The Last Mile - ADSL?

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ABSTRACT

Internet data rates have been increasing over the past few years, where corporate networks have increased their data rates to allow most users access to broadband communications. Unfortunately, the weakest area, at the present, is the last mile to the user's home. This is because most home users connect to the Internet using telephone-standard cables using dial-up modems. A key focus for the future is thus to upgrade this connection in some way to support high-speed data transfer. This paper presents some of the current methods, and gives a technical background in one of the best methods: ADSL.

Keywords: ADSL, GPRS, Cat-3, Cat-5, Satellite access

1. Introduction

The usage of the Internet grows at a vast rate. It emerged from commercial organizations, mainly through the killer applications, such as e-mail and WWW access. The applications of it, and people's dependence on it, also increases. It has now been well established in commercial organization, but the next major growth will be into the home. For this the demand for bandwidth is ever increasing as video and audio requires much larger bandwidth requirements than can be delivered over a standard modem.

Most commercial organizations can obviously afford to upgrade their cabling to fiber optics and Cat-5 cabling which can provide bandwidths of over 1Gbps. Unfortunately it would be too expensive to provide these cables to every home subscriber. The only way, at present, is to use the existing telephone cable network, and migrate this towards high-speed access.

The first solution that was proposed was ISDN[1] which integrates directly into the phone network. In its base form it uses two 64kbps data streams, which gives an overall rate of 128kbps. This is a two-fold increase over a standard 56kbps modem. Unfortunately ISDN uses a similar technique to a standard phone connection, where the connection is made for the time of the call. This is called *circuit switching*, and users are charged for the time they are connected, rather than the amount of data that they transfer. An improved method is *packet switching*, which is only charged for each data packet sent. Packet switching also has the advantage that it does not *hog* the bandwidth when no data is being sent, whereas circuit switching guarantees bandwidth for the complete time of the connection, even if it is not being used at any given time.

An excellent technique to connect to a high-speed network is to use a T-1 (1.054Mbps)/T-3 stream, which gives a high-speed connection to the digital telephone network. Unfortunately, this requires a large investment in fibre cables. If this cannot be provided, the solutions at present for the connection of home users include (Figure 1):

- **Cable modems**. These use the existing cable TV network, and provide high-speed access. Cable TV is a technology which involves *broadcasting* TV signals to many subscribers. Thus, for cable TV, the available network bandwidth will be shared between all the connected subscribers. For example if there was an available bandwidth of 30Mbps, with 1000 subscribers there is only an available bandwidth of 30kbps. Fortunately, not all the subscribers will be using their available bandwidth at any given time, thus giving an access rate of several hundred kbps, and a burst rate of up to 2Mbps. Cable modems, though, suffer in that they are setup, mainly, to deliver data from the provider to the subscriber, thus there is typically more bandwidth available from the Internet to the subscriber (the *down link*), and less from the subscriber to the Internet (the *up link*). This thus provides a good technology for downloading data, but is not so good when providing information, such as running a WWW server, or an FTP server. Most of the time this suits a typical home subscriber, who will not run many applications which will source data, rather than receive it. Electronic mail is obviously one application which requires large uploads, especially with large attachments. This, though, tends to be achieved in the background, where the user does not really care the amount of time that is taken in uploading the data.
- **GPRS**. This is a technique which supports a *packet switched* connection over the public mobile phone network. It is typically expensive for data, but allows for an always-on connection, which is charged per byte. The data rate is around 1Mbps. Its main advantage is the availability of the mobile phone network, especially in rural areas.
- **Satellite access**. This technique uses a special uplink and a downlink, and is typically expensive, but can be used in remote locations.

[1] ISDN - Integrated Service Digital Network

- **ADSL** (Asymmetric Digital Subscriber Line). This overcomes the requirement for a cable TV connection, as it uses standard telephone lines. ADSL is a modulation technique which allows data to be integrated with voice over Cat-3[2] cables. It currently allows a downlink of around 8Mbps and an uplink speed of 640kbps. As this is different in both directions it is defined as asymmetric. There is thus 10 times the amount of bandwidth for the down link, than the up link.
- **Wireless connections.** Wireless networks are still in their infancy, but are growing in the scope. There are still major problems to be overcome with security, and coverage, but wireless is likely to become one of the leading methods to connect to the Internet, both a home, and on the move. This technique will be covered in Unit 10.

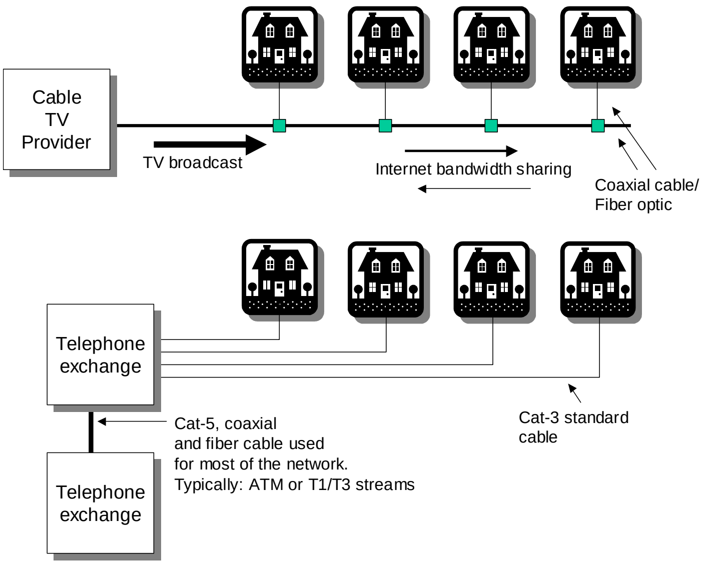

Figure 1 From centralisation to distributed

2. ADSL connections

ADSL differs from traditional modems in that it uses a direct connection rather than a dial-up one. It integrates with the home telephone using an ADSL filter, which directs the telephone signals (0-3.4kHz) to the telephone, and the ADSL data to and from the network (above 194kHz), as illustrated in Figure 2. It will require an ASDL modem and a filter in the home, and also the equivalent in the telephone exchange.

Key factors which affect ADSL bandwidth include:

- **Loop length**. ADSL uses higher signal frequencies than telephone signals, which tend to be attenuated[3] more, and are thus more susceptible to noise. Thus the length of the cable from the telephone exchange to the subscriber has a significant effect on the available bandwidth.
- **Un-terminated taps**. In high-speed networks, all connections should be properly terminated, thus all taps from the cable should be terminated using junction connectors.
- **Radio signals.** AM frequency radio uses a similar range of frequencies as ASDL, thus these can affect the quality of the ADSL signal.
- **Crosstalk.** As the cables used between the home subscriber and the exchange are not the best types of cables for data transmission, and have been designed to support low-frequency telephone signals, they are thus susceptible to crosstalk from other ADSL circuits, and from power cables, especially caused by the switching of high-powered electrical equipment, such as with electrical motors.
- **Cable quality.** The quality of the ADSL network will depend on the quality of the cable used, especially in the thickness of the cores, as thin cores will cause a much greater attenuation of the signal.

The modem in telephone exchange is typically defined as an ATU-C (ADSL Transceiver Unit-Central), and in the subscribers home as an ATU-R (ADSL Transceiver Unit-Remote).

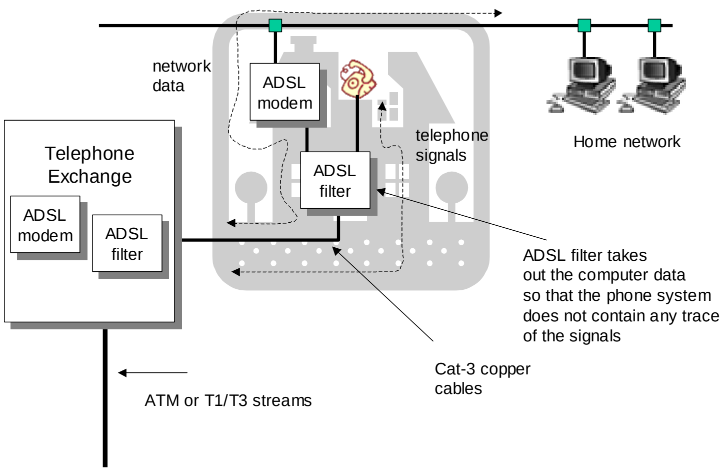

Figure 2 ADSL connections

2.1 ADSL and bandwidth

ADSL uses the signal frequencies above ISDN and voice, as illustrated in Figure 3. A voice signal uses the frequencies up to 4kHz, and ISDN uses frequencies up to 84kHz. There is then a gap up to 94kHz, where the upstream channel uses the frequencies between 94kHz and 106kHz, and the downstream has a larger span and splits into 256, 4kHz channels. Each of these can thus support modem-like data rates.

If one bit is sent at a time, the bit rate of a channel is normally approximated as **twice the bandwidth of the channel**, thus if we assume that the bit rate of each channel is **8kbps**, then the overall downstream link

[2] Cat-3 cables – Voice quality cabling
[3] Attenuation – A measure of signal loss

will be:

$$\text{Bit rate(Downstream)} = 256 \times 8\text{kbps}$$
$$= 2.048\text{Mbps}$$

ADSL uses a modulation technique where three bits are sent at a time (known as signalling elements). Thus maximum downstream rate will be:

$$\text{Bit rate(Downstream)} = 256 \times 3 \times 8\text{kbps}$$
$$= 7.44\text{Mbps}$$

Some of this data rate is used for signalling and synchronising, thus the actual data rate is nearer 6.2Mbps. The upstream uses the frequencies between 94kHz and 106kHz (12kHz) then is approximated as:

$$\text{Bit rate(Upstream)} = 3 \times 2 \times 12\text{kbps}$$
$$= 72\text{kbps}$$

which, accounting for signalling and synchronising, gives an upstream data rate of around 64kbps. In general the stated rates for ADSL are:

Class	Downstream	Upstream
1	6.144Mbps	64kbps
2	4.608Mbps	64kbps
3	3.072Mbps	64kbps
4	1.536Mbps	64kbps
5	6.2Mbps	576kbps
6	3.1Mbps	384kbps
7	1.544Mbps	160kbps
8	768kbps	64kbps
9	384kbps	32kbps
10	160kbps	16kbps

Class 1 to 4 are typically used for real-time video, as the upstream rate is only required for synchronisation of the video information. Classes 5-10 can be used for network-type applications. These rates vary with the quality of the connection between the exchange and the subscriber.

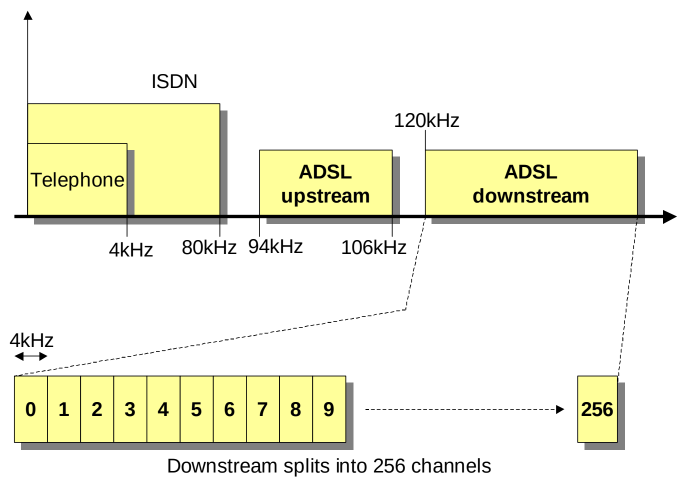

Figure 3 ADSL spectrum

2.2 Radio interference

As previously mentioned, ADSL can be affected by radio transmissions, especially with AM radio frequencies. Figure 4 shows an example of two UK AM radio stations which transmit at frequencies within the ADSL downstream range. Thus, if possible, all ADSL equipment should be shielded, as much as possible, to reduce the effect of radio-based interference. Other equipment, such as automobiles and electrical motors can also generate air-borne noise which can be coupled into the ADSL band, and cause errors in the data.

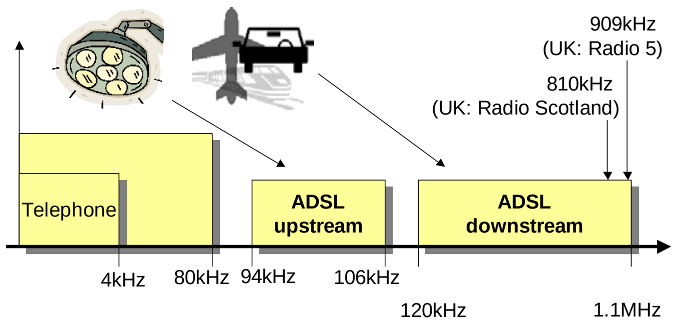

Figure 4 ADSL spectrum

2.3 Modulation

ADSL uses Trellis-Encoded Quadrature Amplitude Module (QAM). This uses two amplitudes and four phases for each transmitted signalling element. This thus gives 8 different combinations of phases and amplitudes, thus 3 bits (000, 001, …, 111) can be sent for each transmitted symbol, as illustrated in Figure 5. Increasing bit rates will be generated with an increasing number of amplitudes and phases. This is similar to the technique used by dial-up modems.

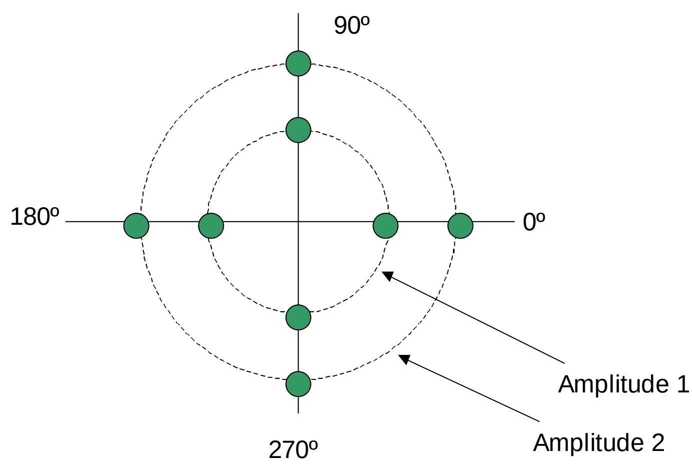

Figure 5 QAM

2.4 Line testing

When the modem initially connects, it tests the line, and adjusts the number of bits transmitted on each carrier to optimize the available bandwidth. The main test is for the signal-to-noise ratio. The more noise on the channel, the less the data rate will be. Each channel can thus be tested, and the rate transmitted on each channel can be matched to the optimal transmission. For example, if one of the channels is affected by a radio channel on a certain channel, the data rate on that channel can be reduced, or even shutdown completely, as illustrated in Figure 6.

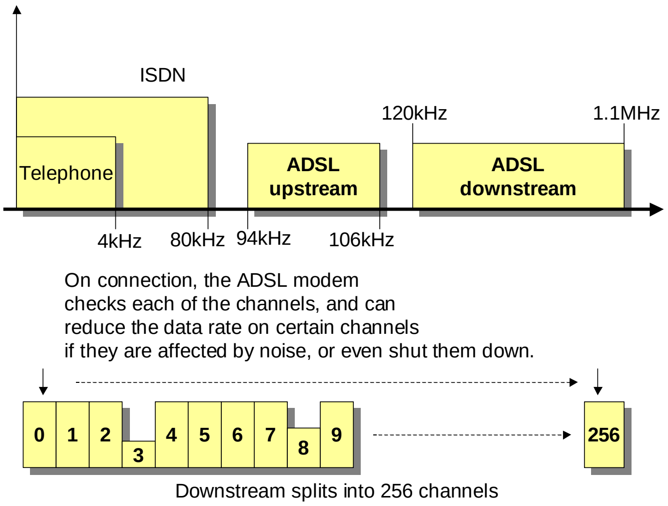

Figure 6 Checking channels

3. Conclusion

ADSL is obviously a short-term fix, in the same way that dial-up modems have been. This is because it does not meet all the demands of the future, such as high-bandwidth data in both directions. Unfortunately it is required at the present time, as the cables which connect to most domestic properties do not have the required specification to allow high-speed data transfer.

In a perfect world each home would be rewired to support high-quality twisted-pair cables (such as Cat-5), or with fiber optic cables. Unfortunately, because of cost, this will not be possible for some time yet (if ever). Thus we must either use the cables used for the telephone system or the ones which are used to transmit cable TV. Both of these have weaknesses. Cable TV systems are typically used to send data from the network to the subscriber, and do not quite support high data rates coming back from the subscriber. They must also share the bandwidth with others.

The improvement in the delivery of data to the home at rates of over 1Mbps will highlight two major problems with the current structure of the Internet:

- That the backbone will require major upgrades as home users provide data streams of several Mbps. As the number of users in countries using broadband connections increase to give millions of users access to data rates of over 1Mbps, will mean that ISP's will have to provide backbone rates of many 100's of Gbps, if not more, in order to satisfy the demand for bandwidth.
- That many WWW services connect to T1-type streams, which only support around a few Mbps. Thus it is not really possible to stream many 1Mbps streams over their connection. Many organisations will thus have to upgrade their WWW connections, in order to keep up with bandwidth demand.

ADSL is thus attractive at the present time as it currently supports many of our requirements for bandwidth, such as the provision of WWW access, e-mail, MP-3 downloads, and so on. Unfortunately, it is unlikely to support the requirement for the future, such as streaming TV, real-time audio, and so on. These weaknesses have been highlighted with Ethernet and dial-up modems, in the past, but they have typically regenerated their selves in a new form, with higher data rates, which overcomes some the weaknesses, so maybe ADSL will do the same. A key element will be to keep the compatibly with existing systems, and migrate to new ones in the future. There are limits to the technology, though, and the major limitation is the quality of the cables provided by the telephone provider.

4. Author

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