you have a bigger bandwidth (and hence better bit rate) to download (the "downstream" direction) than the telephone exchange has for you to upload ("upstream" direction)

To go back a bit in time, the digitisation of the subscriber line started with ISDN. It offered bit rates upto 144 Kbps. This took real voice off the line, digitising and making it just another of the bitstreams commuting over the line. Next was HDSL (High data rate DSL) which endeavoured to replace the T1/E1 lines with twisted pairs. Bit rates upto 2 Mbps was possible. Ignoring a plethora of other interim DSL technologies, we come to the dominant DSL technology of today - ADSL (Asymmetric DSL). Initially conceived as a video-on-demand system, it evolved into a method that delivers 8 Mbps downstream, and 640 Kbps upstream, and can coexist with existing POTS facilities. The DSL technology of the future is VDSL (Very high data rate DSL) which can squeeze through an incredible 52 Mbps over twisted pairs - admittedly over much shorter distances than DSLs.

How it works

Currently accepted ADSL standards use discrete multitone (DMT) modulation scheme to transmit data. 'Multi-tone' means that there are many carriers (usually 256), each of which individually undergoes QAM (quadrature amplitude modulation). This means that there are sine and cosine versions of the carrier wave at each carrier frequency, whose amplitudes are determined by the modulating bit pattern. The signal on the line is thus a sum of a number of QAM modulated sine waves. In contrast, voice band modems transmit data by modulating a single carrier, which is usually a 2.4 KHz sine wave. POTS compatibility is achieved by keeping clear of the POTS band - 0 to 4 KHz, as well as by having an additional guard band - from 4 KHz to 30 KHz. The ADSL band extends from 30 KHz to around 1 MHz. This band is split into several 'tones', each of which is modulated and occupies 4 KHz. Thus one could say that the DSL modem comprises of 256 'voice modems' all running in parallel. Approximately one-eighth of these bands are set apart for upstream data transmission and the rest for downstream data. This bigger downstream bandwidth gives the 'asymmetry' to ADSL. This goes well with web-based applications where the subscriber is more often downloading data off the web, rather than sending data into the web.

The twisted pair

At this point it is worthwhile to take a look at our communication medium - the twisted pair. Discovered in the 1870s by Alexander Graham Bell, this common-mode noise reducing wire pair has indeed come a long way. Interestingly, the problem eliminated by the twist (interference) comes back as a major obstacle when we try to achieve high bit rates. This is to say that the occasional and almost inaudible cross talk over voice channels, which can be overcome merely by the listener's patience, can pose a serious problem for DSLs. There are two types of cross-talk. One is caused by your neighbour's ADSL transmission that goes into the same bundle as your twisted pair goes into, and getting back into your receiver. This is called near end cross-talk (NEXT). The other type of cross-talk is caused by your neighbour's signal leaking into your line and travelling up to the receiving end. This is termed far end cross talk (FEXT). The intensity of such perturbations depend on the proximity of the twisted pairs, number of disturbing pairs, their leakage and many such factors. Very extensive surveys have been conducted the world over to analyse these lines and curve-fitted analytic models of all relevant parameters are now available. External sources like AM radio transmission, vehicle electronics etc. also are major sources of interference.

In addition to this interference, signals sent along the twisted pair, are naturally affected by attenuation as well. Figure 1 gives an indication of this effect. This attenuation is dependent on wire length, wire gauge and even the age of the wires. What emerges is that the performance of the twisted pair at higher frequencies is poor.

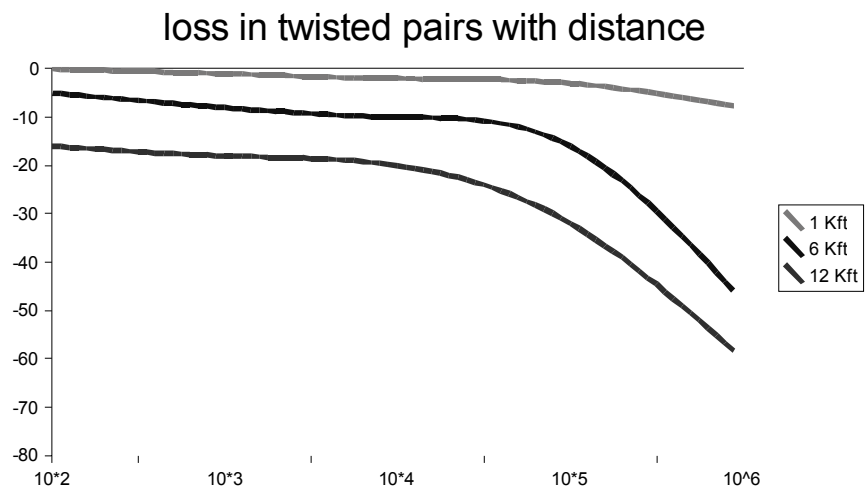


Figure 1 : Attenuation in the 26 AWG twisted pair

However, the most damaging of all is the presence of load coils and bridged taps on the line. Load coils are placed on the wire for achieving excellent voice band performance, at the cost of lowered high frequency performance. Bridged taps are unterminated pairs running off a pair under use. These are put in to prevent wiring of a fresh pair for new subscribers. Both of these cause severe degradation in high frequency performance, and can turn out to be show-stoppers.

Once the twisted pairs have been carefully evaluated and modelled, their channel capacities can be calculated. Though these channel capacities can never be attained in practice, they serve as benchmarks to compare performance and effectiveness of DSL systems.

How the signals get across

Given all the limitations described above, how do the DSL signals get across? The answer lies in liberal use of advanced signal processing techniques at every step, not forgetting the high precision, high performance analog front ends.

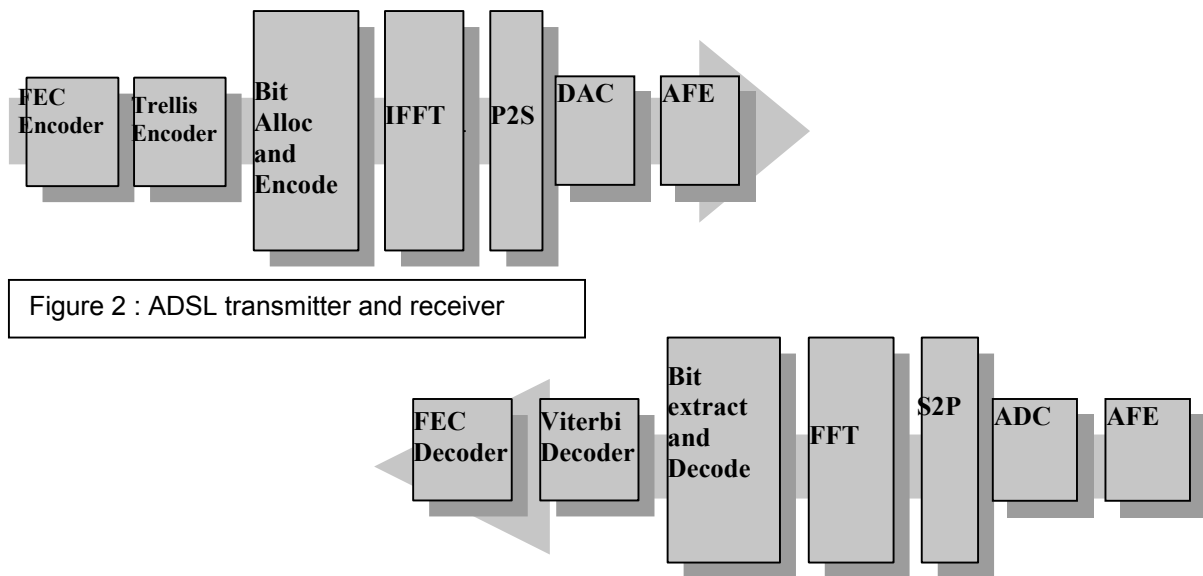
During the initialisation phase of the setting up of an ADSL connection, the capacity of each carrier of the DMT is evaluated and the maximum number of bits that can be stuffed into each carrier is determined. The bits to be transmitted are then distributed across these carriers, such that the carrier with the best performance gets the most bits and the most noisy one gets the least, or no bits. This means that the high performance carriers, which are usually the low frequency ones, are very finely modulated to a maximum of 15 bits. This is done in real time as well, so that the bit rate remains unaffected by the time varying nature of the noise in the channel.

ADSL supports two modes of transport called the fast channel and interleaved channel. The fast channel is meant to transfer latency-critical but error tolerant data streams like real time video. The interleaved path is a slower but reliable path, and can be used for data that is intolerant to errors like file transfer.

Data to be transmitted over the line is usually sourced by an ATM network. In fact, ATM is one of the best network matches with a physical level protocol like ADSL. The interface to the ATM network is generally UTOPIA (universal test and operations interface to ATM), which basically provides the modem with ATM 53-byte cells. The cell headers are verified, and repacked into ADSL format frames. In addition, if no cells are

available, idle cells are inserted. Data scrambling using a standard polynomial is done to ensure the random nature of the data.

Given in Figure 2 is the block diagram of an ADSL transceiver.



The ADSL format frames are then encoded by a Reed-Solomon encoder and then optionally by a trellis encoder. Together, these two powerful error correction schemes ensure error free bit transfer. The data then is either fed straight to the QAM (quadrature amplitude modulator) or moves via the interleaver to the QAM. The interleaver is a circuit that shuffles the data at the transmitting end, which process is undone by the deinterleaver at the receiving end. This is to spread out the possible burst errors in the channel so that the ECC blocks are not overawed by the bursts and can perform the required correction. Next, the bits are packed into their respective frequency bins as determined by the line conditions and converted into XY (cosine amplitude, sine amplitude) values by the QAM.

Generation of the DMT signal is an interesting process. Now that we have the amplitude of all the carriers to be transmitted, the modulation is carried out by performing an IFFT (inverse fast fourier transform) on the whole set of XY points. Each XY point corresponds to the phase and frequency of one carrier. Since the output of the modem has to be obviously a real signal, in practice, each XY pair and its complex conjugate enters the 'waveform generation' process.

A few of these XY points are repeated before being fed to the IFFT block, to ensure that the frame looks cyclic. This help in channel equalisation. These repeated XY pairs are called cyclic prefix.

The ADSL frame is now ready for transmission. The frame forms one symbol that travels across the channel at a symbol rate of 4 KHz. Synchronising non-data frames are added every 68 frames. The serialised time-domain data output of the IFFT is then input to a 2.2 MHz DAC and then fed to analog transmission filters.

All the above mentioned processes are reversed at the receiver. The samples of input waveform are converted into parallel form and FFT is done after discarding the cyclic prefix. FFT is performed on these set of points, and the XY values for each carrier is obtained. QAM demodulation gives back the data. Deinterleaving, Reed-Solomon decoding and Viterbi decoding follow. The time domain equalisation is to ensure maximum symbol rate with the minimum ISI (inter symbol interference). The frequency domain equaliser normalises the spectral power of each of the carriers so that symbol decision of all channels are on the same based on a common threshold.

At the remote ADSL frames are translated back to ATM cells and goes into the local network or PC. Ethernet output at the remote sites are also possible.

Splitterless ADSL

Initially the so-called full rate (8 Mbps) failed to make an impact because of conflict among vendors in the modulation scheme, and general lack of standardisation, all resulting in poor interoperability. This led to the emergence to a simplified version of ADSL termed ADSL lite. which rolled back the bit rate from 8 Mbps to 1.5 Mbps, and eliminated the splitter. This also helped in bringing down the price of ADSL modems significantly, as the chips required to do lesser signal processing. Installation of a splitter at each subscriber premise is an unacceptably costly proposition for the telecomm operators, and had met with much

resistance. Also, by reducing the rates it was possible to ensure a larger percentage of the subscribers with a uniform and assured data rate, rather than a bit rate depended on the distance of the subscriber from the CO (central office). ADSL has met with significant success, and is widely installed.

Installations and predictions

Currently, it is estimated that there are 600,000 DSL installations worldwide. It is expected to grow to around 5 million in the next two years, The standardisation of ADSL lite and growing tendency of PC manufacturers to include ADSL modem in the 'standard PC' will further fuel the growth of DSL.

Competing technologies

The biggest competitor of ADSL is the cable modem. The cable modem attempts to add a reverse path to the TV signal-carrying coaxial cables, in addition to carrying data streams in the downstream direction. However, the coax remains a shared medium, and was as well not originally intended to carry any signals, far less data, upstream. Yet, the penetration of cable is very high, even 100% in few Scandinavian countries, and may as well give ADSL a run for its money.

Wireless data (3G mobile) and Direct broadcasting Satellite (DBS) are potential competitors to DSL. Even though they are currently geared more for towards broadcast rather than interactive communication, they could become major players in the future.

The future : VDSL

ADSL has tremendously increased the bit rates over twisted pair, but the best is yet to come. VDSL (Very high bitrate DSL) delivers 52 Mbps over shorter wire lengths. Mostly, the assumption is that a high capacity carrier (like FTTCab (fibre to the cabinet)) that carries high bandwidth data from the CO to the neighbourhood exists, and the last link to the subscriber is still over twisted pairs, that carries VDSL signals. Standardisation is still in progress, even though some VDSL products are already available. VDSL is envisaged as not necessarily asymmetric, but can have asymmetric rates for connecting to data sources like web servers etc.

Conclusion

ADSL is undoubtedly the prime twisted pair technology available today. It achieves hither to unachievable bitrates by using the unused portion of the bandwidth and employing state of the art signal processing techniques. It has been widely accepted and will continue to grow in the future, till more advanced technology like VDSL takes over.

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