The Broadband Revolution

Broadband is a culture that has changed how we work, shop, play and communicate. Key to any culture is learning from others and adopting beneficial practices. Broadband technologies are simply the tools we use to adopt these practices, by providing ever more efficient and cost-effective methods to access a wealth of services, some of which have yet to be conceived.

Technologies such as Asymmetric Digital Subscriber Line (ADSL) have made this concept a reality by providing low-cost, high-speed connectivity to the masses. Although limited by distance, ADSL will play a vital role over the coming years as Service Providers enter new markets in order to accommodate this growing culture. However, through the frenzied hype and marketing haze there is still too much confusion surrounding ADSL.

ADSL within the UK

ADSL based services vary enormously depending on the country and Service Provider. This is due to a number of reasons, including:

- An ever increasing number of ADSL standards
- The geographic dispersion of the country (as ADSL is a distant dependant technology)
- Different quality of service (QoS) requirements (real-time and/or non real-time applications)

This paper concentrates on the current ADSL implementations within the UK, based on:

- Simultaneous services for ADSL and POTS (Plain Old Telephone Service) on the same copper pair (but <u>not</u> with ISDN)
- Conforming to G.992.1 (G.dmt)

ADSL Overview

ADSL is a non dial-up modem technology that provides an ‘always on’ data connection over the conceptual ‘last mile’. ADSL is a broadband access technology that does not require an expensive coaxial or fibre optic connection. Instead, ADSL utilises an existing cable infrastructure: telephone lines. Practically every household and business has a telephone line already connected to their premises. By modifying telephone exchanges, a series of central access points can be geographically dispersed very quickly across the country.

The high-speed data transfer is achieved between two ADSL modems (one in the end user's premises and one in the local exchange) without effecting the normal telephone service. These ADSL modems are designed to exploit the physical transmission capabilities of the copper line to achieve the higher data rates.
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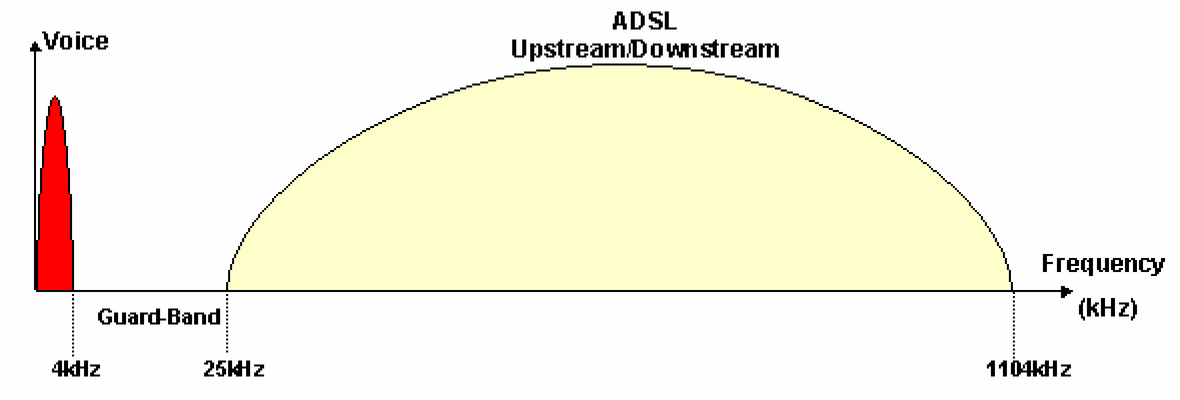
The term ‘asymmetric’ signifies that the data transfer rate is not the same in both directions. The directions are referred to as 'upstream' (towards the exchange) and 'downstream', (towards the end-user). While POTS (voice) uses frequencies under 4 kHz, the ADSL data streams utilise frequencies above 25 kHz, thereby avoiding any interference. The amount of usable bandwidth available (above 25 kHz) over a copper pair is dependent on a number of factors, including length, impedance, signal power, frequency and line coding techniques.



The data and voice frequencies are separated at either end of the copper cable by filters. ADSL is terminated at the exchange by a unit known as the Digital Subscriber Line Access Multiplexer (DSLAM).

The DSLAM contains high density ADSL line cards and filters in a rack mount configuration. The DSLAM passes the voice connection to the existing PSTN, and the ADSL data service to the appropriate broadband network.

Figure 1.

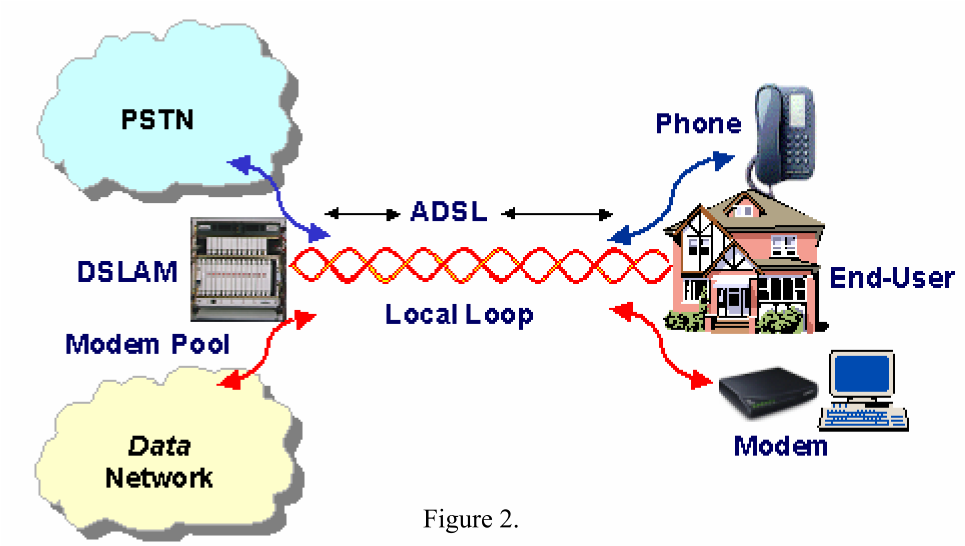


Figure 2.

The DSLAM multiplexes (combines) the ADSL data received from many ‘end- users’ into a single output for transmission. (Typically a 155Mbits/s ATM pipe).

Standards

ADSL was first ratified as a standard by the American National Standards Institute (ANSI) in 1995. ADSL was later submitted for global approval to the International Telecommunication Union (ITU) in 1999. As a result, the ITU approved two standards; G.dmt (G.992.1) and G.lite (G.992.2). Since 1999, the ITU has introduced a series of new standards:

ADSL Version	Standard	Date Ratified
ADSL	G.992.1 G.dmt	1999
ADSL	G.992.2 G.lite	1999
ADSL2	G.992.3 G.dmt (bis)	2002
ADSL2	G.992.4 G.lite (bis)	2002
ADSL2+	G.992.5 ADSL Plus	2003

Table 1

G.992.1 (G.dmt)

G.dmt describes the connectivity between the exchange and the end-user's premises in terms of ADSL transceivers and not modems. The standard provides options to accommodate POTS or ISDN over the same copper pair. As previously stated this paper will concentrate on ADSL with POTS only. G.dmt, also known as 'full-rate ADSL', can provide data rates of up to 8 Mbit/s downstream by utilising a modulation technique known as discrete multi-tone (DMT).

DMT builds on the same concepts as Quadrature Amplitude Modulation (QAM) but utilises multiple constellation encoders. QAM modulates two variants, amplitude and phase, with a constant frequency. DMT utilises the same modulation technique but with multiple (256) frequencies. The concept of using different frequencies to transmit information is not unique to DMT - television and radio have employed such techniques for decades. However DMT has a receiver tuned to all of the channels at the same time, whereas TV or radio would typically be tuned into one channel at a time.

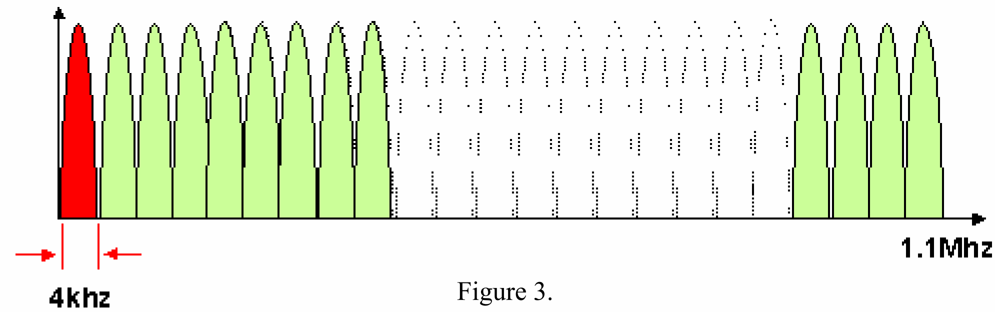


Figure 3.

DMT divides the frequency spectrum (up to 1.1Mhz) of the copper local loop into 256 sub-frequencies. Each sub-frequency acts as an independent subchannel and has its own stream of signals. At 8 samples per cycle using QAM, the 256 subchannels can provide a theoretical capacity of greater than 8 Mbits/s.

DMT is able to allocate data so that the throughput of every single subchannel is maximised. If any subchannel is unable to carry data, it can be turned off and the use of available bandwidth is optimised. Subchannels are transmitted in both directions but with more channels being transmitted downstream.

QAM - 256 x 32 kbit =8.1 Mbit/s

Figure 3

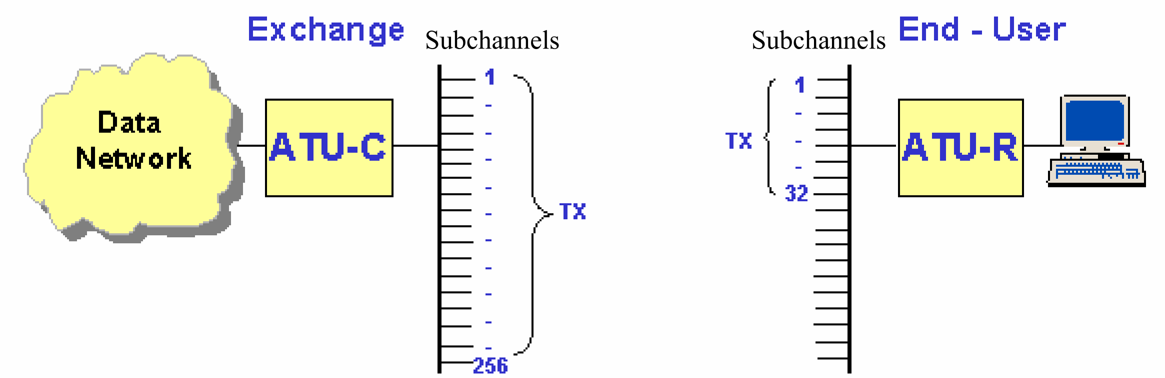


Figure 4.

ADSL connectivity is achieved via two "Transceiver Units". Each ADSL Transceiver Unit (ATU) is identified by its location 'C' (Central) for the exchange and 'R' (Remote) for the remote end-user. In concept the ATU-C can transmit 256 subchannels (downstream) and the ATU-R can transmit 32 subchannels (upstream), resulting in 8.1 Mbit/s and 1 Mbit/s respectively. However most systems allow a guard-band to avoid interference with POTS. This protection is achieved by not utilising the first five frequencies in either the upstream or downstream directions. Therefore the rates are limited to 8 Mbit/s downstream and 832 kbit/s upstream.

The actual lower limit for data traffic in the upstream direction, (to the ATU-C), will depend on the type of POTS/ISDN filters. This also determines the upstream/down frequency split. For example simultaneous ADSL transmission on the same copper pair as ISDN, could use subchannels 32 to 64 to provide the duplex capability instead of channels 1 to 32.

Subchannel No.	Frequency (kHz)	Function
6	25.875	Lower limit for upstream data
18	80	Upper limit for ISDN (2B1Q)
28	120	Upper limit for ISDN (4B3T)
32	138	Upper limit for upstream data
64	276	Pilot – POTS (not used for data)
96	414	Pilot – ISDN (not used for data)
256	1104	Nyquist (not used for data)

Table 2.

Prior to the start of symbol transmission, the ATU-R and the ATU-C exchange equalisation sequences so that the precise number of subchannels can be calculated. Subchannel number 64 (276 kHz) is reserved for a pilot, and is used to ensure timing integrity between the ends. The sequence transmits across all 256 subchannels, and the response is measured, taking into account the attenuation and any other characteristics found on the line. The resultant number of subchannels, and the number of symbols per subchannel, can then be determined.

DMT Operating Modes

DMT has two different operation modes: Echo Cancellation and Frequency Division Multiplexing (FDM). Echo Cancellation assigns the upstream band to over-lap the downstream (25kHz to 138kHz) and separates the two by means of local echo cancellation.

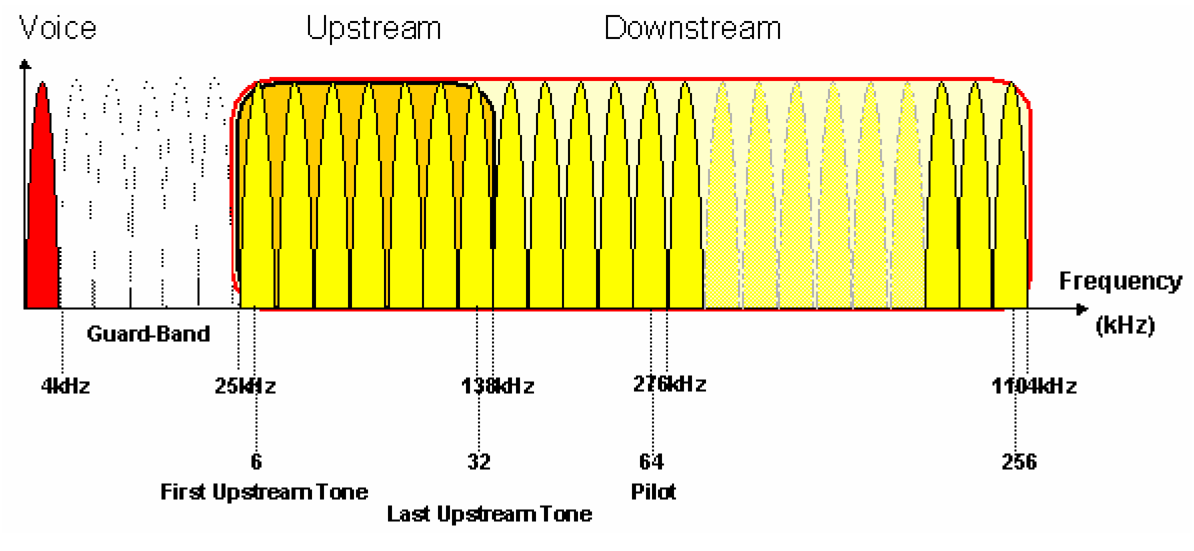


Figure 5.

Echo Cancellation however is deemed to be too complicated. Therefore the most common DMT mode is FDM, where the available bandwidth of a single copper-loop is divided into three parts; Voice, Upstream and Downstream. One drawback, however, is that the downstream bandwidth

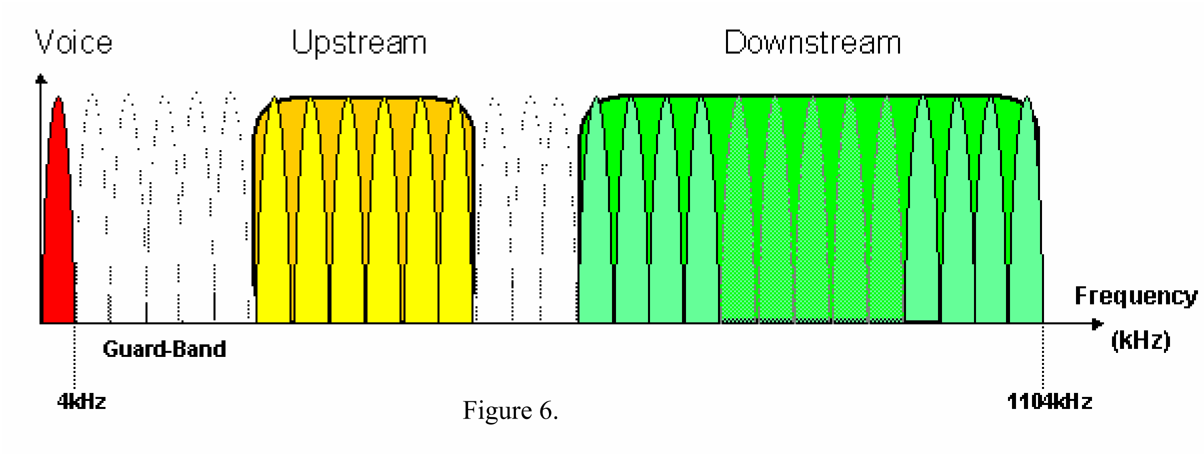


Figure 6.

is reduced in comparison to an echo-cancelled system.
(8 Mbit/s minus the Upstream kbit/s). G.dmt standard makes reference to a minimum of 6.144 Mbit/s downstream and 640 kbit/s upstream.

Practical Implications

The actual data rates of ADSL will be impacted by the copper line characteristics. Signals propagating on copper are attenuated by an amount that increases with the length of the line. Downstream data rates are more noticeably affected as high frequencies of a signal are attenuated more than low frequencies. As a consequence, ADSL is described as a distant dependant technology: the higher the data rate required on the line, the shorter the transmission distance available.

One way to minimise attenuation is to use lower-resistance copper wire. Thicker-gauge copper wires have less resistance than thin wires, which in turn means less signal attenuation and therefore the signal can travel a longer distance.

Performance is also adversely affected by traffic on adjacent copper lines in the same cable interfering with the transmitted signal; an impairment known as crosstalk.

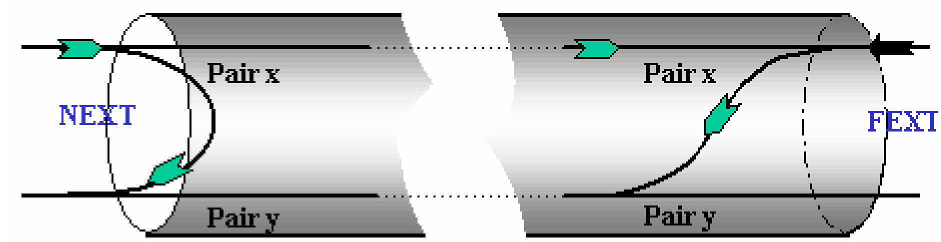
Crosstalk

Electrical energy is radiated onto adjacent copper pairs in the same cable bundle and this effect is known as crosstalk.

Crosstalk can be categorised into two types;

- Near End Crosstalk or NEXT
- Far End Crosstalk or FEXT

NEXT is the more significant of the two as the high-energy signal from an adjacent system can



induce relatively significant crosstalk into the primary signal. FEXT is less of an issue because the far end interfering signal is attenuated as it traverses the loop. Crosstalk is a dominant factor in the performance of communication systems.

Transmitting and receiving information using the same frequency spectrum creates interference within the single loop system itself. This differs from crosstalk because the offending transmit waveform is known to the receiver and can be effectively subtracted out from the attenuated receive signals by echo cancellation. Alternatively, separate frequency bands can be used, by implementing FDM. The advantage of FDM over echo cancellation is that NEXT is eliminated, so FDM provides better performance.

Figure 7.

Upstream & Downstream Frequencies

It is possible to transmit a signal a greater distance from the exchange to an end-user than can be achieved in the opposite direction. This is due to the effects of crosstalk, which are more prominent on the exchange side of the copper loops than on the end-user side. A greater number of copper pairs are combined in large bundles as they get closer to the exchange, each of which induces a crosstalk component. As the bundles leave the exchange the loops branch off for connection, resulting in fewer loops. Therefore, less aggregated crosstalk is introduced by the transmitters at the far end.
FDM can improve performance by utilising the lower frequencies in the upstream direction (towards the exchange). Since lower frequencies are attenuated less than higher ones, this arrangement ensures that the received signal is as high as possible when it reaches the noisy exchange environment.

Key points to be aware of when considering ADSL are:

- ADSL is a distant dependant technology: the higher the data rate required on the line, the shorter the transmission distance available.
- The main factors impacting upon range include the thickness of the wires and the amount of interfering noise present (as outlined below).

Loop Insertion Loss @ 300 kHz	Nominal length (km)	Downstream Data Rate (kbit/s)	Subchannels	Upstream Data Rate (kbit/s)	Subchannels
20 dB	1.40	6144	192	640	20
30 dB	2.15	2048	64	512	16
50 dB	3.50	2048	64	128	4
60 dB	4.20	576	18	128	4

Table 3.

ADSL Services within the UK

BT, the largest ADSL Service Provider in the UK, has launched a series of products at rates up to 2 Mbit/s.

Three main options are currently available:

- 2Mbits/s downstream and 256 kbit/s upstream
- 1Mbits/s downstream and 256 kbit/s upstream
- 500 kbits/s downstream and 64 - 256 kbit/s upstream

BT currently provides ADSL based services up to a maximum distance of 6km, from the nearest ADSL enabled exchange.

Other Service providers are offering up to 8 Mbit/s to their business users, but it is not clear over what distance.

Where next?

In July 2002, the ITU completed G.992.3 and G.992.4, two new standards for ADSL technology, collectively called "ADSL2". G.992.3 – G.dmt (bis) adds new features and functionality targeted at improving performance and interoperability, and adds support for new applications, services, and deployment scenarios. Among the changes are improvements in data rate and reach performance, rate adaptation, diagnostics, and stand-by mode.

The ITU sanctioned G.992.5 in January 2003 as the newest member of the ADSL family. Also known as ADSL2+ it doubles the bandwidth used for downstream data transmission, effectively doubling the maximum theoretical downstream data rates up-to 20 Mbit/s.

However, it is still not clear how beneficial these new standards will be in the short term, as the economics of upgrades and backward compatibility must be addressed.

About the author
Steve Higgins, Technical Product Manager, Communications, QA.
Steve is an ICT professional with more than 30 years of experience in systems engineering, training and consultancy. As a network consultant at QA, Steve specialises in a wide range of technologies including: LANs, VPNs, Wi-Fi, TCP/IP, VoIP, DSL, ISDN, Frame Relay, ATM, Voice Signalling Systems, GSM, GPRS, and UMTS. Steve works with the UK's largest telecommunications providers and recently designed and developed a series of DSL-based courses for a leading service provider. The training was designed to accommodate over 4,000 personnel from various internal and external sectors. Steve holds an HND in Electrical Engineering and is a member of the IEEE.