QUESTION 12/2

Examine broadband communications over traditional copper wires

ITU-D STUDY GROUP 2 2nd STUDY PERIOD (1998-2002)

Report on DSL technologies

Telecommunication Development Bureau (BDT)

International Telecommunication Union

THE STUDY GROUPS OF ITU-D

The ITU-D Study Groups were set up in accordance with Resolutions 2 of the World Telecommunication Development Conference (WTDC) held in Buenos Aires, Argentina, in 1994). For the period 1998-2002, Study Group 1 is entrusted with the study of eleven Questions in the field of telecommunication development strategies and policies. Study Group 2 is entrusted with the study of seven Questions in the field of development and management of telecommunication services and networks. For this period, in order to respond as quickly as possible to the concerns of developing countries, instead of being approved during the WTDC, the output of each Question is published as and when it is ready.

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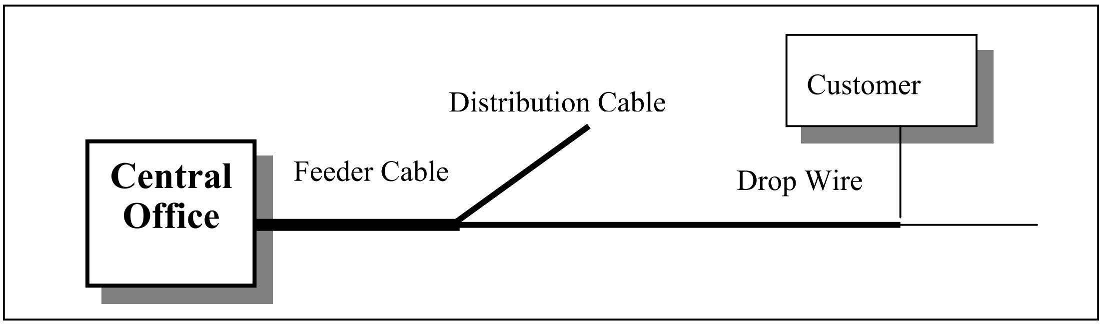
1 Introduction

Users of telecommunication services – subscribers – are connected over the access network to the transit networks. Historically, these connections, subscriber loops, contain twisted copper pairs assembled in pair cables. Figure 1.1 shows an example of a telephone loop plant with feeder cables to concentrated customer areas, distribution cables to potential customer sites and drop wires to customer premises.

Figure 1.1 – Example of telephone loop plant



Subscriber loops have been under study for many years and different models exist to describe important parameters such as:

- cable type (wire diameter, isolation material);
- cable length;
- loop structure (load coils, bridged taps);
- noise sources (cross talk, impulse noise, radio-frequency interference).

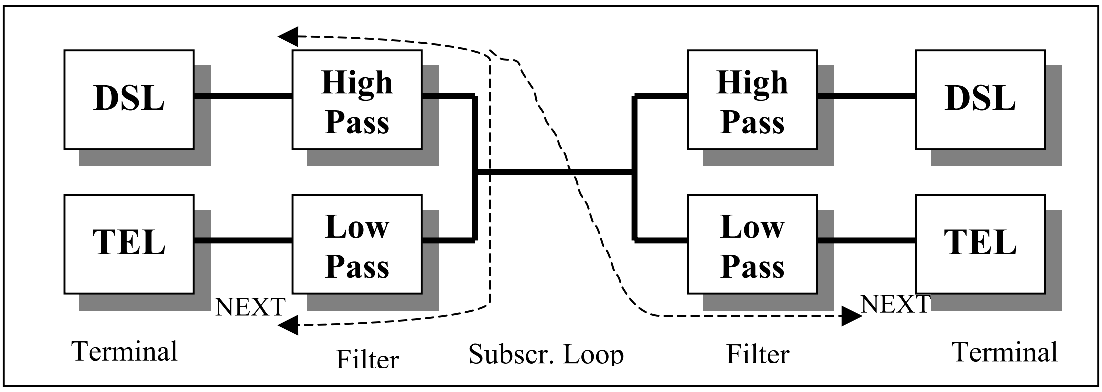
For analogue voice frequency signals up to 4 kHz, normally the attenuation based on the wire gauge determines the length of a subscriber loop. Load coils are used in some cases to extend the range and bridged taps for multipoint network configurations.

The introduction of new services demanding digital signals with higher and higher bit rates requires either extending the usable bandwidth of existing subscriber loops with sophisticated technologies or replacing the twisted pairs with broadband transmission media such as fiber/coaxial cables or wireless transmission.

The extensive cost related to the replacing of existing subscriber loops and at the same time the development in the field of digital signal processing influenced the development of Digital Subscriber Loop (DSL) technologies to achieve better utilization of the available bandwidth and, as a result, the transmission of higher bit rates. In some cases telephone signals (POTS) can use the same subscriber loop as DSL signals.

Simultaneous transmission of voice frequency signals and higher frequency signals, in the same or opposite directions, can require splitter installation as illustrated in Figure 1.2.

Figure 1.2 – Example of splitter installation



Near-end crosstalk (NEXT) is a major impairment for systems that share the same frequency band for upstream and downstream transmission. NEXT noise is seen by the receiver located at the same end of the cable as the transmitter that is the noise source. Far-end crosstalk (FEXT) is the noise detected by the receiver located at the far end of the cable from the transmitter that is the noise source. FEXT is less severe than NEXT because the FEXT noise is attenuated by traversing the full length of the cable.

Splitter configurations contain a low-pass and high-pass filter permitting to isolate Telephone (POTS) and DSL applications. In addition splitters decreases the influence of on-off hook related impedance changes, pulse, ringing and crosstalk disturbances. Near-end crosstalk has to be attenuated as a DSL transmitter sends with about 100 mW and a telephone receiver works with 0.1 mW.

With powerful Digital Signal Processing it is possible to achieve sophisticated coding methods, channel equalization and echo cancellation techniques decreasing the influence of crosstalk. The spectrum used for voice frequency signals of up to 4 kHz can be extended to about 500 kHz for the transmission of digital signals using DSL technologies leading to bit rates in the range of Mbit/s across existing physical subscriber loops.

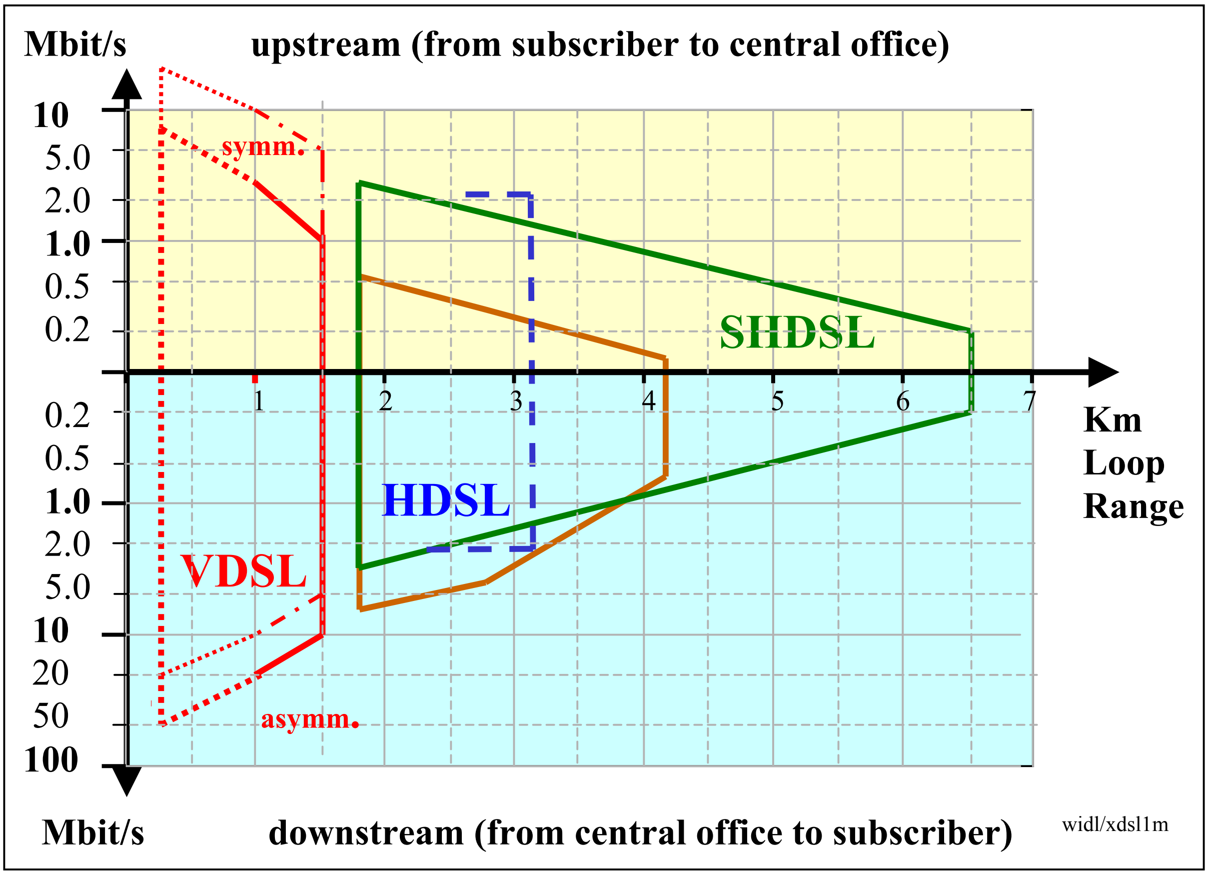
2 Broadband Access Technologies

In the domain of wide area network access, there are numerous technology options that are presently competing for market share and acceptance. These technology options originate from both the WAN and LAN environments and include e.g. ISDN, ATM, switched Ethernet Frame Relay, several technologies for data transmission over coaxial (CATV) cable, and the family of Digital Subscriber Line technologies. In the past years, DSL technologies have attracted a great deal of attention as the access solution of the future – in both the home and business application environments. Originally, DSL technologies, operating over the existing infrastructure of copper wiring, were proposed as an intermediate access solution for the residential area before the extensive installation of hybrid fibre-coax (HFC) or fibre-to-the-home (FTTH) infrastructures. It has become apparent that the installation of an HFC or FTTH infrastructure will require a far larger investment and a much longer deployment schedule than previously envisioned. Therefore, the “intermediate” period of DSL deployment may well be with us far into the 21st century, in particular in developing countries.

Although DSL technologies have emerged from data communications laboratories and pcm development only recently, they have actually existed for a number of years – although without the notoriety they enjoy today. However DSL has suddenly achieved its present status as potentially the most promising of the broadband access technology options for both residential and business users based on the increased demand for higher data rates for data transmission and Internet This paper attempts to shed light on this question from both the technical and market perspectives.

The following Figure 2.1 and Figure 2.2 illustrate the access type, bit rate, range and pair requirement for different technologies. The values shown in the table depend on many parameters, such as e.g. wire gauge, bridged taps, disturbances, margins etc. In addition, due to the continuous development of new technologies the values can change.

Figure 2.1 – DSL systems, typical data rate/range diagram (1 pair and no regenerators)



Type	Description	Access/Speeds/Range/Pairs	Applications
BB	**Baseband Modems**	Symm.: 32 kbit/s to 2 Mbit/s Range: Few km Pair: 1	Leased lines
V.22 to V.90	**Voice Band Modems**	Symm.: 1200 bit/s to 56000 bit/s Range: unlimited Pair: 1	Dial-up data communications
DSL ISDN	**Digital Subscriber Line**	Duplex: 160 K (2B+D+M) Range: up to 5500 m	ISDN service Voice and data communications
HDSL	**High Bit Rate Digital Subscriber Line**	Symm.: Range: up to 3000 m (without repeater) Pair 1: 1 × 2320 kbit/s down / up Pairs 2: 2 × 1168 kbit/s down / up 2 × 784 kbit/s down / up Pairs 3: 3 × 784 kbit/s down / up	T.1 and E.1 services Synchronous services
SHDSL	**Single Pair High Speed Digital Subscriber Line**	Symm.: fractional bit rates n × 128 kbit/s (n = 1-18) Range : 6500 m for 192 kbit/s 1800 m for 2304 kbit/s Pair: 1 (use of regenerator possible)	T.1 and E.1 services Synchronous services
ADSL	**Asymmetric Digital Subscriber Line** **Splitterless ASDL (ADSL Lite)**	Asymmetric: Downstream: 1.5 to 6.144 Mbit/s Upstream: 16 kbit/s to 640 kbit/s Range : 2800 m 4096 kbit/s down / 320 kbit/s up 0,4 mm 3500 m 2048 kbit/s down / 128 kbit/s up gauge 4200 m 578 kbit/s down / 128 kbit/s up 2800 m 1536 kbit/s down / 256 kbit/s up 3500 m 1536 kbit/s down / 96 kbit/s up 4200 m 512 kbit/s down / 96 kbit/s up Pair: 1	Internet access VoD and video access services Remote LAN access Interactive multimedia
VDSL	**Very High Data Rate Digital Subscriber Line**	Asymmetric: Downstream: 13 Mbit/s to 51 Mbit/s Upstream: 1.6 Mbit/s to 6.6 Mbit/s Range: 1500 m 13 Mbit/s down / 1.6 Mbit/s up 1000 m 26 Mbit/s down / 3.2 Mbit/s up 300 m 52 Mbit/s down / 6.6 Mbit/s up Symmetric: Range 1000 m up to 26 Mbit/s Pair: 1	Same as ADSL and HDTV

T1 = 1544 kbit/s E1 = 2048 kbit/s M = management information 16 kbit/s

3 The Essence of DSL

For decades it was assumed that analogue modems would reach a 56 kbit/s ceiling in terms of maximum possible bandwidth without compression. In actuality, the 56 kbit/s threshold refers only to the amount of bandwidth that is theoretically possible over the audible spectra of frequencies. The audible spectra consists of only the bottom 4 kHz of total spectra available on a typical pair of telephone wire. However, the entire spectra of frequency transmittable over copper wire is typically in the area of 500 kHz. The way DSL technologies achieve their exponential increase over analogue modems that are common today is by exploiting frequencies above 4 kHz. These frequencies have previously not been used due to the difficulties they cause for normal transmission of voice traffic. Frequencies above 4 kHz transmitted over a pair of copper wires in a binder tend to disrupt Plain Old Telephone Service (POTS) by introducing unacceptable levels of near end crosstalk to other wire pairs in the same binder.

DSL technologies employ highly sophisticated techniques that limit near end crosstalk and, therefore, greatly expand the bandwidth potential over a single pair of copper wires. As an added benefit, some of these techniques permit POTS service to continue simultaneously on the same wire pair upon which DSL transmission takes place. These techniques have been made possible by the continuing advancement of lower cost and more powerful Digital Signaling Processing (DSP) chips that require less and less electric power.

A problem recognized recently is the need to specify spectral compatibility between different DSL systems in the same cable and used by various operators (unbundling).

Normally the regulator is responsible for the spectrum management defining the unbundling requirements. Specification work in this area is ongoing at ANSI and ETSI.

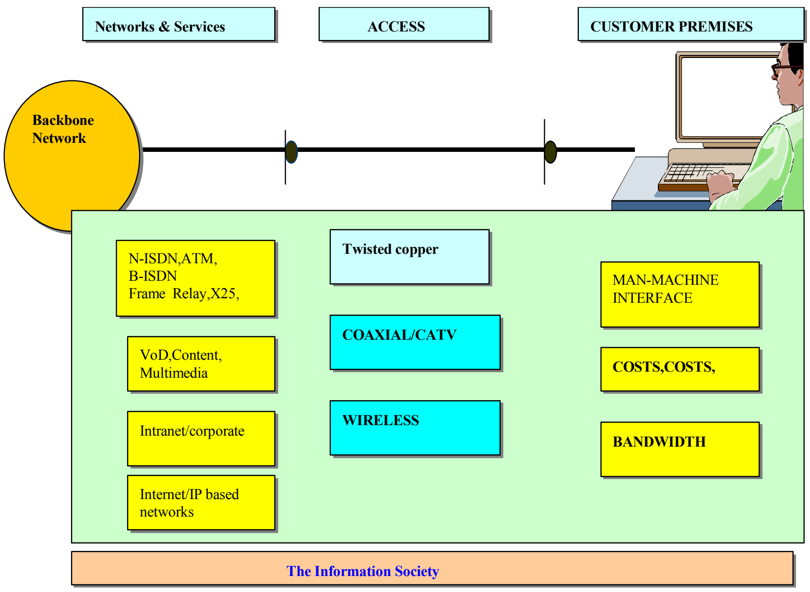
In the early 90s, DSL technologies (specifically HDSL and later ADSL) were tested by some of the operators in the United States as well as by several European PTTs. HDSL was used as symmetrical access technology delivering T1 or E1 into the access and trunk network. Many of the tests gave birth to full-scale trials. For ADSL at that time, the driving applications behind deploying DSL were video on demand (VOD) and interactive TV (ITV). Those applications were seen as potential sources of revenue growth for the residential market, and ADSL was the phone companies’ delivery weapon, against the CATV networks that were gearing up to deliver these services over their coaxial cable infrastructure. Much to the disappointment of cable companies and Telcos alike, both VOD and ITV failed as “killer applications” that would justify a full scale roll out of these services. At that point, ADSL was, to a large degree, forgotten.

In 1995, interest shifted toward the online world and, more specifically, the World Wide Web (WWW). As has been clear from the beginning of the Web in 1993, far more bandwidth is required in order to make the Web an universally accessible “information superhighway”, as well as to support the more demanding Web-based applications. The increasing demand for bandwidth to access the Web is one of the primary applications at which DSL technologies are now targeted. However, DSL technologies are also being looked at in conjunction with several other applications and these applications may produce in the long run a far greater revenue stream compared to broadband Web access for the residential market. Among these applications are:

- <u>Voice-over-DSL</u> (VoDSL) which should not be confused with conventional base band voice transmission. In the case of VoDSL the voice signals are digitized, inserted into DSL code words and transported e.g. through DSLAM access nodes at frequencies above the POTS physical layer of the DSL link in order to provide telephony services. Splitting filters are not required for VoDSL.

- Intranet access for organizations that are standardising on a Web-based, client server model. An organization that has implemented an Intranet will require the higher bandwidth afforded by DSL in order to link their Remote Office/Branch Office (ROBO) environments and telecommuters to the more demanding business-oriented applications running on their private Web servers.
- Low cost, high throughput, LAN-to-LAN connectivity. DSL technologies have the potential to prove far more effective in this role than ISDN or traditional leased lines.
- Frame Relay Access. Since DSL operates at the physical layer, it could emerge as the most cost effective method of carrying Frame Relay traffic from the service subscriber to the Frame Relay network. Frame Relay over DSL serves the first two applications mentioned, as well as greatly reduces the cost of using Frame Relay in other applications such as carrying legacy mainframe traffic or even voice traffic.
- ATM network access. As with Frame Relay, DSL technologies can also be used to carry ATM cells to an ATM access device where they are statistically multiplexed over an ATM backbone.
- Leased Line Provisioning. DSL can be used to greatly reduce the cost of provisioning T1/E1 lines from the central office (CO) to the customer's site. The following Figure 3.1 shows the relationship between user's requirements and technology with a view to approach the Information Society:

Figure 3.1 – Relationship between user requirements and technology



4 DSL Systems

Simplified technical descriptions of DSL systems can be found in Annex 2.

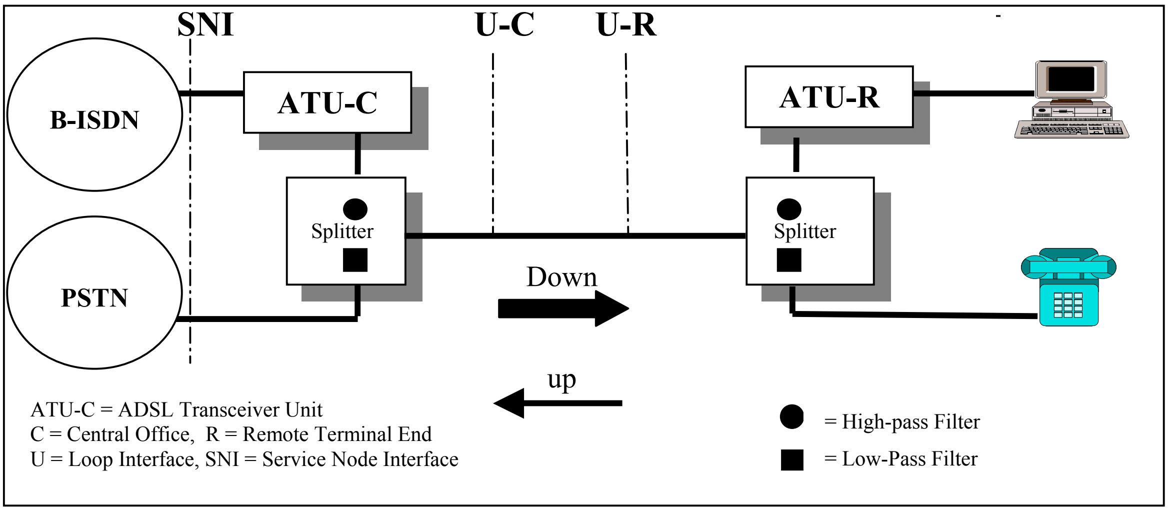
4.1 ADSL – Asymmetric Digital Subscriber Line

In the past, ADSL has perhaps gained the most attention as the flavor of DSL that holds the greatest near term potential for providing broadband access to residential and SOHO (small office, home office) markets. However, recently, ADSL has been recognized as a potentially ideal solution for the corporate inter-networking market and the general consumer market.

As its name indicates, ADSL apportions bandwidth asymmetrically. That is, more bandwidth is allocated for “downstream” transmission (i.e. for traffic from the service provider to the subscriber) than upstream traffic (i.e. for traffic from the subscriber to the service provider). ADSL achieves its asymmetrical bandwidth structure with four classes of channels: higher bandwidth simplex (uni-directional) channels, lower bandwidth duplex (bi-directional) channels, a duplex control channel, and a POTS channel, which occupies the lowest 4 kHz of frequency on the line. Transmission occurring on either the simplex or duplex channels does not affect the POTS channel. This ability to simultaneously provide POTS service alongside broadband data and/or video services across the same copper wire pair is one of ADSL’s primary advantages relative to other access technologies, such as ISDN. In the European Version even simultaneous transport of ISDN together with ADSL is provided.

In addition to these standardized bandwidth specifications, progress in DSP chip-sets have enabled ADSL modems to achieve even faster speeds both upstream and downstream. The fastest speeds announced to date are 12 Mbit/s and 2 Mbit/s for downstream and upstream speeds respectively. Needless to say, ADSL features a very large number of speed options within a single technology. Nevertheless, ADSL seems to offer the highest potential in the DSL family for cheap, broadband access to both the home and the office in the near term.

Figure 4.1 – ADSL Configuration



Two versions of systems are considered as shown in Figure 4.2:

- Full-rate ADSL with a cut-off frequency of 1104 kHz;
- ADSL Lite with a cut-off frequency of 552 kHz.

The available bandwidth of the subscriber loop is divided into frequency bands for:

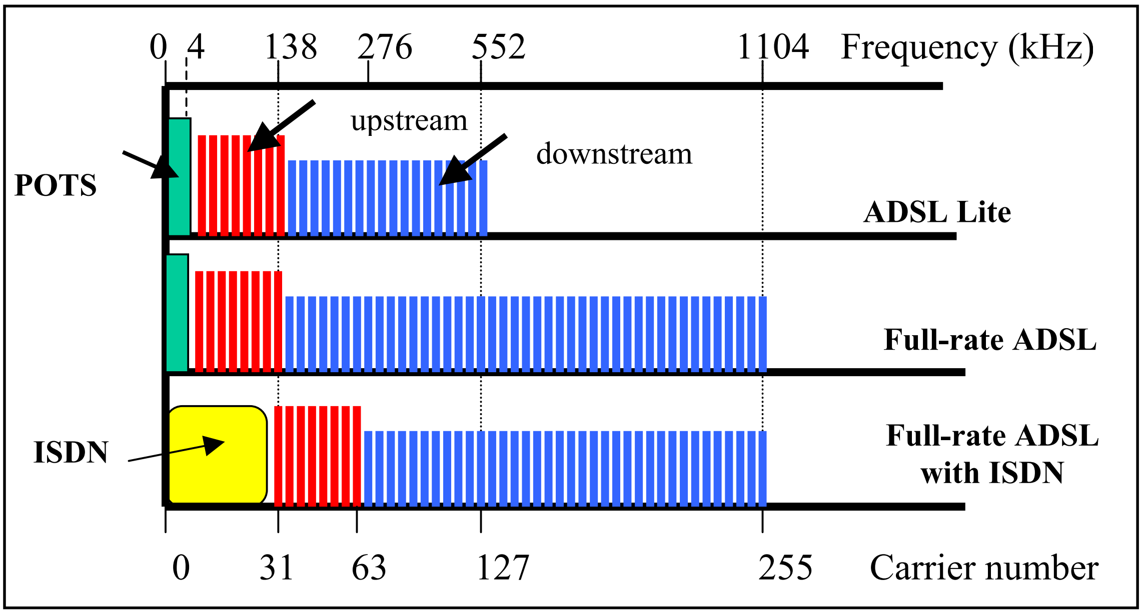
- analogue POTs or ISDN;
- upstream subcarriers;
- downstream subcarriers.

In addition to the versions shown in Figure 4.2 ADSL Lite and Full-rate ADSL can use echo cancellation, i.e. the frequency band 4-138 kHz is used for both upstream and downstream transmission.

The technology specified for ADSL is based on Discrete Multitone (DMT) transmission, i.e. the line signal consists of a number of parallel frequencies, leading to up to 15 bits/s per Hz bandwidth. An ADSL transceiver contains functions such as e.g.:

- transmit and receive filtering, automatic gain control A/D and D/A conversion;
- modulation/demodulation, coding /decoding and bit packing/unpacking;
- Fast Fourier Transform and Inverse Fast Fourier Transform;
- adaptive echo cancellation, adaptive channel equalisation, symbol/bit conversion and timing recovery.

Figure 4.2 – Frequency Plan for ADSL



ADSL Lite is expected to replace voice band modems for internet access and will be used in considerable quantities if the following can be achieved:

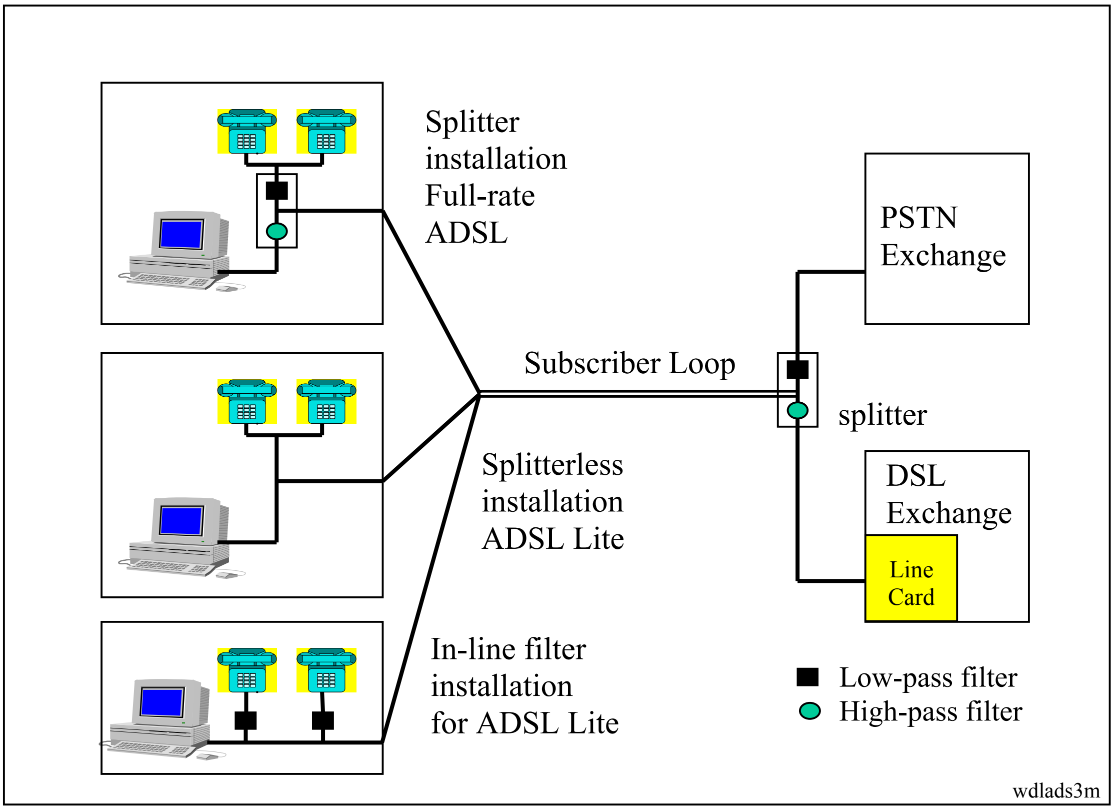
- easy end-user installation without splitter and without service personnel;
- long transmission distance;
- flexible data rates up to 1.5 Mbit/s to users;
- interoperability and compatibility with Full-rate ADSL.

It should be pointed out that the throughput data rate depends on the quality of the subscriber loop. The throughput will be decreased automatically in case of deteriorations.

The requirements for easy installation make splitterless installation an important provision for ADSL Lite. However, in certain cases ADSL Lite demands splitters or additional Filters to protect the telephone sets as illustrated in Figure 4.3.

RADSL technology is a sub-set of ADSL that automatically adjusts line speed based on a series of initial tests that determine the maximum speed possible on a particular line. RADSL is specified by ANSI T1, but not recommended by ITU. In areas where there is a large variance in the length of the local loop (distance from the subscriber to the CO), the gauge of the wire, and the condition of the line, it becomes difficult to determine what speeds should be provisioned over each line. Fluctuating conditions, e.g. such as weather, further act to change the maximum possible throughput on a given line. Since RADSL accommodates the maximum speed available across a particular line, much of the effort can be taken out of provisioning ADSL. However, so far RADSL systems have not been used to a great extent.

Figure 4.3 – Examples of ADSL installations



4.2 HDSL – High-bit-rate Digital Subscriber Line

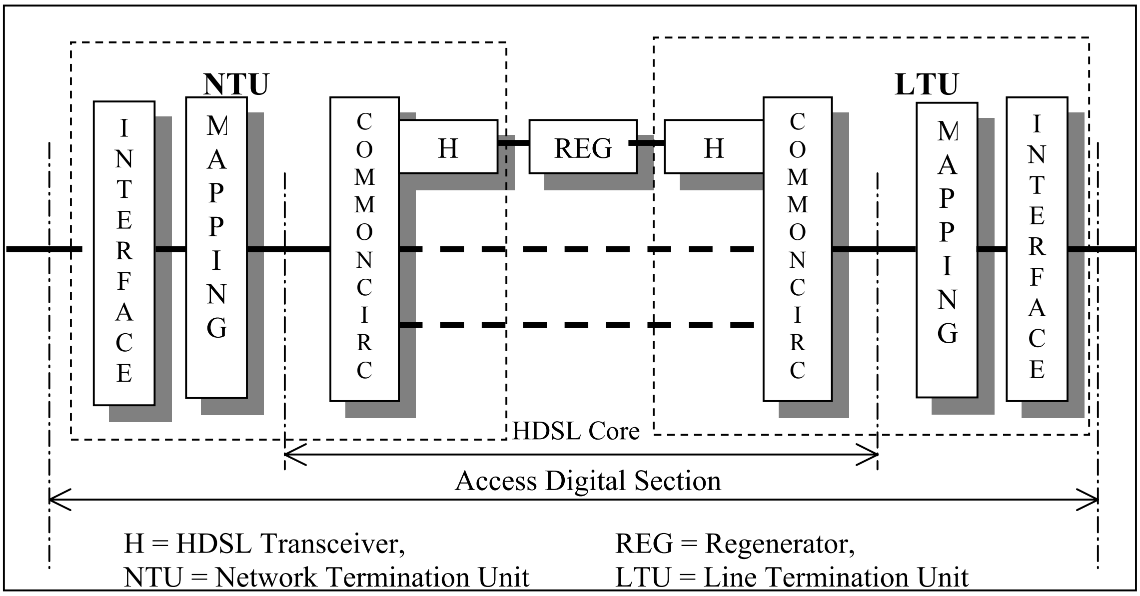
HDSL has been the most widely deployed of the DSL technologies and has been commercially available for a number of years. HDSL uses two or three of copper twisted pairs. Most HDSL implementations provide either 1.5 Mbit/s or 2 Mbit/s of symmetrical bandwidth at up to 3000 m from the CO. These speeds conform to T1 and E1 standards respectively and, therefore, HDSL's primary application to date has been the provisioning of T1/E1 leased lines in areas that have a high density of business customers (e.g. office parks) and a collocated CO.

HDSL systems can work in different working modes:

- Dual Duplex Mode 1.544 HDSL systems operate on two pairs of wires, with each pair conveying 768 kbit/s payload and 16 kbit/s Embedded Operation Channel (EOC) in both directions. 2.048 HDSL systems operate on 3 pairs. Each pair transmitting 784 kbit/s or on 2 pairs each pair transmitting 1168 kbit/s.
- Single Duplex Mode Systems operate on one single pair, transmitting 2320 kbit/s using echo-cancelled hybrid transmission. However this mode will be replaced by SHDSL.
- Dual Simplex Mode Systems use two pairs with one pair carrying the full payload in one direction and the other pair the full payload in the opposite direction. Due to the wide spectrum the resulting performance is inferior to Dual Duplex operation.

Echo-cancelled hybrid transmission normally uses 2B1Q line codes.

Figure 4.4 – HDSL Configuration



HDSL has been attractive in the T1/E1 space because it greatly reduces the cost of traditional T1/E1 provisioning by eliminating the need for repeaters, loop conditioning, or pair selection. HDSL enjoys a relatively large installed base for this application and, to a certain extent, has been responsible for the substantial decrease in leased line costs that we have seen over the last few years. It is likely that SHDSL, requiring only a single copper pair for transmission, will emerge as the superior solution.

4.3 SHDSL – Single-Pair High Bit Rate DSL

Single-Pair High-Speed Digital Subscriber Line (SHDSL) service is used for data transport in telecommunications access networks. SHDSL transceivers are designed primarily for duplex operation over mixed gauge two-wire twisted metallic pairs. Four-wire operation may be supported for extended reach applications and optional signal regenerators for both single-pair and two-pair operation are specified, as well. SHDSL transceivers are capable of supporting selected symmetric user data rates in the range of 192 kbit/s to 2304 kbit/s using a Trellis Coded Pulse Amplitude Modulation (TC-PAM) line code across distances from 1.8 up to 6.5 km. Fractional data rates of n × 128 kbit/s are proposed for longer loops, noisier environments, or service requirements. They are designed to be spectrally compatible with other transmission technologies deployed in the access network, including other DSL technologies. SHDSL transceivers do not support the use of analogue splitting technology for coexistence with either POTS or ISDN. Regional requirements, including both operational differences and performance requirements, and requirements for signal regenerators are specified. SHDSL provides the same bandwidth upstream as downstream. Most technologies in use today for transmission over the wide area are symmetric (e.g. TDM, Frame Relay, etc.). Therefore, SHDSL can be used as the underlying transmission scheme for traditional network technologies and services.

Frame Relay service or a leased line could be provisioned over a single pair of telephone wires rather than multiple wires or even fibre optic cable. This has the potential of greatly reducing the cost of provisioning existing services for that applications demand today. In the case of Frame Relay, the demand is expected to continue to increase for years to come.

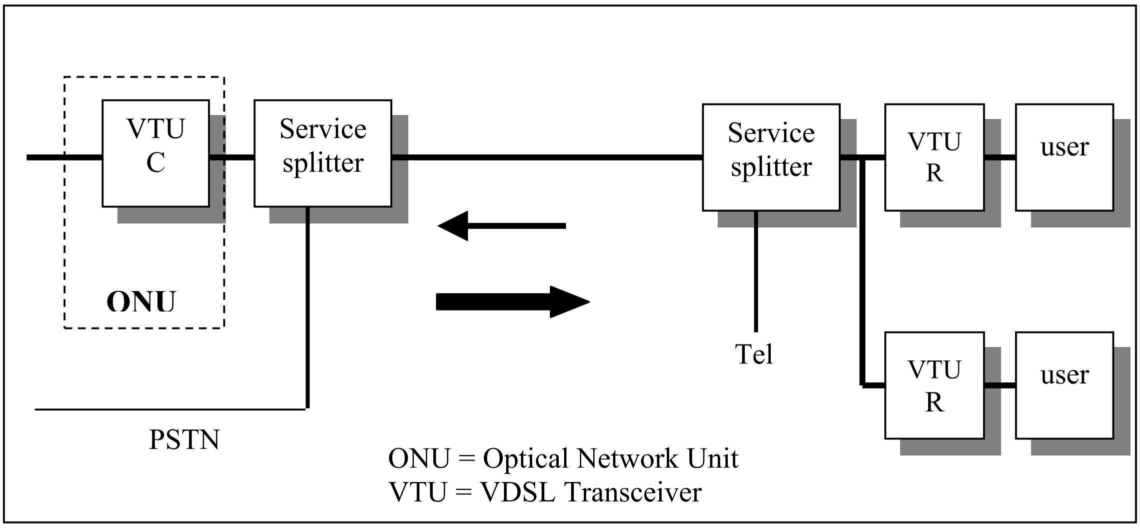
SHDSL’s symmetric transmission scheme is also optimized for some emerging applications as well. Isochronous applications, such as video conferencing, have the same bandwidth requirements upstream as they do downstream. SHDSL is also well suited to a peer-to-peer Internet model where web sites are very highly distributed (i.e. a web site in every home). However, the current trends indicate that, while everyone may have their own web site, they are co-located on centralized servers, thus preserving the asymmetric traffic model. As for video conferencing, while it has a very strong business case, it remains to be seen whether this application will become a dominant form of personal communication in the near term.

4.4 VDSL – Very-high Digital Subscriber Line

VDSL can be used over a broad spectrum of transmission rates from 2 Mbit/s up to 51 Mbit/s achieving distances of some km to some hundred meters. VDSL can be used symmetrically and asymmetrically. However, compared to ADSL, VDSL is designed for much higher transmission rates (up to 30 to 51 Mbit/s) than ADSL over extremely short distances (1500 to 300 m). For this reason VDSL is seen by some people as a much more futuristic technology relative to other DSL technologies, becoming appropriate only when applications begin to demand that kind of bandwidth and in conjunction with Fibre to the Curb (FTTC) deployment. In addition, the VDSL's severe distance limitation precludes it from being implemented in all but the densest environments. Despite these shortcomings, there are situations in which VDSL deployment could be justified. Where dense access environments exist, such as large office buildings or business parks that typically have a CO located on or very near the premises, VDSL could be used to provide lower cost integrated access or LAN-to-LAN connectivity across a broadband network such as ATM, SONET or SDH.

VDSL only covers the link between the cabinet and the customer premises, for this reason VDSL requires a Fibre to the Node architecture with an Optical Network Unit (ONU) sited in the existing metallic access network (or at the serving Local Exchange or Central Office) for the broadband data transport between the exchange and the cabinet. This architectural model covers both short- and long-range options for the VDSL fibre optic connection as illustrated in Figure 4.5.

Figure 4.5 – VDSL configuration



4.5 ISDN

ISDN can be used for DSL services offering full duplex and bit sequence independent transmission of two B-channels (2 × 64 kbit/s) and one D-channel (16 kbit/s). The payload 2B+D transmission of 144 kbit/s is increased with overhead information for bit timing, octet timing and frame alignment. Additional overhead information (C) is required for activation, deactivation, operation and maintenance.

The transmission media are twisted copper pairs without loading coils and restricted use of bridget taps. The transmission methods are Echo Cancellation (ECH), i.e. simultaneous sending/receiving and Time Compressed Multiplex (TCM), i.e. alternate sending and receiving DSL systems with different line codes, frames, overhead information and transmission methods are mentioned in ITU Rec. G.961. Typical line codes are listed below:

MMS43 Modified Monitoring State Code mapping 4 bits into 3 ternary symbols (ECH transmission). Symbol rate = 120 kbaud, Bit rate = 160 kbit/s (C = 1 kbit/s)

2B1Q 2 bits are carried by 1 quaternary symbol. (ECH transmission). Symbol rate = 80 kbaud, Bit rate = 160 kbit/s (C= 4 kbit/s)

AMI Alternate Mark Inversion, a binary one is alternately represented as a positive or negative signal.(TMC transmission). Symbol rate = 320 kbaud, Bit rate = 150.8 kbit/s, (C = 3.2 kbit/s)

SU32 Substitutional 3B2T, each binary triplet is converted into a ternary duplet. (ECH transmission). Symbol rate = 108 kbaud, Bit rate = 432 kbit/s (C = 5.33 kbit/s)

5 DSL Recommendations and Standards

As is the case for many physical layer technologies a considerable number of standardization bodies are actively involved in creating recommendations and standards for DSL. These organisations include: ITU-D, ANSI, ETSI, IETF, ATM Forum, DSL Forum (former ADSL Forum), TIA, and DAVIC. These organisations are creating interoperability specifications that span the end-to-end residential broadband systems. While the ATM Forum covers only ATM over ADSL, SHDSL and VDSL, the other organisations e.g. IETF also produce specifications for IP/packet mode and bit synchronous mode over ADSL and VDSL end systems.

The study of DSL technology started in 1993 when ANSI TIE1.4 used the DTM technology (Discrete Multitone) as the support of ADSL standards. A cooperative work, was also carried out together with ETSI, in order to address Europe's specific requirements.

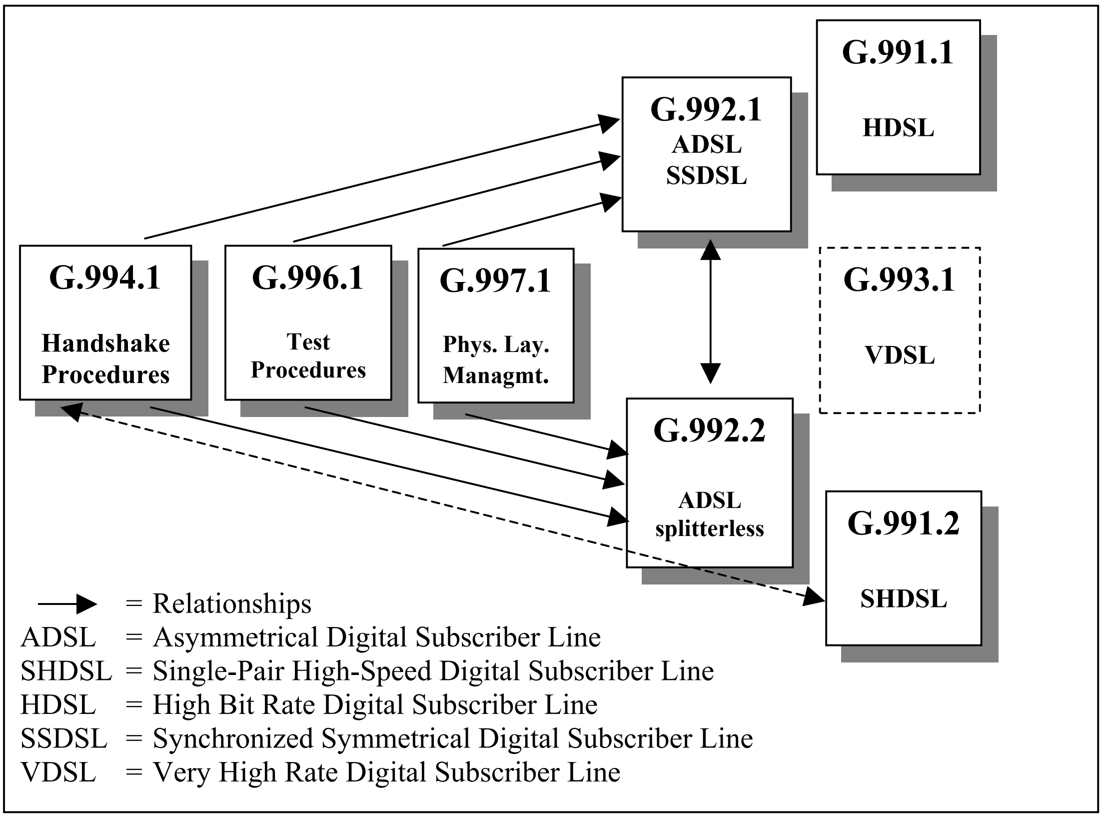
5.1 ITU Recommendations

ITU-T, in the 1996-2000 Study Period has been assigned a new question to Study Group (SG) 15, "Access Network Transport" [Q4/15]. The question calls for international standardization for Data Communication Equipment providing high-speed digital access services including modulation techniques and procedures for e.g. HDSL, ADSL, and VDSL. While the core DSL work has begun in SG15 in 1997, SG13, involved in the development of the wider architectural concept denominated by GII, has also made provisions in terms of methodological scenarios which include DSL technologies.

In 1997 ITU-T began defining a series of Recommendations for DSL systems and at present (year 2001) ADSL and SHDSL are appreciated by the telecommunication world. Recommendations have been elaborated by Study Group 15 dealing with functions, management, handshaking and test principles for ADSL, HDSL, SHDSL and are in progress for VDSL systems. A study of the DSL related Recommendations of the ITU G. 99x Series reveals the complexity of the DSL systems; about 1000 pages are required to define the systems!

Figure 5.1 illustrates relationships between the different DSL Recommendations.

Figure 5.1 – DSL Recommendation Overview



For the time being the Recommendations listed in Figure 5.2 below are considered:

Figure 5.2 – List of ITU DSL Recommendations

- G.991.1 High bit rate Digital Subscriber Line (HDSL), Transceivers.
- G.991.2 Single-Pair High-Bit-Rate DSL (SHDSL) Transceivers
- G.992.1 Asymmetrical Digital Subscriber Line (ADSL), Transceivers
- G.992.2 Splitterless Asymmetrical Digital Subscriber Line (ADSL), Transceivers (other term: ADSL lite)
- G.993.1 Very High Rate Digital Subscriber Line (VDSL), Transceiver (Not finalised)
- G.994.1 Handshake Procedures for Digital Subscriber Line (DSL)
- G.995.1 Overview of Digital Subscriber Line (DSL) Recommendations
- G.996.1 Test Procedures for Digital Subscriber Line (DSL), Transceiver
- G.997.1 Physical Layer Management for Digital Subscriber Line (DSL), Transceivers

SG13, under the new architectural concept of the GII, has developed several general Recommendations, in particular Annex A to Y.120 provides a number of scenarios which include the DSL technology. Work is in progress to meet new requirements for the access network, see ITU-T Study Group 15, Working Party 1, Question 4/15 (http://ties.itu.int/u/tsg15/sg15/wp1/94).

This book attempts to explain technical aspects of DSL with reference to the main standards set by ITU-T and other relevant fora. Applications and services related to the use of DSL are also covered herein. Both the technical and market development of DSL technologies are considered in this Report. It would be highly desirable to include cost/benefit analyses in this Report, however, relevant material could not be obtained.

An overview of the ITU DSL standards and related interactions is found in Figure 5.2 and Annex 1.

The work of SG 15 is focused on proposals for Recommendations on ADSL and HDSL based on the existing ANSI Standard T1.413 and ETSI ETR152 Edition 3 respectively by making reference to them as appropriate. Additionally, the work toward later issues of these Recommendation will also cover 1) Support of high level protocols and associated interfaces such as ATM, USB, Firewire, IP over Ethernet, 2) International/Global POTS Splitter issues, 3) Network Modeling and Standard Testing Methods, 4) Data Compression, 5) Network Management MIB's and finally definition of a logical interface which could be optionally implemented.

5.2 ETSI

Since its inauguration ETSI, the European Telecom Standards Institute, with its headquarters in Sophia Antipolis, France, dealt with transmission specifications and standards in the Technical Committee TM. Since 1992 TM3 and later TM6 have written specifications for Access Transmission Systems on Metallic Lines.

TM6 has produced a set of specifications for HDSL working on 3, 2, and single pairs with and without simultaneous transport of ISDN. The standards are partly included in ITU-T Rec G.991.1

For ADSL, TM6 has written an Annex to the ANSI Standard T1.413, reflecting European requirements. These have also become part of G.991.2.

On VDSL and SDSL TM6 has finalized in May 2000 the specifications for the Functional and the Transmission Requirements. After formal approval within ETSI these are to be published and may be updated in a further work item. Cooperation with ANSI T1E1.4 and the ITU-T SG15 has been very close during the progress of this work.

Finally, TM6 works on Spectral Management, to specify the compatibility of different DSL systems which can be installed in the same cable by different operators.

Relevant ETSI Technical Specifications for Transmission and Multiplexing (TM) related to DSL are:

ISDN BA: TS 102080

Integrated Services Digital Network (ISDN) basic rate access; digital transmission system on metallic local lines.

HDSL: TS 101135

High bit-rate Digital Subscriber Line (HDSL) transmission systems on metallic local lines; HDSL core specification and applications for combined ISDN-BA and 2048 kbit/s transmission.

SDSL: TS 101524

Access transmission system on metallic access cables; Symmetrical single pair high bit rate Digital Subscriber Line (SDSL); part 1: Functional Requirements, part 2: Transceiver Requirements.

ADSL: TS 101388

Access transmission system on metallic access cables; Asymmetrical Digital Subscriber Line (ADSL) – Coexistence of ADSL and ISDN-BA on the same pair.

VDSL: TS 101270

Access transmission system on metallic access cables; Very high speed Digital Subscriber Line (VDSL), part 1: Functional Requirements, part 2: Transceiver Specification.

5.3 ANSI

The work on DSL standards by USA committee T1 resulted in the following approved standards:

- T1.601 Basic rate ISDN line (basis for ITU Rec. G.961);
- T1.605 Basic rate ISDN T interface (basis for ITU Rec. G.960);
- T1.413 Full rate ADSL (basis for ITU Rec. G.992.1);
- T1.418 HDSL2 1.5 Mbit/s symmetric (basis for ITU Rec G.shdsl);
- T1.419 Pointer to ITU Rec. G.992.2.

Work on new DSL standards:

- T1E1.4 began work on a draft ANSI spectrum management standard in 1997 to provide generic technical specifications for DSL systems that may safely coexist in the same cable. The first draft of spectrum management will lead to a voluntary standard. (Co-ordination with T1E1 and ETSI TM6);
- VDSL (T1E1.4 with ITU and ETSI TM6);
- Symmetric DSL (T1E1.4 with ITU and ETSI TM6);
- HDSL2 (T1E1.4);
- Microfilter (T1E1.4);
- Line sharing splitter for Central Office (T1E1.4);
- ADSL modem testing (TR30.3, T1E1.4);
- Voice over DSL: (DSL Forum, ATM Forum);
- ADSL inter operability (DSL Forum);
- Improved ADSL performance (ITU, T1E1.4).

5.4 The DSL Forum

DSL Forum is a consortium of more than 400 leading industry players covering telecommunications, equipment, computing, networking and service provider companies. Established in 1994, the Forum continues its drive for a mass market for DSL, to deliver the benefits of this technology to end users around the world over existing copper telephone wire infrastructures.

Throughout its six years, DSL Forum has worked on defining the core technology as it develops, providing inputs to international standards bodies and on establishing processes to deliver maximum effectiveness in the deployment and use of DSL. The Forum is focused on the complete portfolio of digital subscriber line technologies designed to deliver ubiquitous broadband services for a wide range of situations and applications that will continue the transformation of our day-to-day lives in an on-line world.

Best practices for auto-configuration, flow through provisioning and a range of other key facilitators of scaleable, global, mass-market deployment of DSL technology are fast-tracked by DSL Forum through its Technical Committee and Marketing Committee working groups. This work takes place at quarterly, week-long meetings, contributions and through continuous working group progress programs with formal technical reports developed from contributions and 'Working Texts". The working groups are at present (August 2001) shown in Figure 5.3:

Figure 5.3 – DSL Forum Working Groups

Technical working groups	Marketing working groups
Architecture & Transport	Ambassador Program
Auto-configuration	Deployment Council
Emerging DSLs Study Group	Mindshare
Operations & Network Management	Summits and Best Practices
Testing & Interoperability	Tradeshows
VoDSL	Public Relations
	Web
	E-Commerce
	SHDSL

Industry-wide support for and contribution to DSL Forum's prioritized action plan to support the global mass-market has been unparalleled with membership exceeding a record 400.

Each member contributes to the work of the Forum through the development of the technology and its effective delivery. They participate in a range of technical and marketing working groups, sharing their knowledge, experience and expertise to create common, agreed protocols, processes and recommendations to standards and other related bodies.

These Forum meetings foster a sharing of knowledge and best practices between members to make DSL the world's primary choice for broadband services.

The Forum continues to establish essential and proven processes for DSL delivery that accelerate the affordable and faster delivery of DSL to the mass market.

Further information on DSL Forum, its work, members and meeting schedule is available on www.dslforum.org

5.5 DAVIC and the ATM Forum

Formed in late 1991, the ATM Forum has two working groups relevant to ADSL specifications. The Physical Layer (PHY) Working Group covers all physical medium dependent (PMD) sub-layers and transmission convergence (TC) sub-layers for ATM. Although the ATM Forum has yet to work on an ADSL or VDSL PMD, contributions have been heard on TC layer issues for both ADSL and VDSL. The end-to-end system aspects for ATM over ADSL and VDSL are discussed in the Residential Broadband (RBB) Working Group. This group meets jointly with PHY on ADSL and VDSL physical layer issues and is exchanging liaisons with nearly all the other organisations mentioned in this section. Recently the RBB group has asked the ADSL Forum for a joint work session to further work on the ADSL Forum's specification for ATM over ADSL and subsequently ATM over VDSL.

DAVIC (the Digital Audio Visual Council) is also considering the publication of an ADSL ATM Mapping specification as part of DAVIC 1.2. This specification includes definition of an ATM TC layer for ADSL. The DAVIC specification will reference the ADSL Forum documents if possible.

Other organizations working on related items include IEEE P.1007, the TIA TR41.5 (specification for a network gateway), and IEEE 802.14 (for VDSL).

5.6 IETF

The Internet Engineering Task Force (IETF) is a large open international community of network designers, operators, vendors, and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet.

The actual technical work of the IETF is done in its working groups, which are organized by topic into several areas, much of the work is handled via mailing lists and 3 meetings per year. The ADSLMIB working group works with the definition of the ADSL Management Information Base (MIB). In addition the working group will define a set of managed objects to be used for management of VDSL and SHDSL consistent with the Simple Network Management Protocol (SNMP) management framework.

6 The Business Case for DSL

Several factors are key in developing the business case for deploying DSL. For the broadband market the business case for DSL systems is based on the following considerations:

- *New revenue.* Value-added services such as Internet access and VOD generate new revenues. Given the eroding POTS market, where price competition is high and the threat of alternatives services such as voice over the Internet is increasing, DSL gives service providers the option to skim the cream by offering higher priced and higher margin residential broadband services.

- *Infrastructure deployment/upgrade costs.* Provisioning simply requires the addition of two DSL transceivers per subscriber line. The utilisation of existing copper twisted pairs does not require any terminal adapters nor special client or host software.

- *Incremental deployment options*. Each and every subscriber line can be made DSL-ready independently. DSL deployment does not require groups of subscribers to be enabled at a time nor an entire switch to be upgraded.

- *Easy migration path.* If higher speed services are needed at a particular subscriber location, lower speed DSL equipment can be replaced by higher speed DSL equipment (and perhaps a longer fibre run). The replaced lower speed DSL equipment can then be reused at another subscriber location.

- *Service provisioning time improvements*. Some DSL installations are essentially "plug and play" (e.g. ADSL) leading to service provisioning time improvements compared to other infrastructures in support of residential broadband services.

- *Network "hold times" improvements*. Internet calls are tying up network resources for hours. The POTS network, originally designed for voice calls averaging only minutes in duration, is becoming increasingly taxed. DSL allows the telcos to free these resources e.g. by redirecting the DSL calls at the central office to an auxiliary high speed data network.

- *Network switch port and loop utilisation improvements*. SOHO workers can replace their two to four line offices (e.g. office for voice calls, office for fax calls, office for Internet/Intranet calls, and office for personal calls) with one office for DSL line service.

- *Integration of services* is possible with an access node deployed at the customer premises containing an Integrated Access Device (IAD) that can simultaneously deliver Class 5 switch voice services, packet voice services, and data services (via LAN ports) over a single WAN link. Integrated Access Devices (IADs) were created to address the needs of Competitive Local Exchange Carriers (CLECs) and other service providers who are challenged with the high cost of co-locating equipment and leasing lines from local telcos. IADs provide a common platform that enables service providers to deliver voice and data over a single access network, reducing the cost of co-located equipment in the telco central office (CO) and allowing service providers to lease fewer transport lines. Simply put, IADs enable service providers to cost effectively deploy next generation managed services for the growing needs of small and medium businesses over a single high speed access link.

- *Voice over DSL* based on IADs and without the need of splitters. This service will be attractive to Small Medium Enterprises (SME), larger business customers and small office and home office (SOHO) users because it permits more complex service combinations at reasonable cost.

  Typical service combinations could be:

  – For SME: 8 voice lines, LAN and videoconferencing;

– For SOHO: 2 voice lines, fax and high speed Internet;

– For large companies: 4 ISDN lines for fax and voice, corporate LAN and Internet.

All this can be achieved without installing additional copper lines and keeps the number of components and effort involved in system management to a minimum. Furthermore, Voice over DSL could prove to be the kick-start that DSL needs to take into the mass-market. VoDSL gives new operators a chance to compete with incumbent PTTs for voice services without having to forsake profit margins or voice quality.

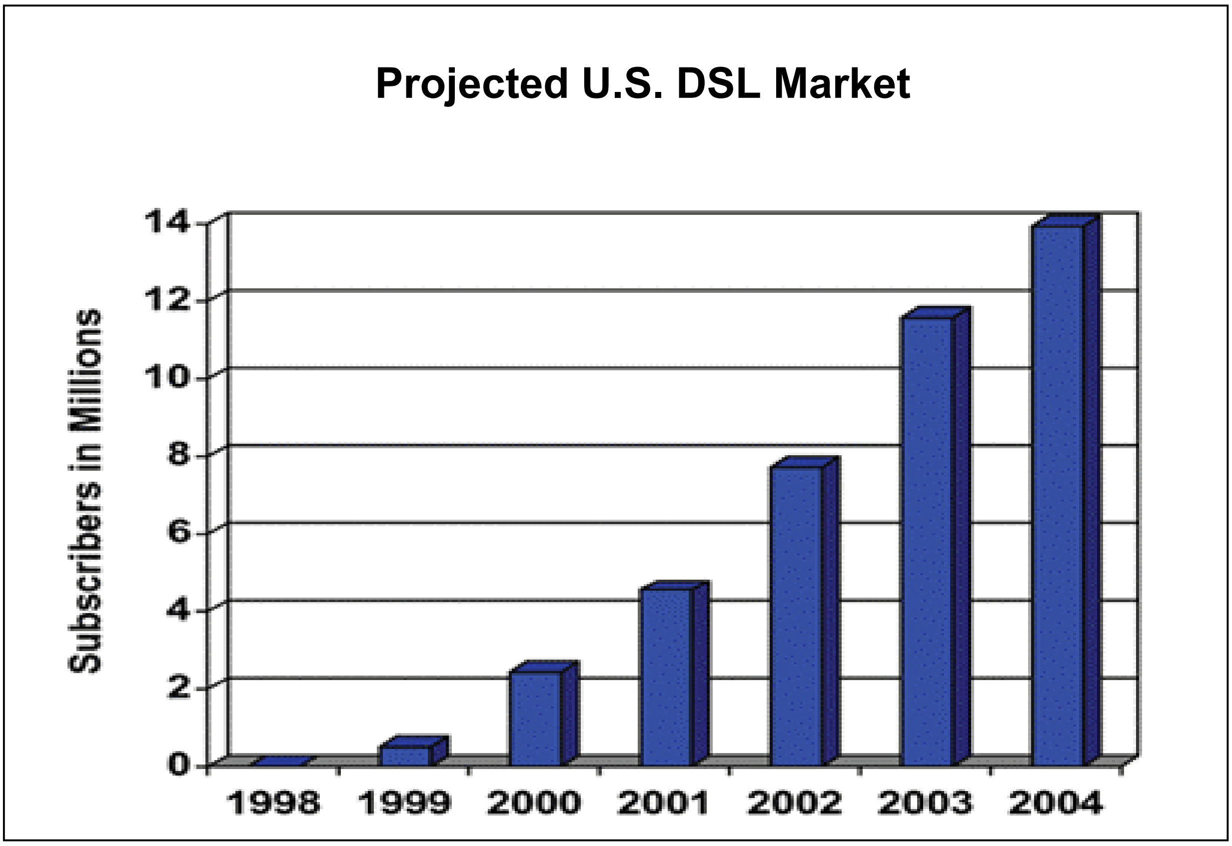
- *Efficient bandwidth utilisation* with SHDSL. SHDSL squeezes the maximum amount of bandwidth out the local loop and virtually provides the same upstream and downstream throughput. SHDSL has also been shown to have approximately 20% better reach than other types of DSL. A varying number of voice channels can co-exist with data channels. The number of voice channels can be changed to match the traffic demands.

With these many factors contributing to building a positive business case, we will witness strong market pull from both the end users and the service providers for DSL. The DSL market is growing fast, end of March 2001:

- about 3 million lines used in the USA;
- about 600 000 lines used in Canada;
- more than 3 million lines installed in Korea and;
- more than 1.5 million lines installed in Europe.

Figure 6.1 illustrates projected US DSL market.

Figure 6.1 – Projected US DSL Market



With multiplexing techniques each Voice over DSL line can serve a number of subscriber telephones. Figure 6.2 shows both the estimated growth of lines and telephones using Voice over DSL technology.

Figure 6.2 – Projected US Voice over DSL market

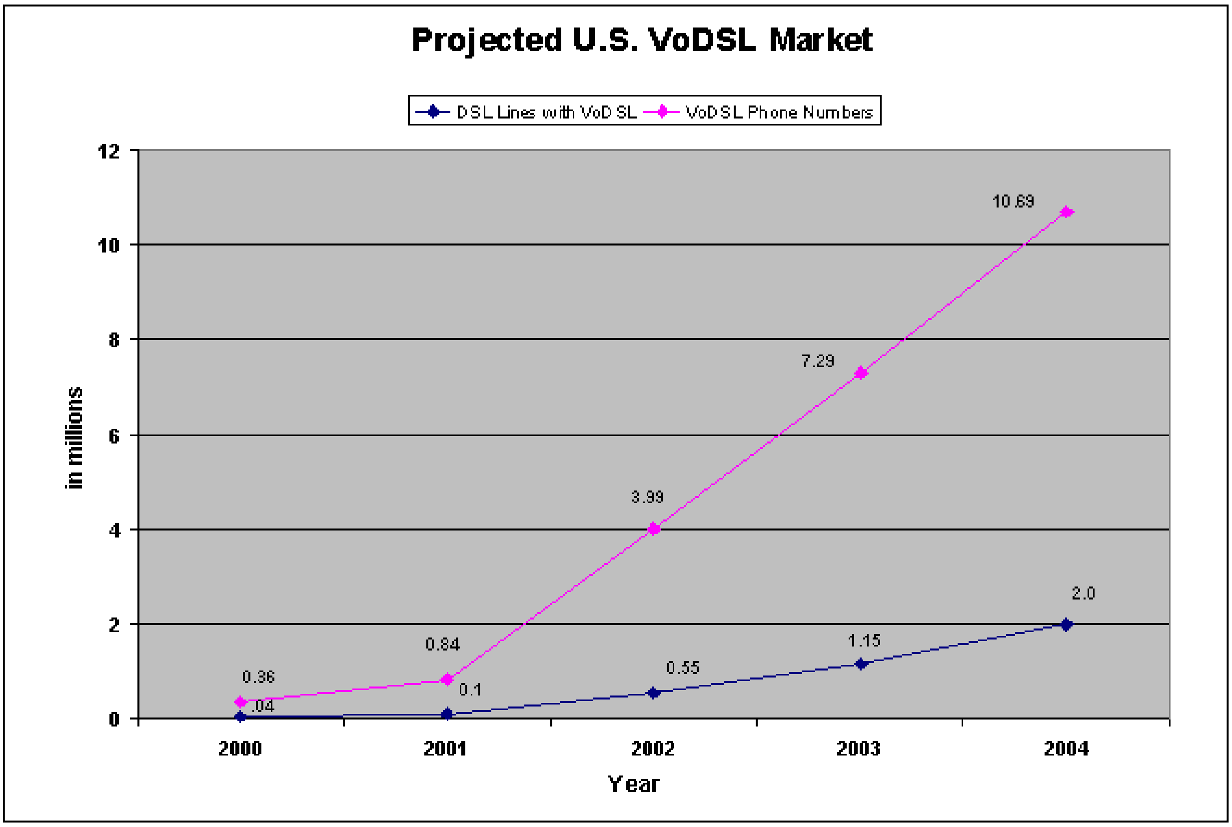
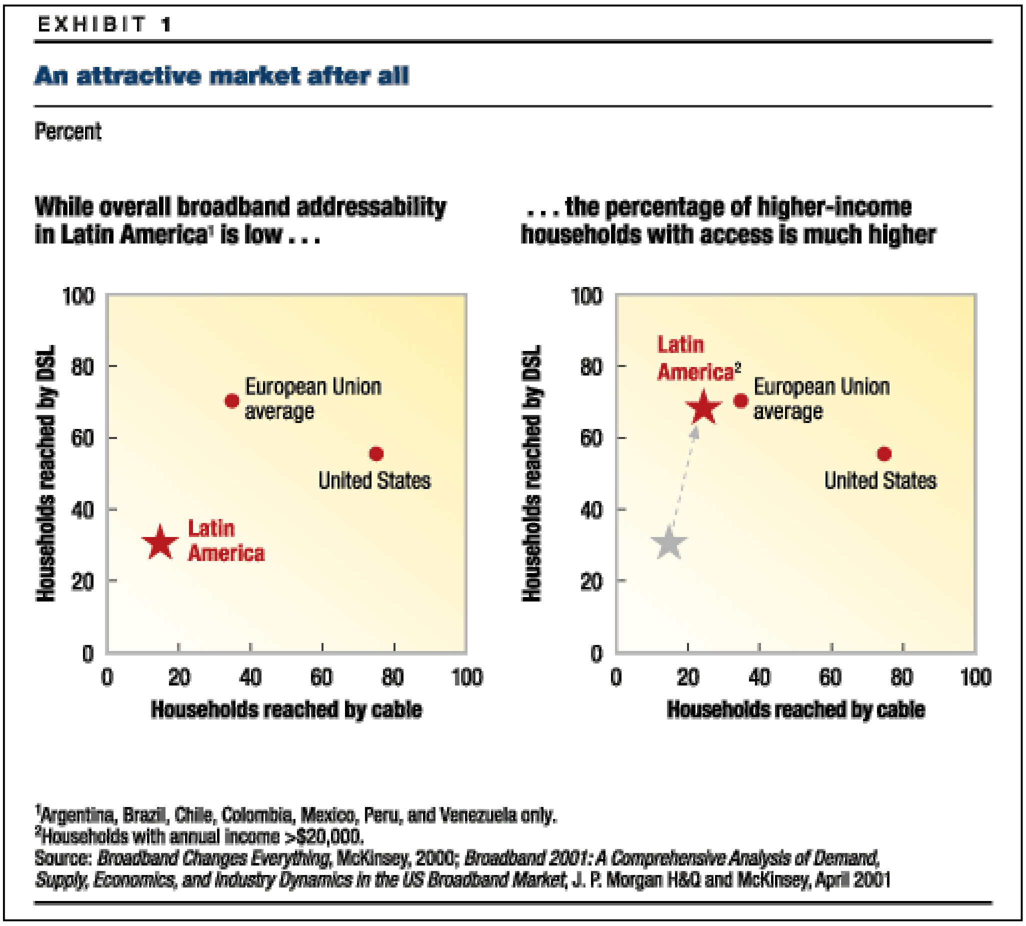


Figure 6.3 shows the percentage of households reached by DSL for the US, European Union and Latin America (Argentina, Brazil, Chile, Colombia, Mexico, Peru and Venezuela). The left diagram indicates the present state and the right diagram the possible future development for Latin American households with annual income higher than USD 20 000.

Figure 6.3 – Households reached by DSL



7 DSL Broadband Service

DSL applications can be roughly divided into residential user and corporate user categories. Over time, in many cases, as work at home and on-line commerce become more prevalent, the distinction between residential and corporate user will blur. The following sub-chapters describe typical DSL services.

7.1 Internet Access

The advent of the World Wide Web has resulted in the phenomenal growth of the Internet over the past years. However, the infrastructure of the Internet has yet to be optimized for transferring the rich graphics common on today's Web sites. The majority of customers accessing the WWW use the Public Switched Telephone Network (PSTN) normally with (V.90) 56 kbit/s modems.

In addition to the bandwidth limitations of analogue access, the switches that make up the PSTN are optimized for short connections that characterize telephone calls rather than calls of several hours that typify Internet access sessions. This problem puts a great deal of strain on the PSTN and potentially threatens the low, fixed pricing model of Internet access.

In addition to expanding bandwidth for Internet access by a factor of over one-hundred, service providers are looking to DSL as a way of keeping Internet traffic off of the PSTN. Although there are various network models, the idea is to shunt traffic from DSL connections off of the local loop directly on to the Internet. POTS splitters at both ends of the local would keep normal telephony service intact.

Another aspect of the Web that makes DSL a compelling access solution is the asymmetric nature of Web-based data communications. In most cases, the only upstream traffic users send to the service provider are Universal Resource Locators (URLs), which are very short text messages that allow the user to move from web page to page. The majority of Web traffic flows downstream in the form of graphic intensive web pages, moderate to large text files, audio files, and even video clips downloaded by the user from web servers. Clearly, ADSL's asymmetric apportioning of bandwidth is optimized for Web access.

7.2 TV/Video-On-Demand (VOD)

ADSL was originally targeted as a way for telephone companies (telcos) to compete with cable companies by delivering TV programming and VOD services to residential customers over the ordinary telephone wires. While VOD did not prove to be the killer application everyone had hoped for, bundled with Internet access, the ROI (return on investment) analysis looks much more compelling. Furthermore, most countries outside of North America do have very small CATV network infrastructures. By delivering TV programming and VOD services bundled with other services, including Internet access and POTS service, ADSL can enable the PTTs of many countries to become a one-stop-shop for communications and content.

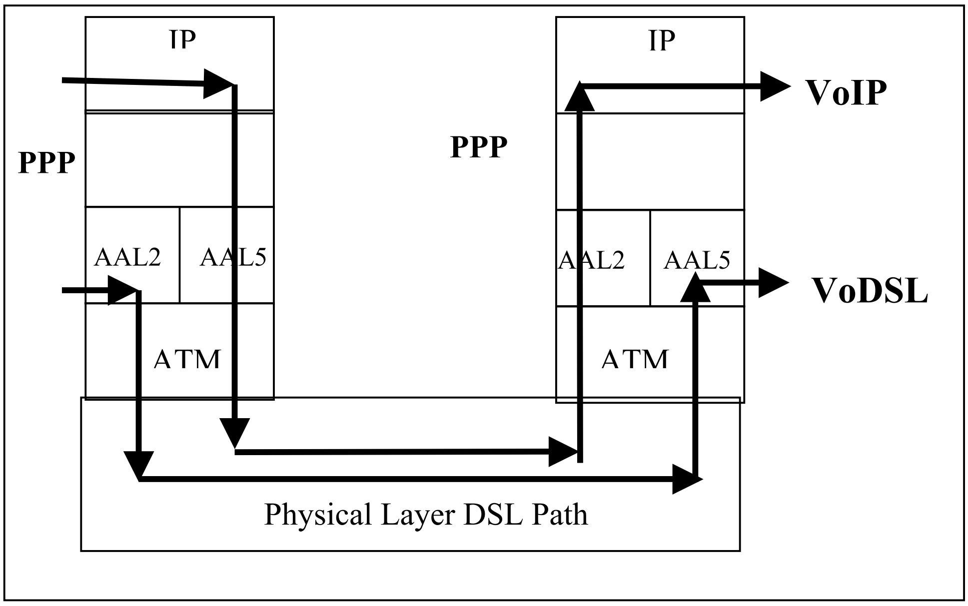
7.3 Voice over DSL

Voice signals can be transmitted in the access network as illustrated in Figure 7.1:

- Plain Old Telephone Service (POTS);
- Voice over ATM using the AAL2 protocol (VoDSL);
- Voice over Internet using the ATM AAL5 protocol, point-to point (PPP) protocol and the Internet Protocol (VoIP).

For the time being VoDSL seems to be the most market-proven way to provide the required Quality of Service (QoS). However, IP is an evolving technology and will therefore in the future match the requirements for voice transmission.

Figure 7.1 – VoDSL Transport Methods



7.4 Leased Line Provisioning

Perhaps the most popular DSL application to date is to greatly reduce the cost of provisioning T1 or E1 leased lines from the CO to the customer's site. HDSL has been used in this way for the last few years and has achieved a great deal success. In the following year, it is expected that SHDSL will replace HDSL in this application since the same performance and reach characteristics can be achieved with only one pair of wires (SHDSL) as opposed to two (HDSL).

DSL technologies, SHDSL in particular, will also give non-telco service providers e.g. VANs (value added networks), ISPs (Internet service providers), and CAPs (competitive access providers) the ability to provision T1 and E1 leased lines themselves, given they have access to the local loop. If these service providers are able to lease subscriber loops ("dark copper") from a particular telco's CO to the customer, as well as lease space for their switching equipment at the CO, then these service providers would be able to provision T1 and E1 leased lines to the customer at very low cost using DSL. It should be noted that, in the US, the recently passed telecommunications reform legislation has been written to allow non-telco service providers access to the local loop and the CO.

7.5 LAN-to-LAN Interconnect

In the legacy host-terminal network environment, wide area bandwidth requirements are modest, requiring only the transmission of keystrokes and textual screen updates. However, as client/server applications continue to take on mission critical tasks of the enterprise, and as they become increasingly bandwidth intensive, cost effective broadband technologies become extremely attractive for linking LANs throughout the enterprise network.

It is the strength of the demand for LAN-to-LAN connectivity solutions that has pushed the Frame Relay services market to above 100% average annual growth over the past three years. DSL technologies is expected to enjoy similar growth over the next several years pushed by the demand to connect LANs at broadband speeds for a fraction of the cost of leased lines. While ADSL is certainly a viable and, in some instances a very attractive technology for LAN-to-LAN connectivity, symmetric technologies such as SHDSL and SDSL will be most popular in this application initially.

7.6 Frame Relay Provisioning

In many of the situations where DSL is used to connect LANs, Frame Relay can be used as the transport mechanism in order to keep the present network architecture in tact, maintain the current network management applications, and ease migration overall. However, provisioning Frame Relay services over DSL has applicability in and of itself for uses outside LAN-to-LAN connectivity such as, integrating legacy data transport and voice transport within the enterprise. This later application is attracting interest in international markets because customers can take advantage of the relatively distance insensitive pricing that characterizes Frame Relay offerings. Essentially, all of the applications that are available using Frame Relay are available when Frame Relay is run over DSL.

The advantages of using DSL as the underlying transport mechanism are:

- Cost – since it can be deployed over an existing telephone line, DSL represents very close to an order of magnitude of cost savings when compared to provisioning a T1 or an E1 for Frame Relay access.

- Increased Bandwidth – at this point, the vast majority of Frame Relay services are limited to T1 or E1 speeds. Using ADSL as a transport technology, Frame Relay could achieve speeds of 6 Mbit/s downstream today.

These costs and bandwidth advantages may enable Frame Relay over DSL to be used in ROBO and possibly even SOHO residential environments.

7.7 Intranet Access

While Internet access will be a critical market for DSL going forward, Intranet access may be more important in the near term. Intranets are private networks that utilize Web-based architectural components (web servers, browser, horizontal linkage, etc.) and Web protocols/languages (TCP/IP, HTML, Java, etc.) to deliver enterprise-wide applications. Many organisations are moving to an Intranet architecture as a way to amalgamate multiple applications, systems, and platforms under the umbrella of a single network architecture. However, Intranet access is at least as, if not more, bandwidth intensive than Internet access. Therefore, ADSL is ideal for enabling organisations to connect telecommuters to the company's Intranet at speeds similar to what they are used to on the corporate LAN. In addition, ADSL can be used to give cheap, high speed Intranet access to remote/branch offices, thus avoiding the expense of installing and maintaining proxy web servers on site at these peripheral offices. Additionally, ADSL can give high speed Intranet access to corporate employees while working from their residence (distance working).

8 DSL Network deployment models

Since DSL is a point-to-point transmission technology functioning primarily at the physical layer, it can support a variety of networking protocols. Most service providers are looking to DSL to serve as the access technology component in a broadband network architecture that will support multiple services and applications. Depending upon the technological or strategic inclination of the specific service provider, the application and/or services delivered, and the market (corporate or residential) for those applications and services, the nature of this new broadband architecture can vary greatly.

8.1 DSL network elements

DSL networks contain network elements such as:

DSL transceiver

for sending and receiving of DSL modulated line signals.

Splitter

for separating of DSL line signals and POTS signals.

Router

is a switching device in a packet-switched network that directs and controls the flow of information through a data network. Router configurations are used e.g. to connect DSL lines to PC or LAN.

Voice Gateway

provides translation of the voice traffic from the circuit – switched public network to the packet-based network and vice versa.

DSL Access Multiplexer (DSLAM)

for statistical multiplexing/demultiplexing. A DSLAM performs a minimum of protocol processes without local switching or routing functions and is located normally within or in the vicinity of Central Offices. Typical DSLAM configurations can be used for the concentration of 200 – 500 ADSL lines into a 34 Mbit/s signal transmitted via ATM. Recent DSLAM configurations may contain additional functions leading to the concept of Integrated Access Devices.

Integrated Access Device (IAD)

contains DSLAM functionalities augmented with additional functions such as e.g:

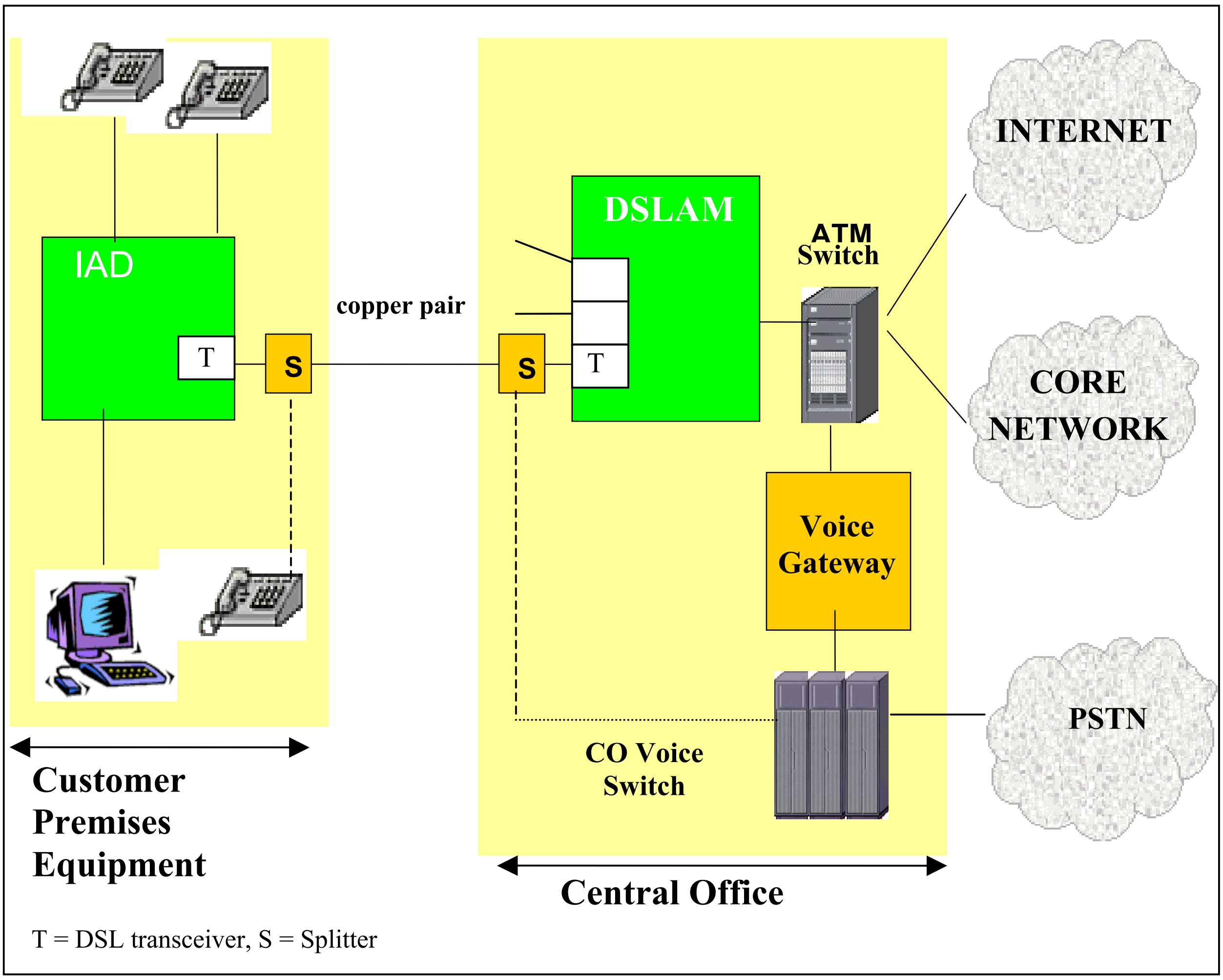
analogue/digital conversion, switching and routing, QoS control for voice, data and ISDN, internet connection to PC and LAN, dynamic bandwidth allocation, echo cancellation and compression, firewall functions, different interface facilities (with wire and wireless) and remote management facilities. IAD configurations are designed for different DSL systems, e.g. for ADSL and SHDSL.

Figure 8.1 shows a typical DSL based network architecture. The Customer Premises Equipment (CPE) contains analogue Telephones, PC, splitter and IAD. The Central Office contains DSLAM, Splitter, ATM switch, Voice switch and Voice Gateway. As the CPE and CO located equipment can be delivered from different vendors interoperability has become an important item. Two kinds of interoperability are studied for the time being:

between IAD and Voice Gateway, and

between the chipsets used in IAD and DSLAM

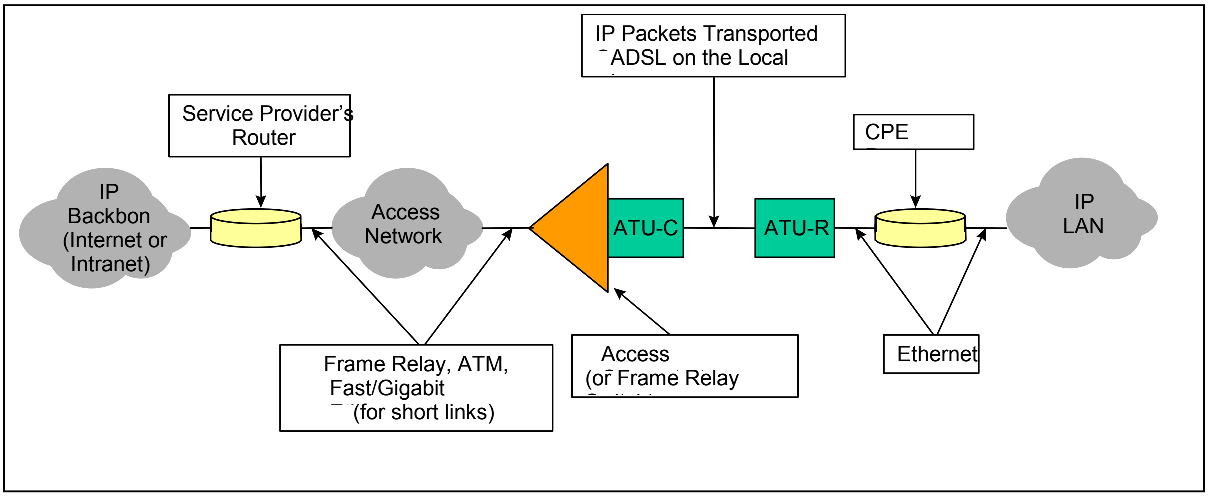
Figure 8.1 – Example of DSL Network Architecture



It is important to understand that, at this stage, there is little consensus regarding which network architecture or model is most appropriate to support DSL technologies as an access technology and that there are several permutations of the basic models outlined here.

8.2 Internet Protocol Model

Figure 8.2 – IP Model



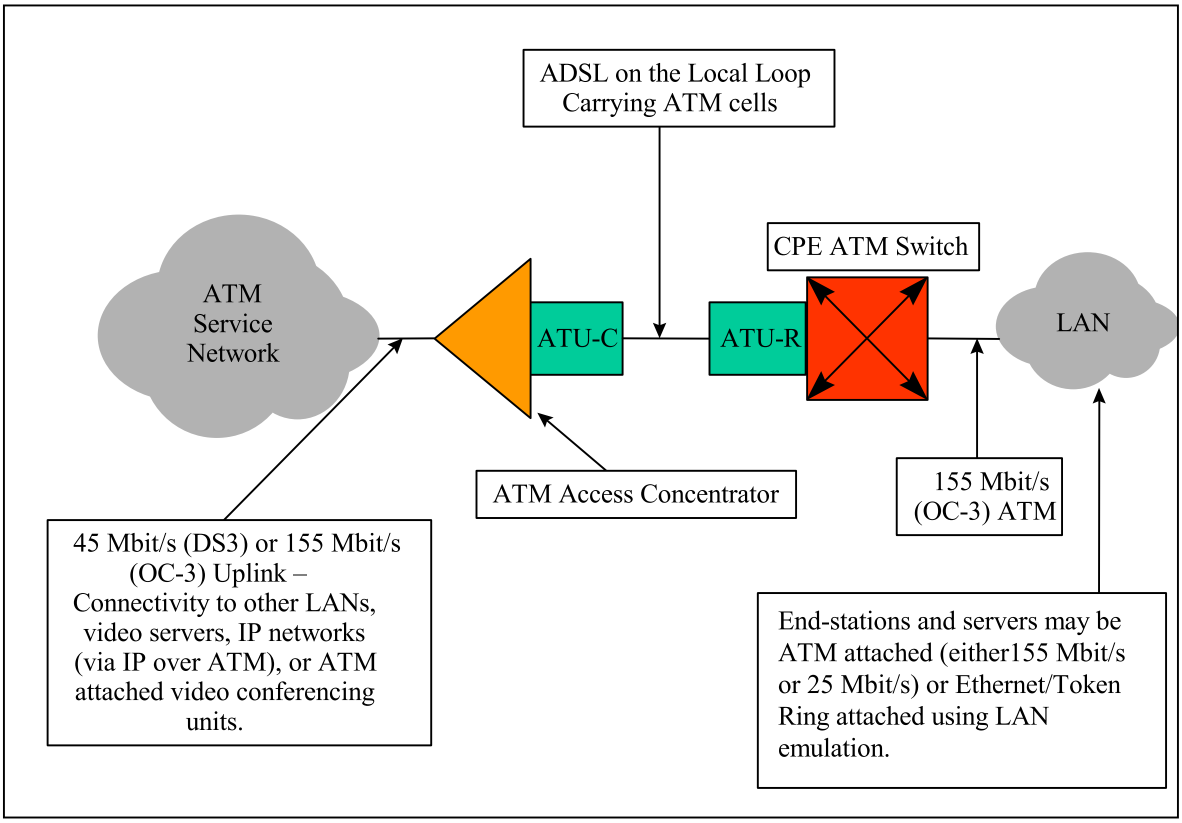
Using ADSL as a transport mechanism for IP traffic is the obvious choice for Internet access applications but the model depicted is only one of many possible versions of this model. In addition, the IP model can also serve other applications as well such as Intranet access, LAN-to-LAN connectivity, and others. The ATU-C is an ADSL transceiver for the central office. The ATU-R is an ADSL transceiver for the remote site.

While several intermediary protocols, such as Frame Relay or ATM could be used between IP and ADSL, the ADSL Forum has also specified transporting IP packets directly over ADSL without the use of an intervening protocol. This scenario can be seen as similar to running IP directly over a physical layer transport mechanism such as SDH or SONET. In this case, a router or a device with integrated routing would be necessary at the CO, rather than an access concentrator or switch operating only at layer two.

Depicted above in Figure 8.2 is a corporate user application. IP can also be used, of course, for residential applications. In this case, a personal computer or, perhaps, an Internet TV is located on the ATU-R side of the ADSL line (the ATU-R may reside in the PC's bus or be connected to the PC via Ethernet) and access to the IP network is established via a PPP (Point-to-Point Protocol) over ADSL connection.

8.3 ATM End-to-end Model

Figure 8.3 – ATM Model



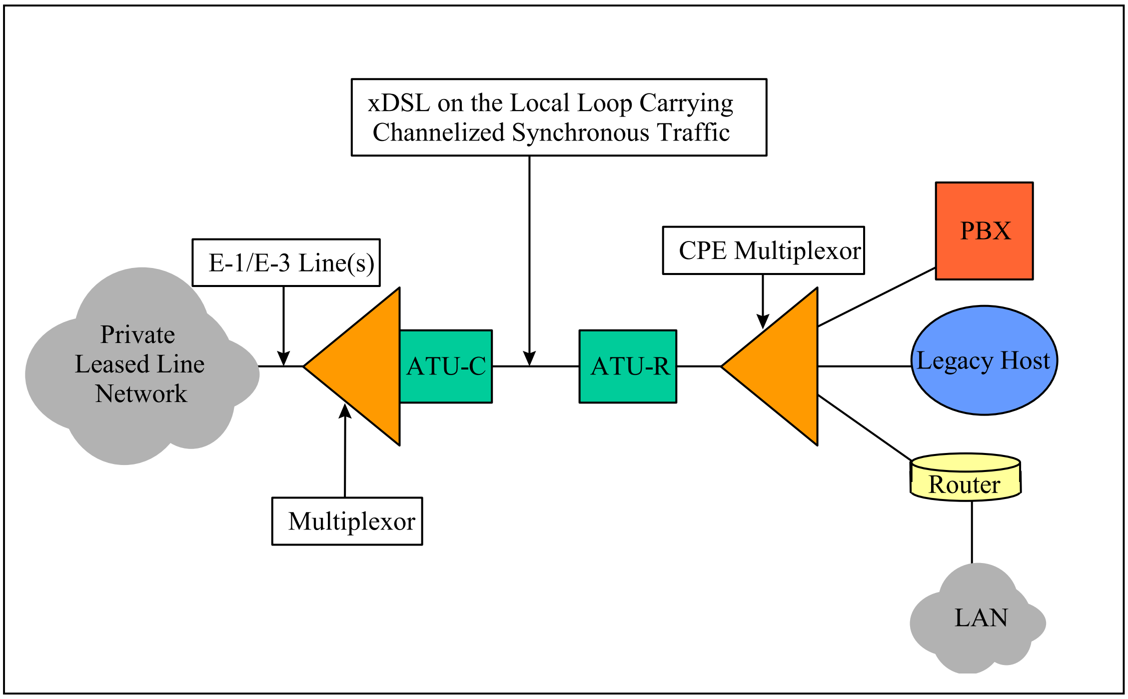
Due to the fact that ADSL provides a dedicated connection of relatively high bandwidth, it may also be used to extend the ATM network and, therefore, the Quality of Service (QoS) properties of ATM all the way to the desktop. The ADSL Forum has specified how ATM cells are transported over ADSL, essentially the ATM User Network Interface (UNI) tunnelled through the ADSL line.

By having desktop applications talk directly to the ATM network, bandwidth can be reserved (and guaranteed) end-to-end across the network. This facilitates the deployment of isochronous, delay sensitive applications such as voice, video conferencing, etc. The release of Windows 98 will include an API, Winsock 2, which will allow applications to request QoS from the ATM network.

However, ATM, particularly ATM operating at speeds below 25 Mbit/s, exacts a fairly high overhead and, therefore, may not be justified by many applications that do not have stringent QoS requirements or are able to function with the non-guaranteed QoS services offered by protocols such as RSVP (ReSerVation Protocol). In addition, many large organisations that would require ATM service may be better off subscribing to a 34/45 Mbit/s (DS-3) or 140/155Mbit/s (OC-3) ATM service operating over fibre rather than transporting ATM cells over multiple ADSL lines. Finally, to the degree that organizations are interested in ATM service for peer-to-peer applications such as video conferencing, the asymmetric apportioning of bandwidth under ADSL would not be optimal. Figure 8.3 illustrates an ATM end-to-end model.

8.4 Circuit-Switched Model

Figure 8.4 – Circuit Switched Model



As mentioned earlier, DSL technologies can be used simply to drastically reduce the cost of leased line provisioning. In this way, DSL technologies can be smoothly integrated into existing network architectures that are based on private, leased lines using Time Division Multiplexing (TDM) technology, as illustrated in Figure 8.4.

9 DSL towards Global Information Infrastructure

The Global Information Infrastructure (GII), is an architectural concept developed by ITU-T SG13, aiming at enabling people to use a set of communication services supporting a multitude of applications and embracing all modes of information, at any time, anywhere, at acceptable costs and quality. The implementation of the GII involves the connection of a number of implemented components. These include the following:

Information appliances – equipment which allow users to gain access to the GII and/or which can mount, invoke and handle software modules including the software modules which are databases and video libraries. Examples include PCs, Set Top Boxes (STBs), network computers, mini and mainframe computers, file and video servers, transaction processors, and in a more restricted way, the telephone, TV and fax machine.

Middleware software modules – software modules which contain middleware functions. Middleware software modules run on information appliances; application software modules – software modules which contain application functions. Application software modules run on information appliances.

Segments of telecommunications networks – segments of the telecommunications network which connect together information appliances and allow middleware functions and application functions which are mounted on different information appliances to communicate with each other. These segments include access segments, core segments, enhanced service provisioning segments and management segments.

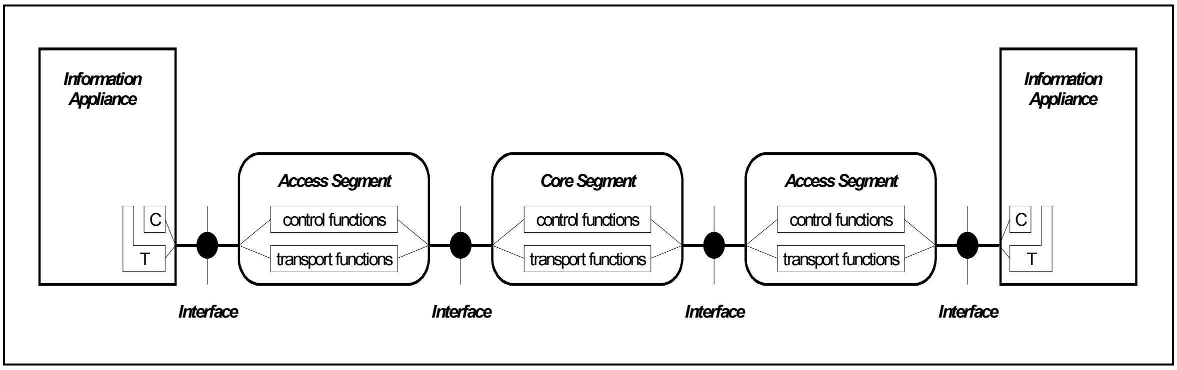
Each of these are segments in the implementation module and are interconnected with interfaces. The interfaces between information appliances and access segments of telecommunications network are physical telecommunications interfaces, as are the interfaces between access segments and core segments. Their specification is derived by the process illustrated in Figure 9.1 with physical interface information added. For example, in the interface between an information appliance and an access segment, the logical interface information between the functions in the information appliance and the functions in the access segment are combined to form the basic interface specification and the physical interface aspects are also added.

Other interfaces are either programming interfaces which are internal to information appliances or protocols which are transparent across the telecommunications networks. These implementation interfaces therefore are not physical interfaces and their specification can be derived directly from the logical interfaces in the functional model by the process illustrated in Figure 9.1.

The nature of information appliances, middleware software modules and application software modules is for further study. The following sections describe aspects of segments of telecommunications networks in the GII.

Figure 9.1 illustrates two information appliances connected by a telecommunications network with three segments, two access segments and a core segment. The information appliances, the access segments and the core segment are technology and implementation dependent, however, the delivery of a particular service will require a certain set of GII functions to be implemented in each of these segments.

Figure 9.1 – Information appliances connected by telecommunications network segments



C = Control Functions, T = Transport Functions

9.1 Structuring of implementation possibilities

For each of the generic segments listed, there are a large number of possible implementations and a large number of interfaces can be used to interconnect them.

Examples of information appliances:

personal computer (PC)
set top box (STB)
network computer
mini computer
mainframe computer
file/video server
transaction processor (e.g. SCP)
telephone
TV
fax machine

Examples of access segments:

PSTN/ISDN copper access network
DSL copper access network
cable TV network
direct fibre access network
passive optical network
radio in the loop (RITL) access network
digital mobile access network (e.g. GSM)
terrestrial broadcast TV network
direct broadcast satellite network
geostationary-satellite access networks (e.g. Inmarsat)
medium- and low-Earth orbit satellite access networks

Examples of core segments:

PSTN/ISDN core network
PSDN core network
X.25 packet network
frame relay network
SMDS network
B-ISDN network
leased line network
Internet

Examples of information appliance to access segment interfaces:

PSTN interface
basic rate and primary rate ISDN interface
Ethernet interfaces
token ring interface
B-ISDN interfaces
DVB satellite air interface
GSM mobile air interface
geostationary-satellite access network air interface
medium- and low-Earth orbit satellite network air interfaces

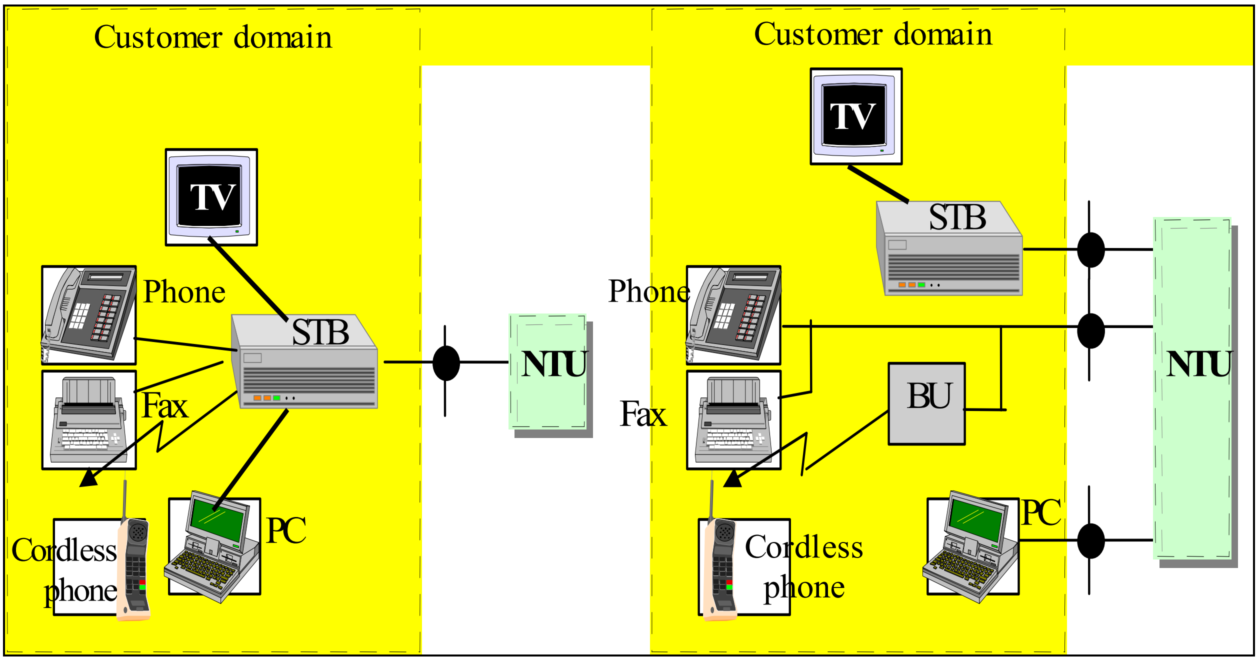
Some examples are selected in the following sections to demonstrate how implementation examples can be constructed based on these segments. The examples concentrate mainly on information appliance, the access segment and the interface between them.

9.2 Information appliance configurations

The configuration shown in Figure 9.2 is related to the information appliances of an end user in the residential environment. The configuration contains a combination of a fixed analogue phone, a cordless telephone, a fax machine, a PC and a STB connected to an analogue TV. The applications are assumed to require GII capabilities including, voice telephony, data transport and interactive multimedia capabilities.

The following two alternative solutions illustrate how such an end user might configure their information appliances for connection to an access segment (terminated with an NTU in these examples). In the first example all the information appliances are connected to the access segment through the STB. In the second example, there are separate interfaces for the phone/fax, the PC and STB/TV.

Figure 9.2 – Examples of a residential end user's information appliances



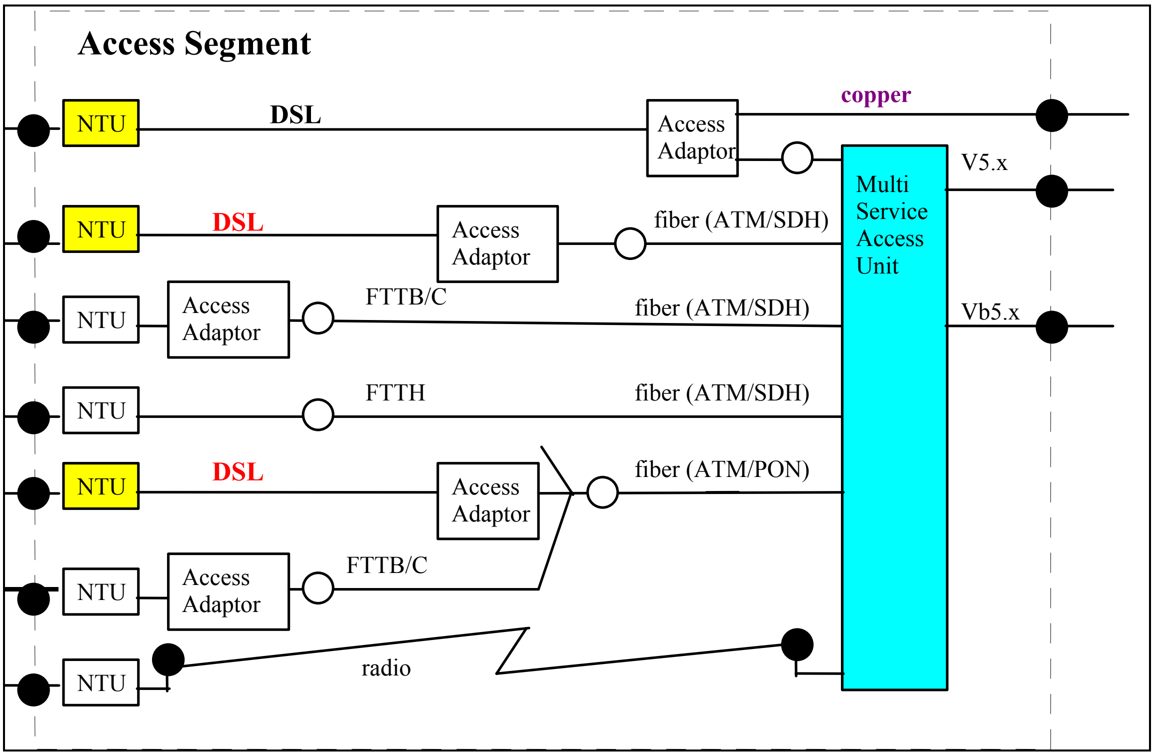
The Network Termination Unit (NTU) is part of the access segment and depending on the network implementation, the end user's information appliances can be supported via one or more access segments. In the example, the TV could be connected via a cable TV network while the phone, the fax machine, and PC could be connected via an ISDN 2B+D access. In this case there would be no backward channel in the cable TV network and so interactivity would be achieved via the ISDN access.

9.3 Access segment configurations

There are a large number of access segment configurations which are possible and these will depend largely on the technology used, governed primarily by the physical media. This could be copper pair, coax, fibre, terrestrial radio or satellite. While many access segments are implemented with only one physical media, other access segments will use a combination of these media.

A fixed network access segment is built mainly on copper pairs and a combination of copper and fibre. In certain areas, however, radio in the loop might be used. The configuration of such an access segment is illustrated in Figure 9.3.

Figure 9.3 – A fixed network access segment configuration



9.4 GII Scenarios Methodologies (Y.120 reference models)

According to the provisions contained in the ITU-T developed GII, the scenarios methodology is here depicted in order to:

a) facilitate the identification of key interface points in a scenario;

b) facilitate classification of interfaces by an appropriate taxonomy scheme;

c) facilitate identification of services that can be carried across such interfaces;

d) facilitate classification of services by an appropriate taxonomy scheme;

e) facilitate identification of end points for service delivery;

f) facilitate investigation of interplay between all components;

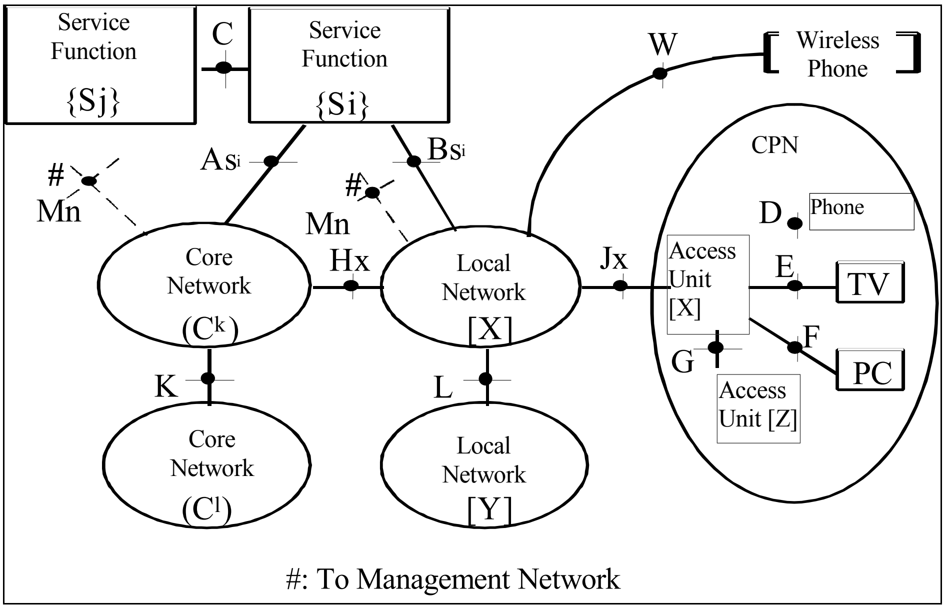
g) accommodate the protocols involved, either directly or indirectly, at a given interface;

h) be generic enough to facilitate scenario development across all technologies and Standards Development Organisations areas.

The scenario technique is also applicable to application requirements as well as network requirements. An interface occurs between any point where two components need to communicate.

Application requirements can be included in the scenarios. The scenarios are primarily oriented towards provision of voice, data and video services. Example scenarios to meet other applications requirements, such as transaction processing, distributed computing, imaging etc. need to be similarly developed.

Figure 9.4 – The generic reference model of the GII (Scenarios methodology according to Annex A to Y.120)



Components:

- Service Function: such as Video Server and Video Service Provider for video service, and IP Router and Point of Presence for Internet service;
- Core Network: such as Telecommunication Network, PSTN, N-ISDN, B-ISDN;
- Local Network: such as CATV Network, ADSL/VDSL, Fibre Network, RITL, Satellite and including access networks as described in the main part of the recommendation;
- CPN (Customer Premises Network): such as Access Unit, TV, PC, Phone, Wireless Phone:

  {S_i, S_j*} means the kind of services;

  (C_k, C_l*) means the technology of core network;

  [X, Y*] means the technology of local network (access technology).

Interface Points:

- As: between Service Function and Core Network (s: kind of service);
- Bs: between Service Function and Local Network (s: kind of service);
- C: between Service Functions;
- W: Terminal Interface for Wireless Phone;
- D: Terminal Interface for Phone;
- E: Terminal Interface for TV;
- F: Terminal Interface for PC;
- G: between Access Units;
- Hx: between Core Network and Local Network (x: kind of access technology);
- Jx: between Local Network and CPN (x: kind of access technology);
- K: between Core Networks;

- L: between Local Networks;
- Mn: between Core/Local Network and Management Network (n: kind of network).

Scenarios:

1) Provision of Voice/Data/Video Service over existing infrastructure;
2) Provision of Voice/Data/Video Services over Cable Networks using B-ISDN;
3) The use of ADSL or VDSL to provide video bandwidth over copper pairs;
4) Fibre Access Scenario;
5) The use of Radio in the Local Loop;
6) Access using satellites;
7) Example of Internet Access.

9.4.1 Voice/Data/Video over copper pairs

Figure 9.5 – Logical representation

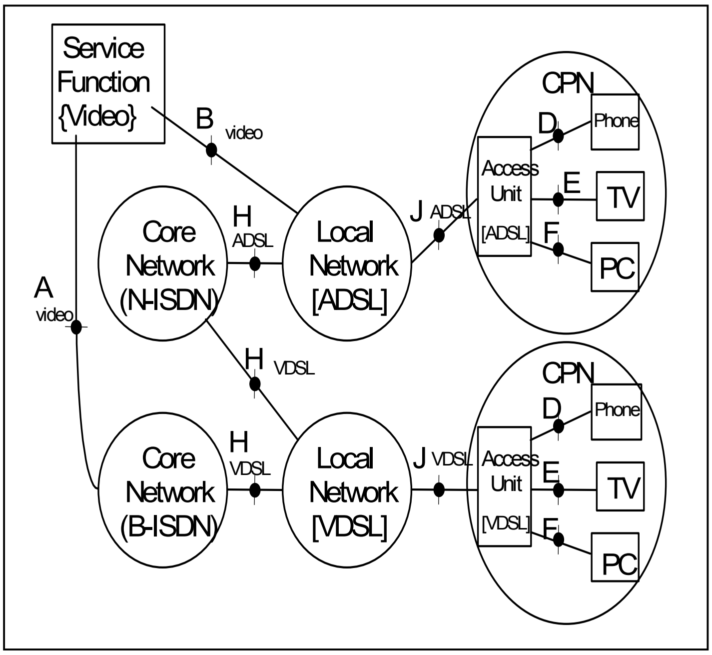


Figure 9.5 shows the logical and Figure 9.6 the physical representation for voice/data/video over copper pairs.

Service function: Video Server

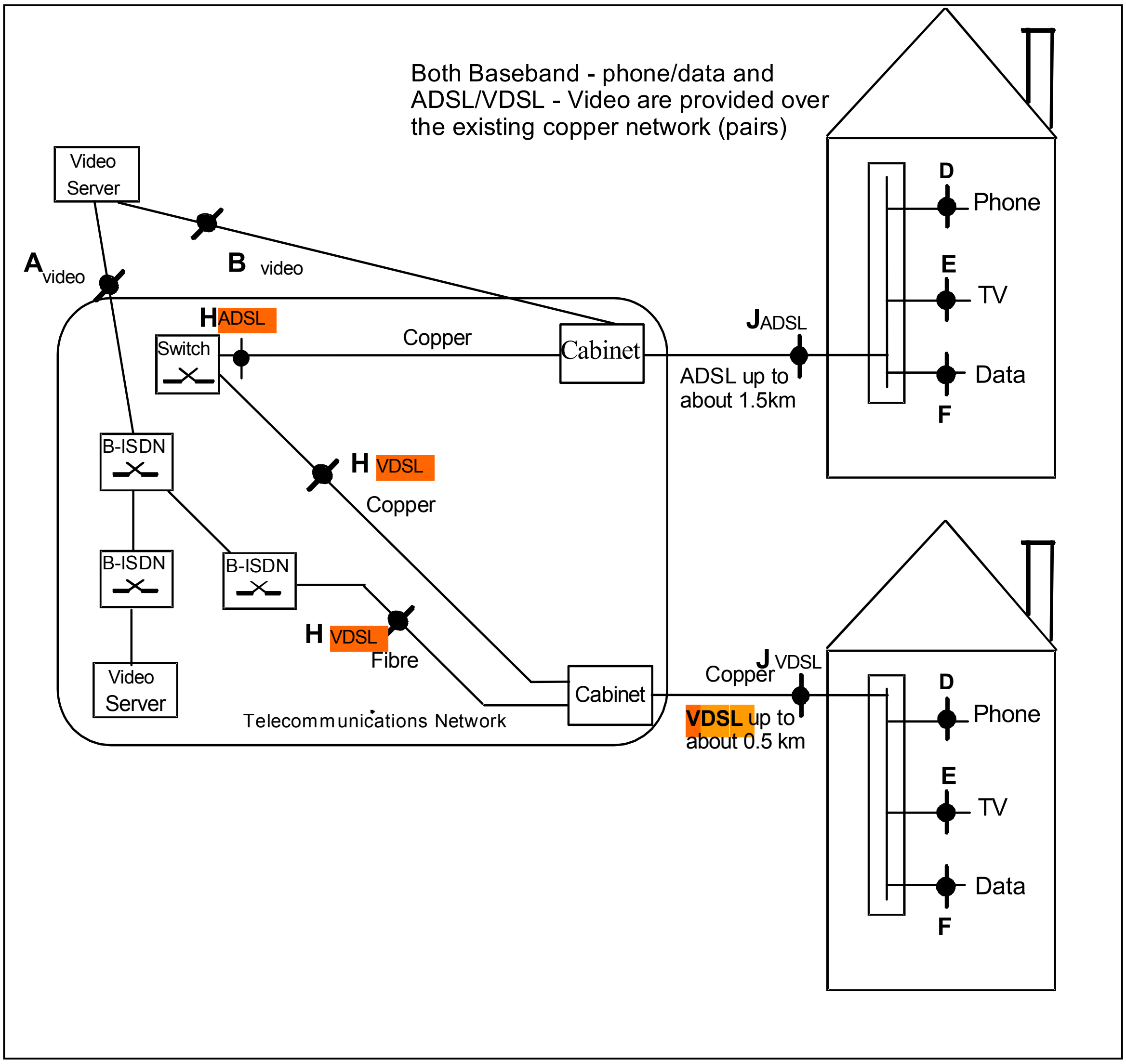
Core network: B-ISDN

Local network: ADSL, VDSL

CPN: TV, PC, Tel Terminal

Access unit for ADSL, VDSL

Figure 9.6 – Physical Representation



Video services can be delivered to the customer's premise:

a) from BVIDEO via JADSL;

b) from the video servers via BVIDEO, HADSL and HVDSL to the cabinet and then via JVDSL, or

c) from the video server via AVIDEO and HVDSL to the cabinet and then via JVDSL.

Control information for video services may be exchanged:

a) via JADSL to the video server via BVIDEO;

b) via JVDSL, HVDSL, HADSL and BVIDEO to the video server, or

c) via JVDSL, HVDSL and AVIDEO to the video server.

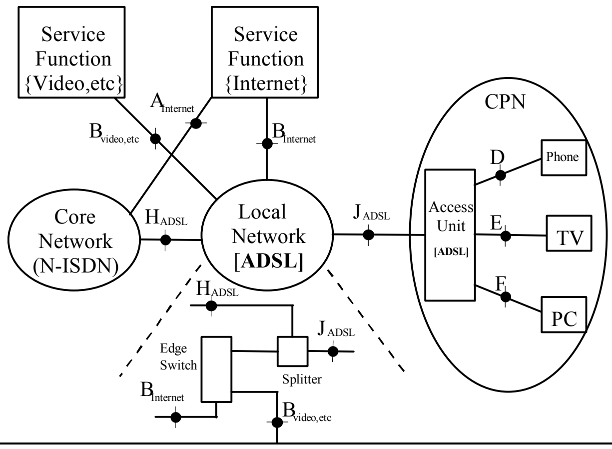
9.4.2 Voice/Data/Video over internet

Figure 9.7 shows the logical and Figure 9.8 the physical representation.

The broadband data traffic from the Internet point of presence comes through high-speed ATM or Frame Relay connections to an edge device; it is transmitted to residential (or business) premises via e.g. ADSL connections. Analogue telephone traffic from the exchange of the local network is combined and separated at both ends of the ADSL link.

Figure 9.7 – Logical Representation

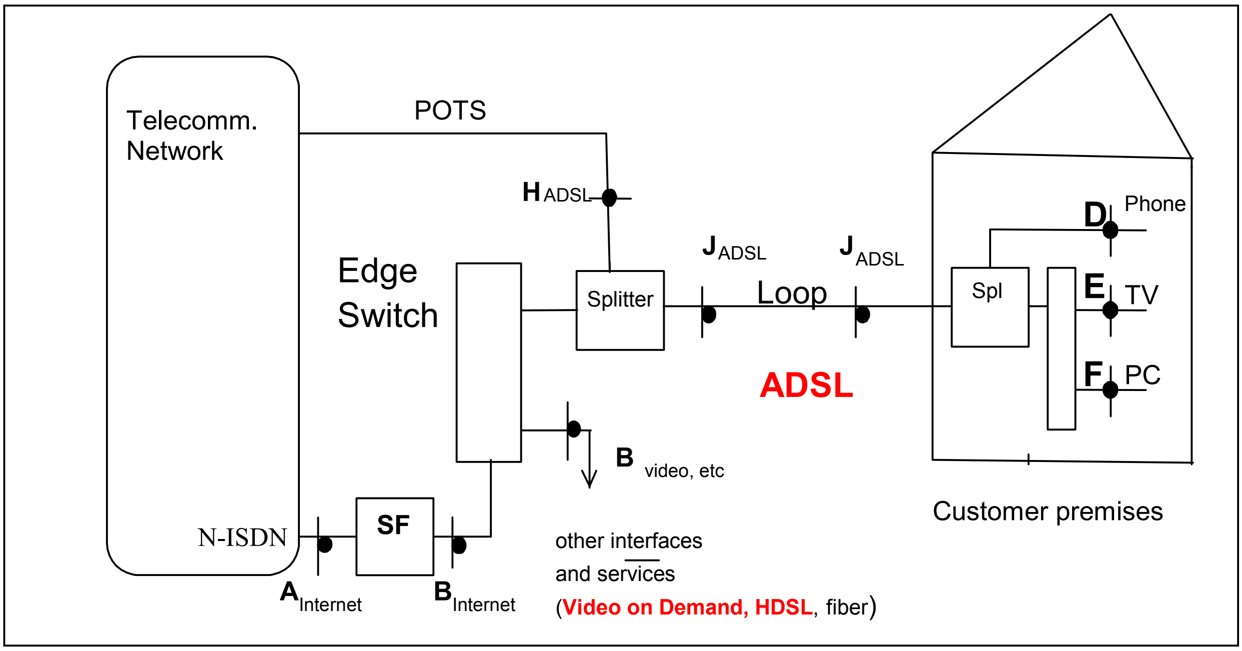
Logical presentation:



Components:

- Service Function: Video on Demand, POP/ IP-Router
- Core network: N-ISDN, POTS, ATM, Frame Relay
- Local Network: ADSL
- CPN: TV, PC, Tel Terminal
  Access Unit for ADSL

Figure 9.8 – Physical Representation



SF = Service Function

The described scenarios are summarized in the table below:

	Scenario SDL	Scenario Internet
Services	Voice/Data & Video over ADSL/ VDSL	a) Data over Internet b) Voice/Video and/or Data over Internet
Core Network	B-ISDN	1) POTS/FR/ATM 2) ATM Backbone
Local Network	ADSL/ SHDSL	1) ADSL 2) PSTN/ISDN, HFC, PON
CPN	Access Unit TV, PC, Phone	Access Unit TV, PC, Phone
Information Flow		

10 Conclusion

The DSL family of technologies provide a wide variety of schemes to accomplish and satisfy different market needs for present and future infrastructures. DSL has applications in both the corporate and the residential environments, leading to a plethora of possibilities. The market needs and DSL technologies are still evolving. There is no single tool to build a house. In the context of DSL, whether two pair, single pair, asymmetric, symmetric, rate-adaptive, or multi-channel, digital subscriber loop technologies are all tools to be utilised in building a service. DSL has the flexibility to meet the market challenges.

ANNEX 1

Overview of ITU Digital Subscriber Line (DSL) Recommendations

The family of DSL Recommendations includes the following Recommendations: G.992.1, G.992.2, G.991.1, G.991.2, G.994.1, G.995.1, G.996.1 and G.997.1.

Recommendations G.991.1, G.992.1, G.992.2 have developed techniques for transmitting a range of bit rates over the existing copper local network from relatively short distances at high bit rates, and to long distances at relatively low bit rates.

Recommendations G.994.1, G.996.1, and G.997.1 support the Recommendations G.992.1, G.992.2 and later G.991.2 by providing common handshake, management and testing procedures.

1 G.991.1 (ex-G.hdsl): High Bit Rate Digital Subscriber Line (HDSL) Transceivers

This Recommendation specifies a “High bit rate Digital Subscriber Line” (HDSL) transceivers which is a bi-directional and symmetrical transmission system that allows the transport of signals with a bit rate of 1544 kbit/s or 2048 kbit/s on the copper twisted pairs of an access network.

G.991.1 describes the HDSL transmission technique as a means for the transportation of several types of applications. The Recommendation defines the requirements for the individual HDSL transmission system, the transmission performance, the HDSL maintenance requirements and procedures.

An individual HDSL transceiver system is a two-wire bi-directional transceiver for metallic wires using the echo cancellation method. Three systems may be utilized, one transporting a bit rate of 784 kbit/s over each of two or three pairs used in parallel, a second with an increased bit rate of 1 168 kbit/s and two pairs in parallel only and a third with a more increased bit rate of 2 320 kbit/s on one pair only.

2 G.991.2 (ex-G.hsdsl): Single-Pair High-Speed Digital Subscriber Line (SHDSL) Transceivers

SHDSL (earlier term: high-speed digital Subscriber Line Transceivers) is envisioned to deliver symmetric service on a single pair of wires as an improvement of the G.991.1 technology that requires two or three copper pairs. In addition to maximum data rates of 1.5-2.3 Mbit/s instead of 784 kbit/s (3 pairs) to 1.2 Mbit/s (two pairs).

This Recommendation describes a transmission method for providing Single-Pair High-Speed Digital Subscriber Line (SHDSL) service as a means for data transport in telecommunications access networks. SHDSL transceivers are designed primarily for duplex operation over mixed gauge two-wire twisted metallic pairs. Four-wire operation may be supported for extended reach applications and optional signal regenerators for both single-pair and two-pair operation are specified, as well. SHDSL transceivers are capable of supporting selected symmetric user data rates in the range of 192 Kbit/s to 2 304 Kbit/s using a Trellis Coded Pulse Amplitude Modulation (TC-PAM) line code and ranging from 1.8 up to 6.5 km. Fractional data rates of n × 128 kbit/s are proposed for longer loops, noisier environments, or service requirements.

SHDSL transceivers are designed to be spectrally compatible with other transmission technologies deployed in the access network, including other DSL technologies. SHDSL transceivers do not support the use of analogue splitting technology for coexistence with either POTS or ISDN. Regional requirements, including both operational differences and performance requirements, and requirements for signal regenerators are specified in various Annexes to the Recommendation.

The Recommendation does not specify all the requirements for the implementation of SHDSL transceivers. Rather, it serves only to describe the functionality needed to assure interoperability of equipment from various manufacturers. The principal characteristics of the Recommendation are as follows:

- provisions for duplex operation over mixed gauge two-wire or optional four-wire twisted metallic pairs;
- specification of the physical layer functionality, e.g., line codes and forward error correction;
- specification of the data link layer functionality, e.g. frame synchronisation and OAM data;
- provisions for optional use of repeaters for extended reach;
- provisions for spectrum compatibility with other transmission technologies deployed in the access network;
- provisions for regional requirements, including functional differences and performance requirements.

The target applications that have been proposed, up to now, for G. 991.2 are: Fixed-rate network services, including:

- ISDN PRI or multiple ISDN-BA transport;
- voice trunks to wireless cell sites;
- T1/E1 transport;
- fractional T1/E1 transport;
- multiple POTS transport.

High-speed business-class voice and data services, including:

- LAN interconnection;
- TCP/IP/PPP/ATM transport for Internet access Frame relay or ATM from or between business sites;
- video conferencing;
- interactive multimedia;
- remote learning;
- advanced data base services.

3 Recommendation G.992.1 (ex-G.dmt): Asymmetric digital subscriber line (ADSL) transceivers

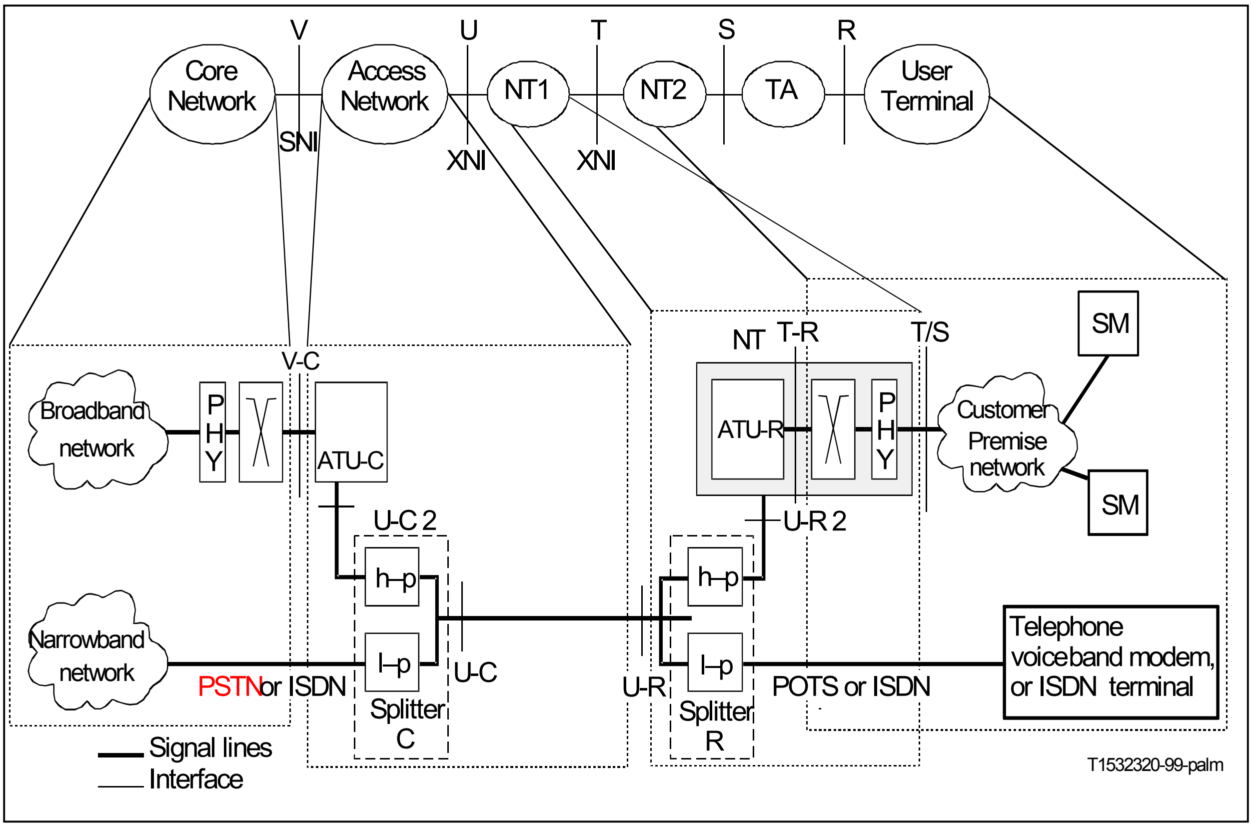
Recommendation G.992.1 describes Asymmetrical Digital Subscriber Line (ADSL) Transceivers on a metallic twisted pair that allows high-speed data transmission between the network operator end (ATU-C) and the customer end (ATU-R). Systems allow approximately 6 Mbit/s downstream and approximately 640 kbit/s upstream data rates depending on the deployment and noise environment.

This Recommendation specifies the physical layer characteristics of the Asymmetrical Digital Subscriber Line (ADSL) interface to metallic loops and Figure 1 gives a system reference model.

This Recommendation has been issued to help ensure the proper interfacing and inter-working of ADSL transmission units at the customer end (ATU-R) and at the network operator end (ATU-C). A single twisted pair of telephone wires is used to connect the ATU-C to the ATU-R. The ADSL transmission units must deal with a variety of wire pair characteristics and typical impairments (e.g. crosstalk and noise).

An ADSL transmission unit can simultaneously convey all of the following: downstream simplex bearers, duplex bearers, a baseband analogue duplex channel, and ADSL line overhead for framing, error control, operations, and maintenance.

Figure 1 – System Reference Model for G.992.1



4 Recommendation G.992.2 (ex-G.lite): Splitterless asymmetrical digital subscriber line (ADSL) transceivers

Recommendation G.992.2 describes the interface between the telecommunications network and the customer installation in terms of their interaction and electrical characteristics. G.992.2 allows the transmission of POTS and V-series data services simultaneously with a digital channel over a single mixed gauge twisted metallic pair. The Recommendation also defines the procedures to operate in a TCM-ISDN noise environment.

The Recommendation includes procedures to allow provisioning without the need for “splitters”, typically installed at the ingress to the customer premises. Additionally, power management procedures and link states are specified to achieve power savings at the central office and customer premises.

The transmission system is designed to operate on mixed gauge two-wire twisted metallic pairs over the existing copper facilities and over the customer premises wiring. These transceivers are mostly addressed to a residential use and are a simplified versions of G.992.1 to allow a “plug-and-play” solution.

A G.992.2 transmission unit can simultaneously convey a downstream and upstream simplex bearer, a baseband analogue duplex channel, and ADSL line overhead for framing, error control, operations, and maintenance. G.992.2 supports a maximum of 1.536 Mbit/s downstream and 512 kbit/s upstream net data rates.

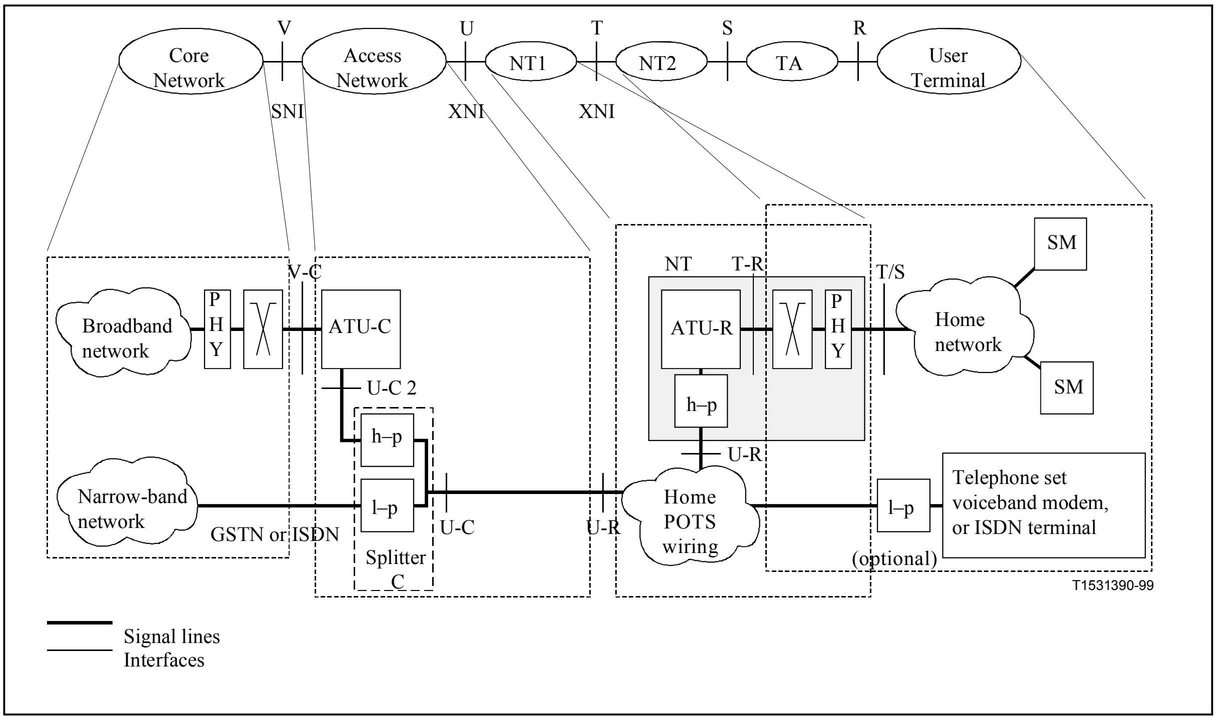
The system reference model for G.992.2 shown in Figure 2 illustrates the functional blocks required to provide this type of ADSL service.

5 G. 993.1(G.vdsl) – Very-high-speed digital subscriber line foundation

VDSL systems address asymmetric rates up to 51 Mbit/s and symmetric rates up to 26 Mbit/s via a single pair of wires optimized for high rate and short range. The upstream speed is within 1.6, 2.3, 19 Mbit/s or equal to downstream in case of symmetric transmission. The distance covered by these systems is around 300 – 1500 m. depending on the bit rate.

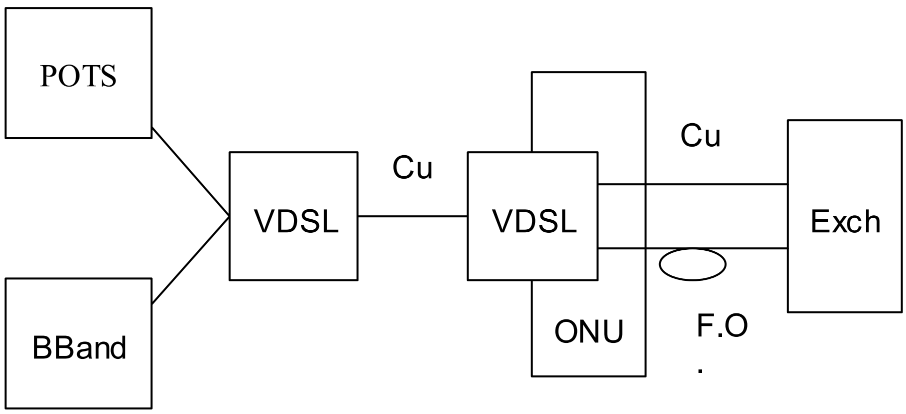
VDSL only covers the link between the cabinet and the customer premises, for this reason VDSL requires a Fibre to the Node architecture with an Optical Network Unit (ONU) sited in the existing metallic access network (or at the serving Local Exchange or Central Office) for the broadband data transport between the exchange and the cabinet. This architectural model as shown in Figure 3 covers both short – and long-range options for the VDSL fibre optic connections.

Figure 2 – System Reference Model for G.992.2



NOTE: An optional ATU-R splitter may be utilized to isolate customer premise wiring and voice-band equipment from the ADSL signal.

Figure 3 – VDSL connection scheme



6 Recommendation G.994.1 (ex-G.hs): Handshake procedures for digital subscriber line (DSL) transceivers

G.994.1 defines signals, messages and procedures for Digital Subscriber Line (DSL) equipment, when the modes of operation of the equipment need to be automatically established and selected, but before signals are exchanged which are specific to a particular DSL Recommendation.

The principal characteristics of G.994.1 are as follows:

- use over metallic local loops;
- provisions to exchange capabilities information between DSL equipment for identifying common modes of operation;
- provisions for DSL equipment at either end of the loop to select a common mode of operation or to request the other end to select the mode;
- provisions for exchanging non-standard information between DSL equipment;
- provisions to exchange and request service and application related information;
- support for both duplex and half-duplex transmission modes.

7 Recommendation G.995.1 – Overview of digital subscriber line (DSL) recommendation

The ITU-T Recommendation G.995.1 provides the necessary guidance and an overview of the DSL family of Recommendations. It describes how the various DSL Recommendations are related. It also defines a generic system reference and a protocol reference configuration for DSL Recommendations and relates it to the system reference models of the DSL Recommendations. It is of informative nature and does not imply any specific requirements.

8 Recommendation G.996.1 (ex-G.test): Test procedures for digital subscriber line (DSL) transceivers

Recommendation G.996.1 describes the testing procedures for ITU Digital Subscriber Line (DSL) Recommendations. The testing procedures described in G.996.1 include methods for testing DSL transceivers in the presence of crosstalk from other services, impulse noise and POTS signaling. Test loops and in-home wiring models are specified for different regions of the world for use during DSL performance testing. Other DSL Recommendations reference this document for testing procedures and configurations. G.996.1 does not specify performance requirements for these other Recommendations. G.996.1 only specifies the procedures for measuring the performance requirements for a particular Recommendation.

9 Recommendation G.997.1 (ex-G.ploam): Physical layer management for digital subscriber line (DSL) transceivers

Recommendation G.997.1 specifies the physical layer management (Network Elements content and syntax for Configuration, Fault and Performance Management) for ADSL transmission systems. It specifies means of communication on a transparent transmission channel defined in the physical layer Recommendations G.992.1 and G.992.2.

10 Relationship between the DSL Recommendations

The DSL Recommendations are related to each other as shown in Recommendation G.995.1.

The G.992.1, G.992.2, G.991.1 and G.991.2 Recommendations are metallic digital physical layer interface specifications for use over the twisted copper pair plants. However, the type of applications, range of date rates, symmetry or asymmetry in the two directions, and the loop plant coverage, and the line code technologies are what differentiate one from the other.

From the perspective of symmetry, G.991.1 and G.991.2 provide symmetric data rates whereas G.992.1 and G.992.2 provide asymmetric data rates in the upstream and the downstream direction. G.991.1 and G.991.2 do not allow simultaneous transmission of broadband and voice-band transmissions. A fully equipped G.991.1 consists of one 2320 kbit/s, two 1168 kbit/s or two or three 784 kbit/s symmetric data rate service.

The G.992.1 systems support 6.144 Mbit/s downstream and 640 kbit/s upstream data rate. In the case of G.992.2, systems support a maximum of 1.536 Mbit/s downstream and 512 kbit/s upstream data rate. It can be noted that G.992.1 has higher downstream to upstream asymmetry ratio than the G.992.2.

From the loop plant coverage perspective, G.991.1 and G.991.2 have shorter loop length compared to the G.992.1 and G.992.2. The length of the G.991.1 and G.991.2 may be increased through the use of regenerators. Regenerators are not specified on the G.992.1 and G.992.2 loops.

From the applications perspective, G.991.1 and G.991.2 are suitable for business applications. G.992.1 may be used for both business and home applications while G.992.2 is mostly suitable for use in home applications. The large downstream bandwidth in G.992.1 is suitable for facilitating some of the broadcast applications such as video on demand. The other data applications are possible under the constraint of lower upstream data rates when compared to G.991.1 and G.991.2.

G.992.2's main focus is simplified installations. It is suitable for high speed Internet Access when compared to the voice band data transmission. The G.992.2 and G.992.1 use the same DMT line code principles. The G.991.1 provides a choice of a 2B1Q or CAP line code.

In some respects, G.992.1 and G.992.2 are closely related. There are other aspects which differentiate them. The close relation of the two lies in the use of the same core DMT line code and its associated parameters. G.992.2 has been developed with considerations for possible interoperability with G.992.1 and is based on modifications to the G.992.1 to meet the key objectives of lower equipment complexity, lower power consumption and splitterless operation. Some of the differentiating features of the G.992.2 are the reduced IFFT size for the downstream transmitter, smaller parameter set for the FEC coding and the Interleaving and the simpler reduced overhead framing structure. Other G.992.2 specific features are the fast retrain and the power saving mechanisms. Fast retrain procedure is used to cater for those situations in which a non-linear phone goes off hook and thus changing the channel characteristics in a significant manner in a splitterless environment.

G.994.1 provides a common mode of automatic selection and operation of the G.992.1 and G.992.2 defined equipment. G.994.1 message signals and procedures take place before those signals are exchanged which are specific to a particular DSL Recommendation. The use of G.994.1 is an integral part of the G.992.1, G.992.2 and will be used even in G.991.2 Recommendations. G.991.1 does not support G.994.1 that is expected to be used in future DSL Recommendations and future revisions of the current Recommendations. G.994.1 has no implications on G.997.1 and G.996.1.

G.996.1 provides a common resource of test procedures, line specifications and noise models to facilitate the performance testing of the DSL Recommendations. Both G.992.1 and the G.992.2 use the test procedures, line specifications and noise models described in the G.996.1 when the performance requirements are specified.

G.991.1 is self-contained in this regard. Future DSL Recommendations are expected to continue to use the G.996.1 resources in the specification of their performance requirements.

G.997.1 specifies means of communications on a transparent embedded operations channel defined in the physical layer. It specifies Network Element content and syntax for configuration, fault and performance management. While G.997.1 provides a common resource of Network Elements and syntax for configuration, fault and performance management for use in all of the G.992.1, G.992.2 and G.991.1, it does not preclude the use of Embedded Operations Channels as currently defined in G.992.1, G.992.2 and G.991.1.

The reference configurations shown in Figures 1 and 2 show abstract functional groupings, which may or may not correspond to real devices. Real devices may comprize one abstract functional grouping, more than one abstract functional grouping or a portion of an abstract functional grouping.

When comparing Figures 1 and 2, it may be observed that the main difference in the system reference model pertains to the absence of a separate POTS splitter functionality. The high pass filter functionality has been shown integrated in the NT, an optional low pass filter is depicted next to the POTS, ISDN or user terminal and the U-R2 interface does not exist in G.992.2.

Anyway this does not preclude the use of G.992.2 transmission system with splitter as shown G.992.1.

ANNEX 2

DSL Technical Descriptions

The implementation of DSL systems use sophisticated Digital and Analogue Signal Processing based on advanced circuit technologies. This annex tries to describe the complex functionalities of some DSL systems in a simplified manner. The knowledge of the basic functions can be useful for the choice of systems, for the understanding of their working conditions and limitations.

1 ADSL Technology

Asymmetrical Digital Subscriber Lines permit the transmission of high data rates over twisted pair cables. Figure 1.1 shows a simplified block diagram describing separately ADSL transmitter and receiver functions. In an ADSL terminal (transceiver) transmitter and receiver functions are connected by a hybrid circuit.

The ADSL transmitter consists of:

Digital interface	
Multiplexor	(MUX)
Frame set-up	(Frame Generator)
Tone ordering	(Ton order)
Constellation coding	(Const. Coder & Gain Contr.)
Inverse Discrete Fourier Transform	(IDFT)
Parallel/Serial converter	(P/S)
Digital/Analogue converter	(D/A &Filter & Amplifier)
Line interface	

The ADSL receiver consists of:

Line interface	
Analogue/Digital converter	(A/D & Filter & AGC amplifier)
Time domain equaliser	(TEQ)
Discrete Fourier Transform	(DFT)
Frequency domain equaliser	(FEQ)
Constellation decoder	(Const. Decod.)
Tone bit regenerator	(Tone Bit Regen.)
Frame handling	(Frame Alignment)
Demultiplexor	(Demux)
Digital interface	

In addition Figure 1.1 illustrates the signal flows, which are partly digital and partly analogue, presented partly in the time domain and partly in the frequency domain.

1.1 Transmitter functions

1.1.1 Line interface

The transmission across the subscriber loop uses the multi carrier principle with Discrete Multi Tones (DMT). The available transmission bandwidth is divided into parallel frequency bands, each band carries a part of the total information flow. ADSL uses 256 sub-carrier frequencies (ADSL lite 128 sub-carrier frequencies) in the downstream direction and 32 sub-carriers in the upstream direction. The sub-carriers are spaced equally 4.3125 kHz. Figure 1.2 illustrates sub-carrier allocations for various ADSL system types. One sub-carrier is used as pilot tone, the other sub-carriers are modulated with a 4000 Baud signal for information transport. Figure 1.3 illustrates the modulation principle. Each sub-carrier frequency carries information coded with Quadrature Amplitude Modulation QAM, i.e. the sub-carrier frequency is modulated with the envelop of the QAM signal. The line signal spectrum contains all sub-carrier frequencies.

1.1.2 Digital interface

Up to 7 bearer channels can be connected to the ADSL transmitter: 4 downstream channels and 3 downstream and upstream duplex channels.

1.1.3 Multiplexor

The available transmission bandwidth of the ADSL link is allocated among the activated bearer channels, timing/synchronisation signals and management signals.

For management interfaces are provided for indicator bits (ib), embedded operations channel (eoc) and ADSL overhead control channel (aoc). The different signals are combined and framed.

1.1.4 Frame set-up

The signal flow is crc-coded (Coded Redundancy Check), scrambled and FEC-coded (Forward Error Correction) and transported in frames. Each frame normally contains signals belonging to a fast track and to a latency track. The latency track uses interleaving which offers a more secure transmission but results in more delay.

Each frame is transmitted as a DMT-Symbol, 4000 frames are transmitted per second leading to a frame duration of 0.25 ms. However the frame content (bits/s) is variable and depends on the line condition. For each group of 68 frames a synchronisation frame is added in the Parallel/Serial converter leading to a super frame containing 69 frames with a duration of 17 ms. Figure 1.4 shows the super frame for an ADSL downstream transmission. Each frame contains fast and interleaved data. The fast byte of each frame carries crc or ib information. The synchronisation frame (synchr.symbol) carries no data.

1.1.5 Tone ordering

A DMT symbol is transported by a number of parallel sub-carriers (sub-symbols) and presented in the frequency domain. Each sub-carrier transports a number of bits during each sub-symbol. The bits are selected from the incoming frame. The number of bits/sub-symbol depends on the quality of the sub-carrier transmission. Up to 15 bits can be carried by a sub-symbol. To evaluate this quality a known pattern (wide band signal) is transmitted during the initialisation process of an ADSL transmission. The received power per sub-carrier and the Signal to Noise Ratio per sub-carrier is measured at the ADSL receiver. Based on these measurements the permitted number of bits and required transmit power per sub-carrier (tone) is calculated and the result is conveyed to the transmitter. Based on this information the transmitter allocates to each sub-symbol the permitted number of bits and transmits the sub-frequency with the required power. Figure 1.5 illustrates with an example the number of transmitted bits based on the received S/N ratio and shows the selection of bits from an incoming frame. A high S/N ratio permits many bits/tone. In the example these bits are secured by interleaved transmission.

1.1.6 Constellation coding

The number of bits per sub-symbol are coded with Quadrature Amplitude Modulation (QAM). N bits per sub-symbol result in 2^N different constellation points (even called 2^N– QAM constellation). The maximum number of 15 bits/sub-symbol offers 32768 constellation points. Figure 1.6 shows the constellations 4-QAM and 16-QAM as examples. 4-QAM can carry the bits 00, 01, 10 and 11 leading to 4 constellation points. The constellation points can be represented as complex numbers. In the lower left example of Figure 1.6 the constellations {00,01,10,11} lead to the complex number X1. (Re is the real part and Im the imaginary part of a complex number.The constellation points are modulated with a sub-carrier frequency to be transmitted as sub-symbol The corresponding modulated signal is:

$$S1(t) = Re\{X1 \exp j2\pi fsc\ t\}$$

The modulation can be illustrated as a rotation of the constellations X1 with $\omega = 2\pi fsc$. (fsc = sub-carrier frequency). This is illustrated in the lower right of Figure 1.6. The described process of constellation coding is applied to each sub-carrier.

1.1.7 Inverse Discrete Fourier Transform

Each of the sub-carriers is modulated and all resulting sub-symbols are added to obtain one DMT-symbol, which can be expressed in the time domain as:

$$S(t) = \Sigma\ Re\{Xi \exp j2\pi\ fsci\ t\},\ \Sigma \text{ from } i = 1 \text{ to } N$$

This equation corresponds to the definition of the Inverse Discrete Fourier Transform (IDFT). The coefficients Xi are determined during the constellation coding process and the iterations performed by IDFT result in the parallel presentation of the sub-symbols as digital samples in the time domain.

1.1.8 Parallel/Serial converter

The parallel digital samples are converted to serial samples. Each DMT symbol is presented by 512 samples, corresponding to the 256 sub-carrier frequencies involved in the information transport. 32 samples are added to the 512 samples as cyclic prefix.

The cyclic prefix, not carrying information, is added at the beginning of each DMT symbol. The cyclic prefix will be used at the receiver Time Domain Equalizer to decrease channel distortion.

1.1.9 Digital/Analogue converter

The digital samples are converted to analogue signals, appearing as a number of parallel sub-frequencies, each is sub-carrier frequency QAM modulated. After amplification and filtering the analogue signals are conveyed to the line via a hybrid, see Figure 1.8.

1.2 Receiver

1.2.1 Analogue/Digital Converter

An AGC amplifier is adjusted during the initialisation process. After filtering the analogue signals are converted to digital samples in the time domain.

1.2.2 Time Domain Equalizer

In Figure 1.7 the example of a channel response to a transmitted DMT symbol is shown leading to interference between DMT symbols (upper right of Figure 1.7). The Figure illustrates a digital process with an analogue presentation for easier understanding. The Time Domain Equalizer (TEQ) shortens the duration of the response signal caused by channel distortion (lower right of the Figure). Residual responses appear in the time interval of the cyclic prefix located at the beginning of each DMT symbol and do not interfere with the detection process (cyclic prefix guard band). After TEQ the cyclic prefix is eliminated.

1.2.3 Discrete Fourier Transform

The DFT converts the time domain samples into the frequency domain.

1.2.4 Frequency Domain Equaliser

The Frequency Domain Equaliser (FEQ) adjusts the gain and phase of the incoming sub-carrier frequencies to permit the use of one common decoder.

1.2.5 Constellation decoder

The decoder determines the QAM constellations of each incoming sub-carrier during a DMT symbol interval.

1.2.6 Tone bit regenerator

The tone bit regenerator converts the QAM constellations of each sub-symbol into bit sequences arranged in frames.

1.2.7 Frame handling

The signals are FEC decoded, descrambled and crc decoded. For the latency track an inverse interleave process is required.

1.2.8 Demultiplexor

The demultiplexor distributes the information to the receive downstream bearer channels and receives information from the send upstream bearer channels. In addition the management information is distributed.

1.3 ADSL Transceiver with echo control

Figure 1.8 shows a block diagram of an ADSL terminal with echo cancellation. The echo cancellation process permits the use of the same bandwidth for upstream and downstream transmission.

1.3.1 Frequency domain equalizer

The local transmitter sends a known wide band signal that the local receiver uses to calculate the echo frequency response.

1.3.2 Time domain equalizer

Signal energy reflected at the far-end transceiver and leaking of hybrid circuits lead to long echo responses, which are counteracted in the time domain equalizer using Circular Echo Synthesis (CES).

1.4 Initialisation Process

Before the payload transmission office and customer ADSL terminals have to be adjusted to match each other and the subscriber loop between. The following processes are required:

Activation: sending and receiving of activation frequencies during determined intervals.

Gain setting: a known wide band signal is transmitted to adjust receive AGC amplifier,
a known wide band signal permits S/N and power measurements per sub-carrier, leading to calculation of required transmit level and permitted bits per sub-symbol.

Synchronisation: a pilot tone with known frequency and phase controls the receiver digital phase lock loop for A/D and D/A converter timing, synchronisation signals based on cyclic prefix are sent without tone and the channel response is used to obtain symbol synchronisation.

Equalization: setting of TEQ and FEQ and echo cancellers with known wide band signal.

Figure 1.1 – ADSL Transmitter and Receiver Principles

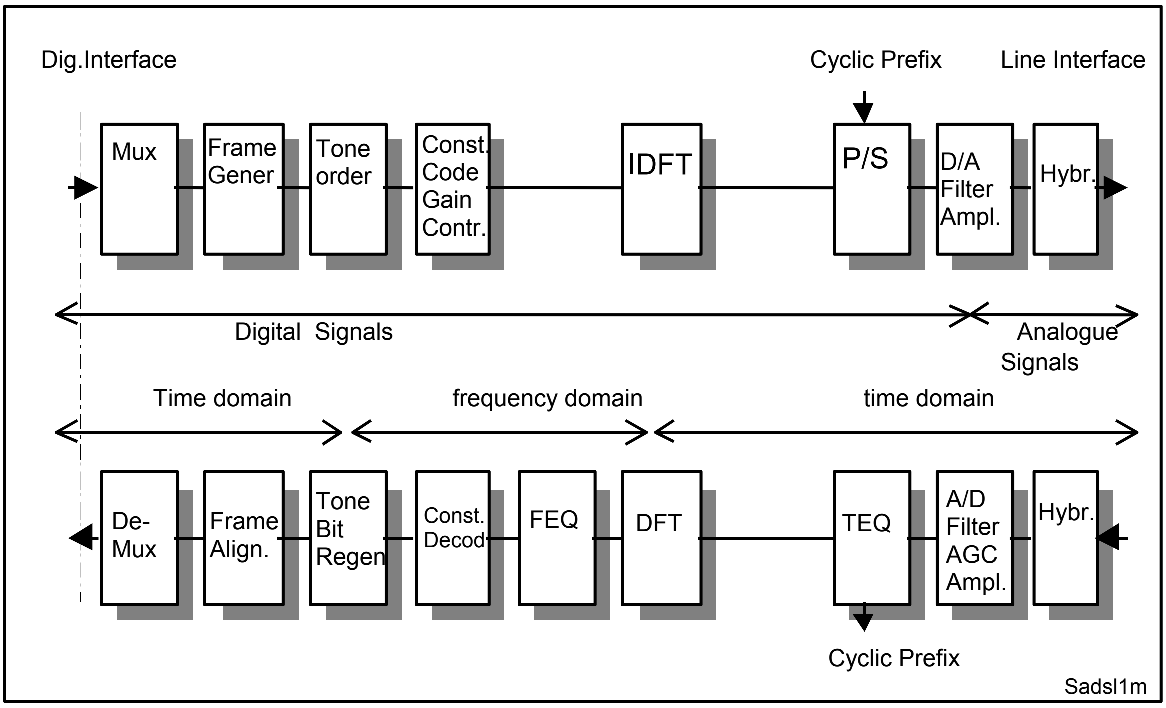


Figure 1.2 – Frequency Plan for ADSL

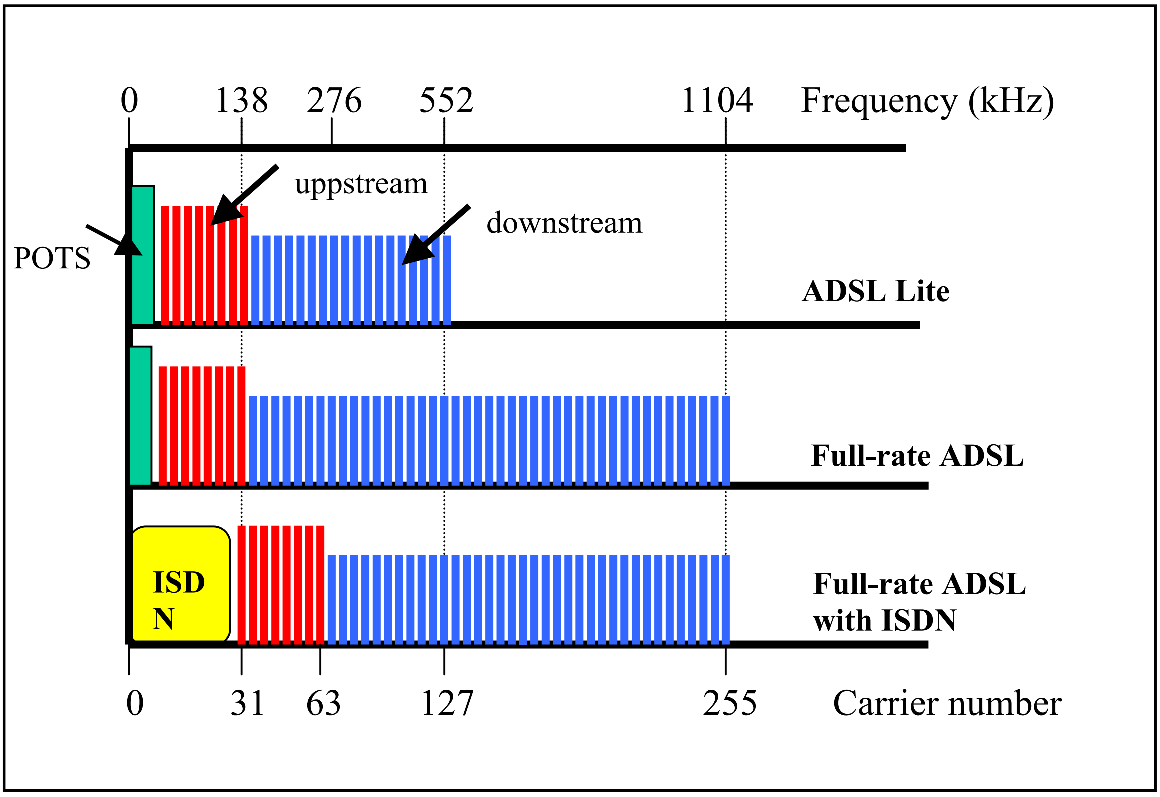


Figure 1.3 – Line signal transmit spectrum

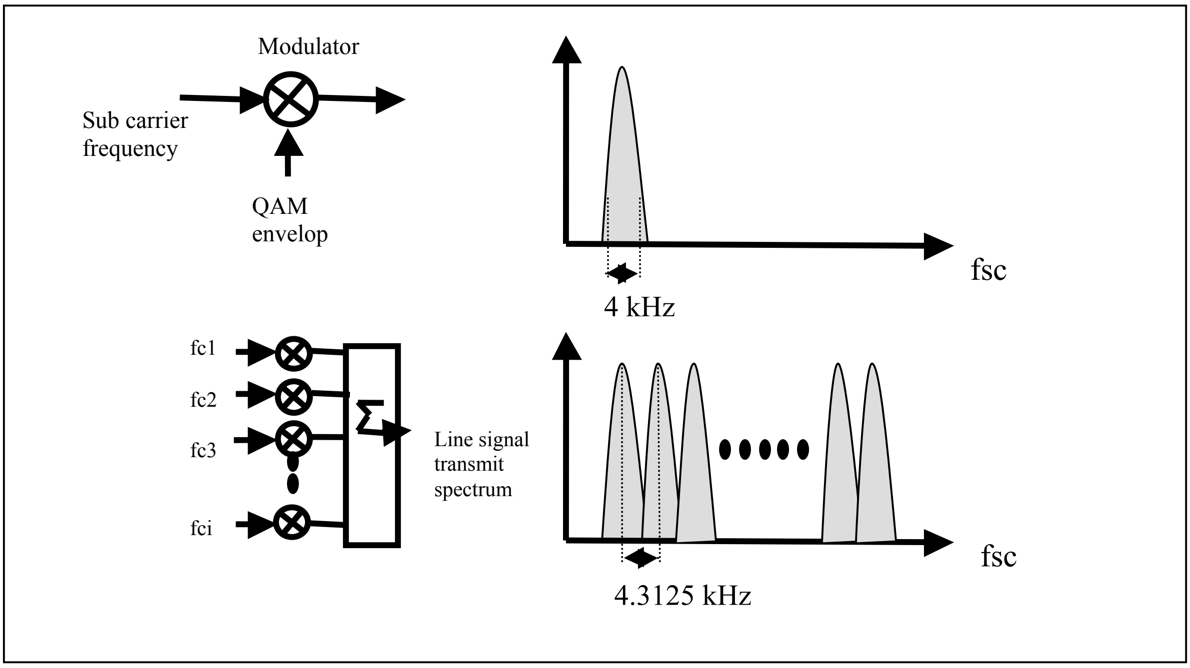


Figure 1.4 – ADSL Super frame and Frame Configuration

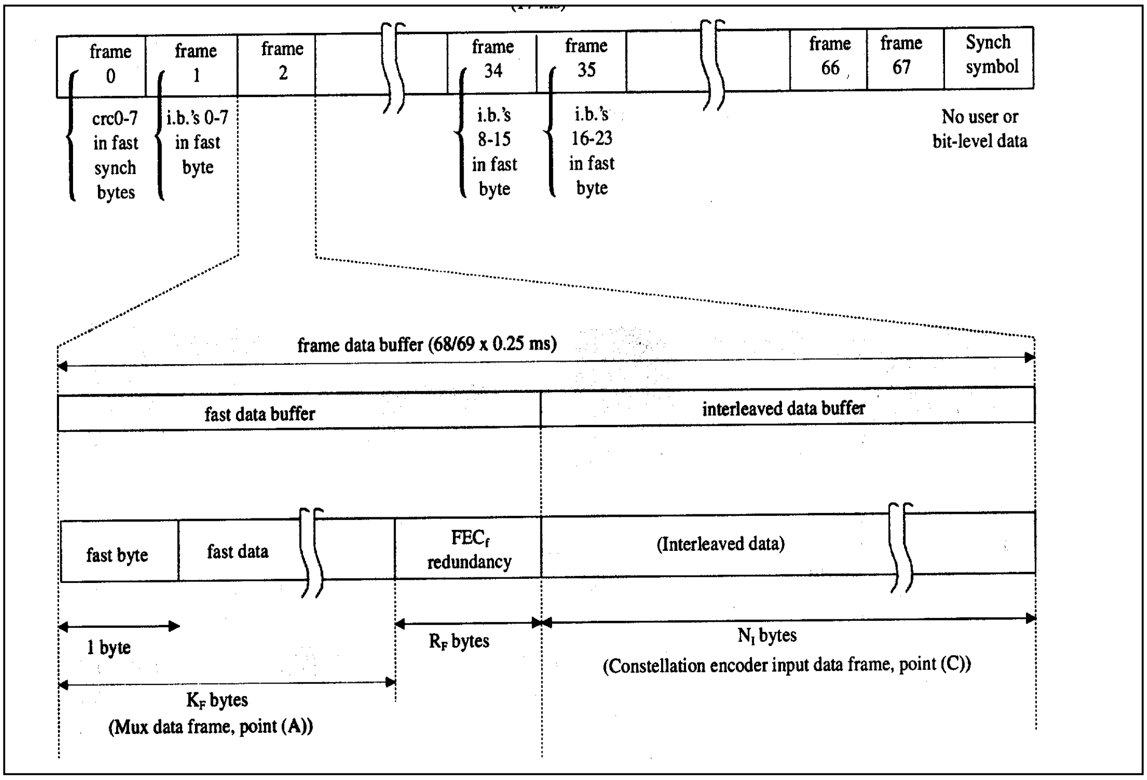


Figure 1.5 – Tone ordering and bit extraction example

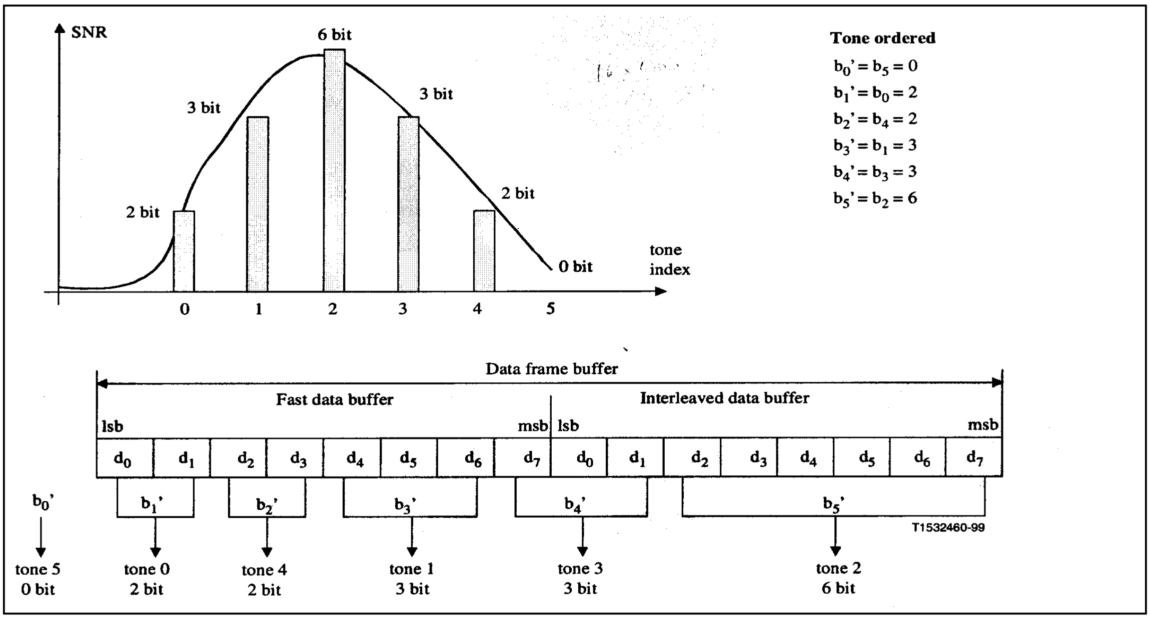


Figure 1.6 – Examples of Constellation Coding and Modulation

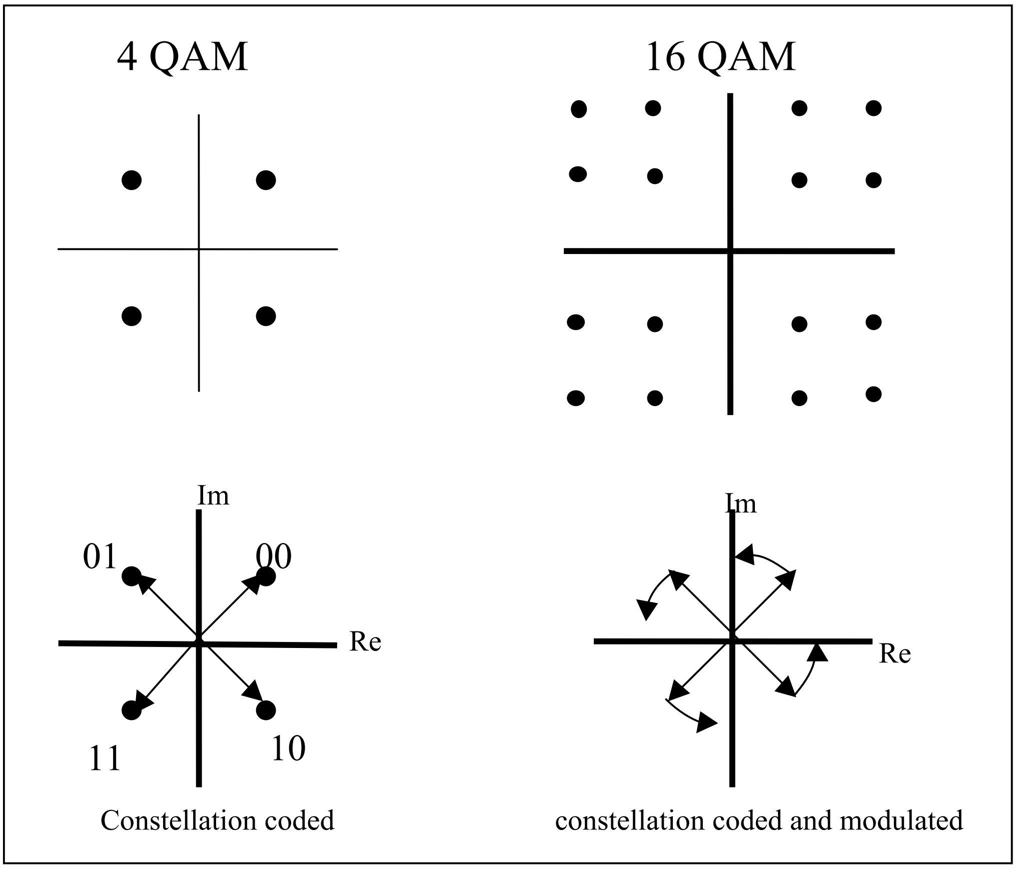
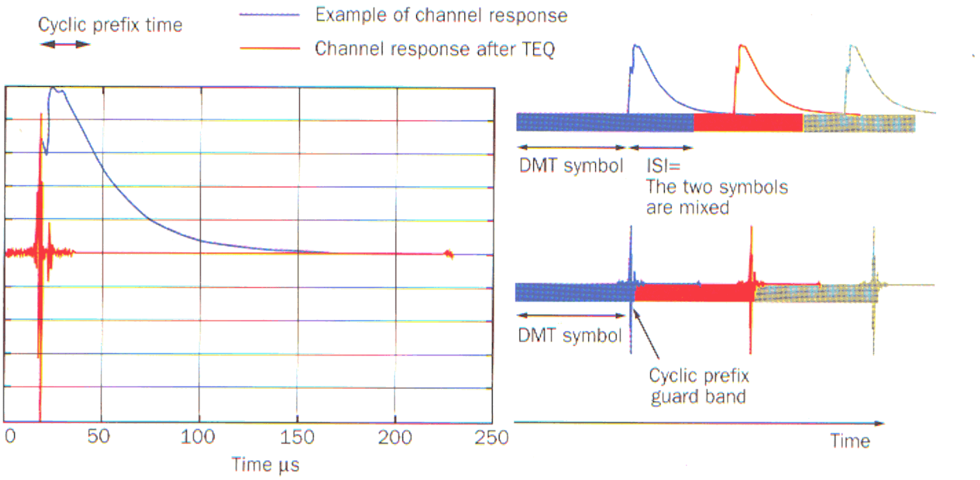
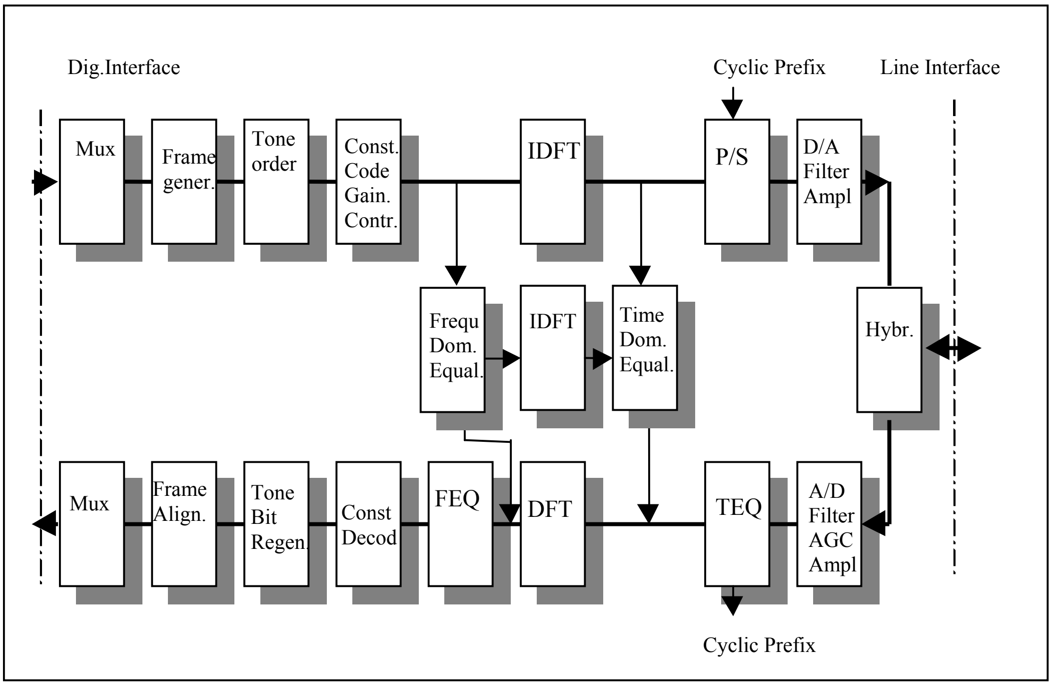


Figure 1.7 – Example of channel response with and without equalization



Ericsson Review No. 4, 1998

Figure 1.8 – ADSL transceiver with Echo canceller



2 SHDSL Technology

Single-Pair High-Speed Digital Subscriber Lines (SHDSL) as defined in ITU-T Rec. G.991.2 permit the transmission of high bit rates over one or two twisted copper pairs, with or without repeaters. SHDSL is a further development of HDSL permitting the same reach, loop impairments, robustness and services as HDSL. In addition SHDSL offers cost reduction and compatibility with some other DSLs. T1 and E1 transmission can be possible over about 4000 m.

The transport capacity for one pair operation supports data rates from 192 kbit/s to 2312 kbit/s in increments of 8 kbit/s. The allowed data rates are given by:

$$(N \times 8 + I) \times 8 \text{ kbit/s}$$

for N from 3 to 36 and I from 0 to 7. For N = 36, I is restricted to the values 0 or 1.
N and I determine payload and overhead data.

The transport capacity for two pair operation permits data rates from 384 kbit/s to 4624 kbit/s in increments of 16 kbit/s.

Figure 2.1 shows a simplified block diagram of a SHDSL transceiver with the following functional blocks contained in the transmitter part:

Interface circuits, customer and application specific
Application send device, application specific, e.g. T1, E1
Framer

Scrambler
Trellis Encoder device
Pre-coder
Spectrum shaper
Digital/Analogue converter and Amplifier

The receiver part consists of:

AGC Amplifier and Analogue/Digital Converter
Adaptive Feed Forward Equaliser
Viterbi Decoder device
De-scrambler
De-framer
Application receive device
Interface circuits

Send and receive signals are combined in a hybrid circuit (H) and compensated in an Echo canceller.

2.1 Transmitter

2.1.1 Framer

Each SHDSL frame contains 4 payload blocks (PA), 4 overhead blocks (OH), frame synchronization (FR) and stuffing information (ST). Each payload block contains 12 sub-blocks, each sub-block carries information bits (payload). The frame length depends on the transmission bit rate, the frame set-up and the particular application.

In the Clear Channel mode no specified relationship exists between the structure of the user data and its positioning within sub-blocks. Any additional structure of the user data depends on higher layer protocols and is not specified by ITU.

Figure 2.2 illustrates an example of a frame transmitting 2048 kbit/s Clear Channel information. The frame contains the following parts:

Frame synchronization: 14 bits
Payload block: k bits $k = 12 (N \times 8 + I)$ bits
Sub-blocks with the length: $ks = N \times 8 + I$ bits
Each sub-block carries N 8 bit time slots (octets)
Overhead information 32 bits
Fixed indicator bits, Embedded operation channel bits (eoc),
Cyclic redundancy check bits (crc)
Stuffing information 1 to 4 bits
Frame with the nominal length: $L = 4k + 48$
Frame with the nominal duration: 6 ms
For the example with $N = 32$ and $I = 0$ the frame length $L = 12\,336$ bits,
Including 48 bits for synchronization and overhead functions.

2.1.2 Trellis Encoder device

The incoming bit flow from the scrambler, as shown in Figure 2.3, is converted into 3 parallel bit groups X0, X1, and X2. In the convolutional coder using Trellis encoding principles a redundant coding bit, representing the least significant bit, is added. The resulting four bits Y0, Y1, Y2 and Y3 are converted into 16 possible PAM values (Symbols). Each symbol appears as time discrete digital sample.

2.1.3 Pre-coder

To counteract channel distortion the transmitted signals are pre-coded in a Tomlinson filter. The filter coefficients are determined in the receiver during start-up procedures and retransmitted to the transmitter to adjust the pre-coder. The coefficients are not changed during payload transmission.

2.1.4 Spectrum shaper

The digital filter for spectrum shaping can be modified by programming to obtain the optimum transmit spectrum for different regions and applications. In North America PAM transmission with interlocked spectrum is used, leading to overlapped but non identical spectra for upstream and downstream transmission, as illustrated in Figure 2.4 (OPTIS line code).

In the SHDSL upstream direction the limitation of the spectrum beyond 250 kHz minimises the interference with downstream ADSL, i.e. SHDSL and ADSL can be used on the same subscriber loop.

2.1.5 Digital/Analogue Converter

The time discrete digital samples (symbols) from the spectrum shaper are converted into analogue signals, amplified and fed across the hybrid circuit to the subscriber line. The symbol rate of the PAM modulated line signal is 1/3 of the payload bit rate.

2.2 Receiver

2.2.1 Analogue/Digital Converter

The analogue signals from the hybrid are sampled and converted to time discrete digital values for each symbol.

2.2.2 Adaptive Feed Forward Equalizer

The equalizer (FFE) is used to remove remaining inter-symbol interference from the receiver data stream. The operation of the FFE is based on a least mean square algorithm and adapts during each received symbol.

2.2.3 Viterbi Decoder Device

Each incoming symbol in the form of a digital PAM signal is decoded in a Viterbi decoder device, see Figure 2.5, consisting of a slicer, which determines X1 and X2 and a Viterbi decoder detecting the least significant bit X0. The state of the Viterbi decoder, up to 2^{20}, is sent to the transmitter in a handshaking procedure. A typical value used in North America requires 512 states. With Viterbi decoding the receiver does not detect a symbol on a symbol-by-symbol basis, but rather on a symbol sequence basis. Looking on a sequence of symbols the decoder selects the symbol sequence with the lowest probability of errors. In addition erroneous bits are recovered using the maximum likelihood Viterbi algorithm. In the case of a 512-state decoder the decoder sequence length is about 64 symbols leading to a typical delay of 500 ps.

2.2.4 De-framer

After de-scrambling and frame alignment the payload and overhead information is passed to the application specific interface circuits.

2.3 Start-up procedures

Before payload transmission pre-activation sequences and activation sequences have to be transmitted.

2.3.1 Pre-activation

Pre-activation is based on the handshaking procedures defined in ITU-T Rec. G.994.1.

During pre-activation timing functions are established between transmitter and receiver. Figure 2.6 shows the functional blocks involved in pre-activation.

2.3.2 Activation

Figure 2.7 shows the functional blocks involved in activation. During activation the pre-coder coefficients are determined, i.e. the Decision Feedback Equalizer (DFE) checks the output of the decision slicer (Q) and identifies disturbing noise and interference. This signal is fed back and subtracted from the next incoming symbol. The DFE determines the line equalization characteristics leading to the required coefficients for the pre-coder at the transmitter side. Before payload transmission the DFE is disconnected and the pre-coder connected with fixed coefficients.

Figure 2.1 – Simplified SHDSL Transceiver block diagram

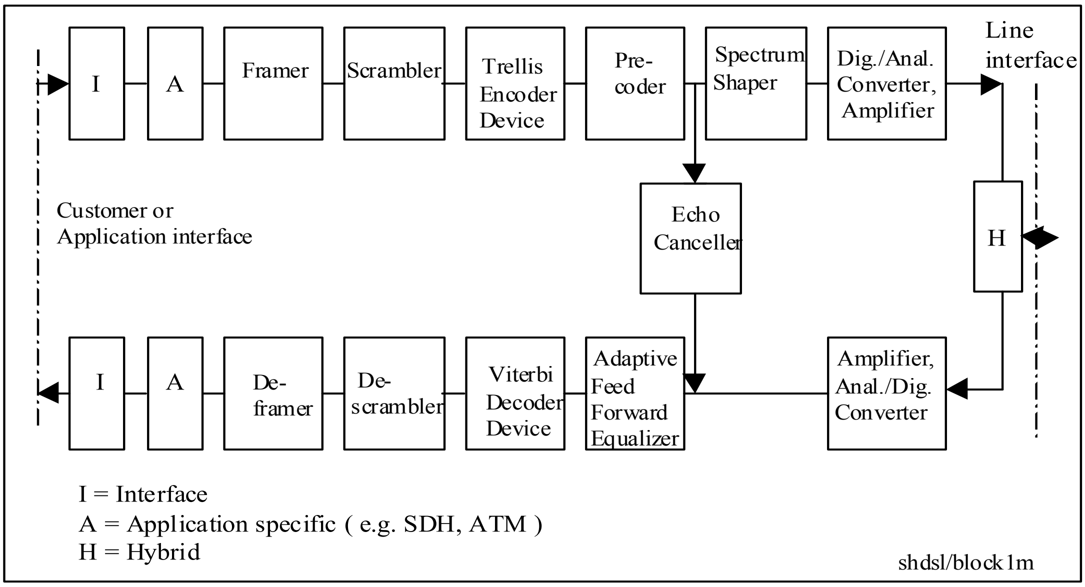


Figure 2.2 – Clear Channel Byte-Oriented Frame

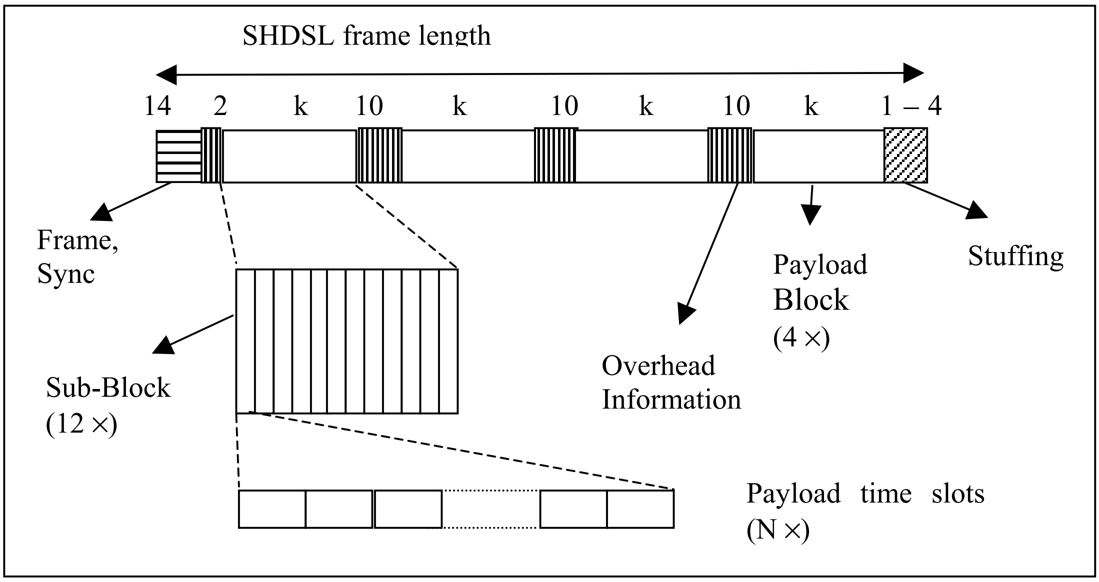
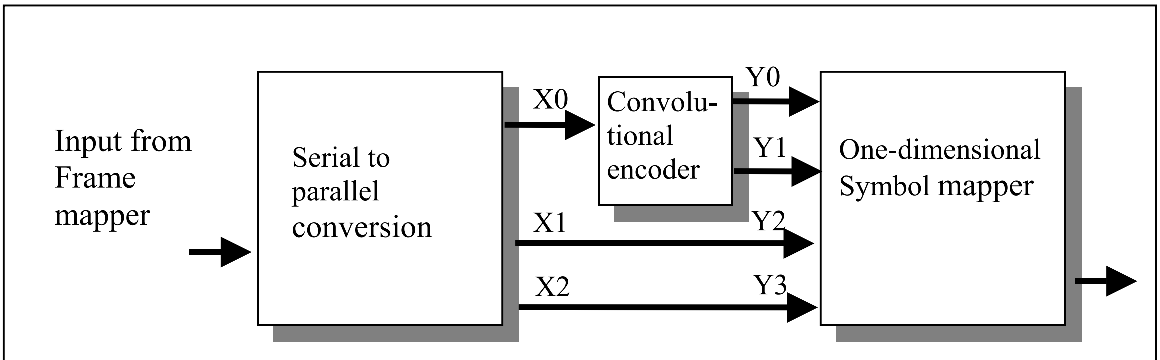


Figure 2.3 – Trellis Encoder Device



–15	–13	–11	–9	–7	–5	–3	–1	+1	+3	+5	+7	+9	+11	+13	+15 PAM Symbol
0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

Figure 2.4 – OPTIS Power Spectrum Mask

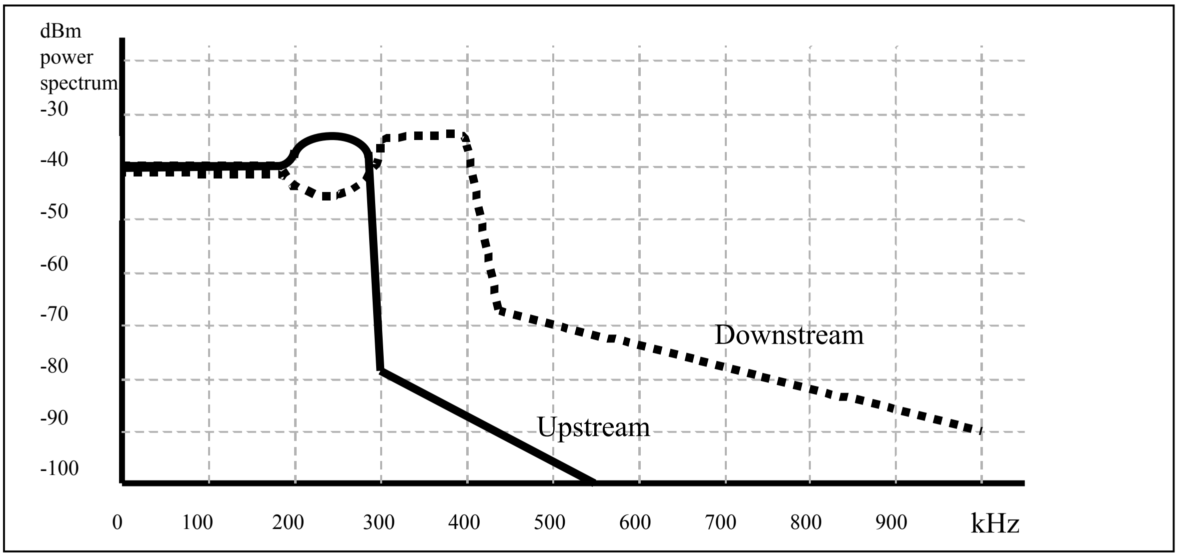


Figure 2.5 – Viterbi Decoder Device

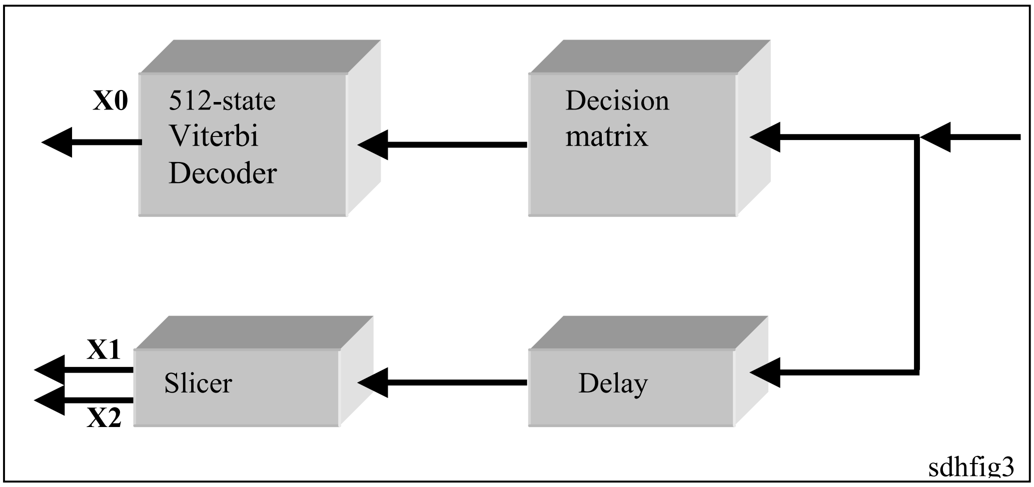


Figure 2.6 – Pre-activation Process

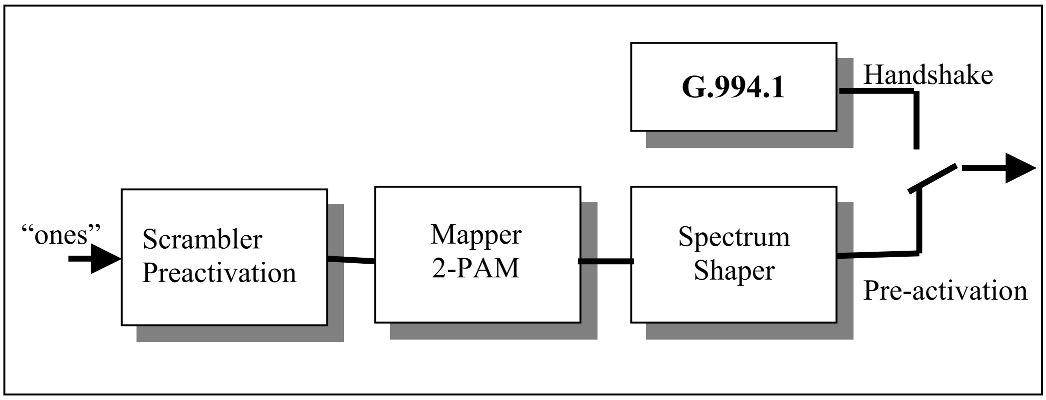
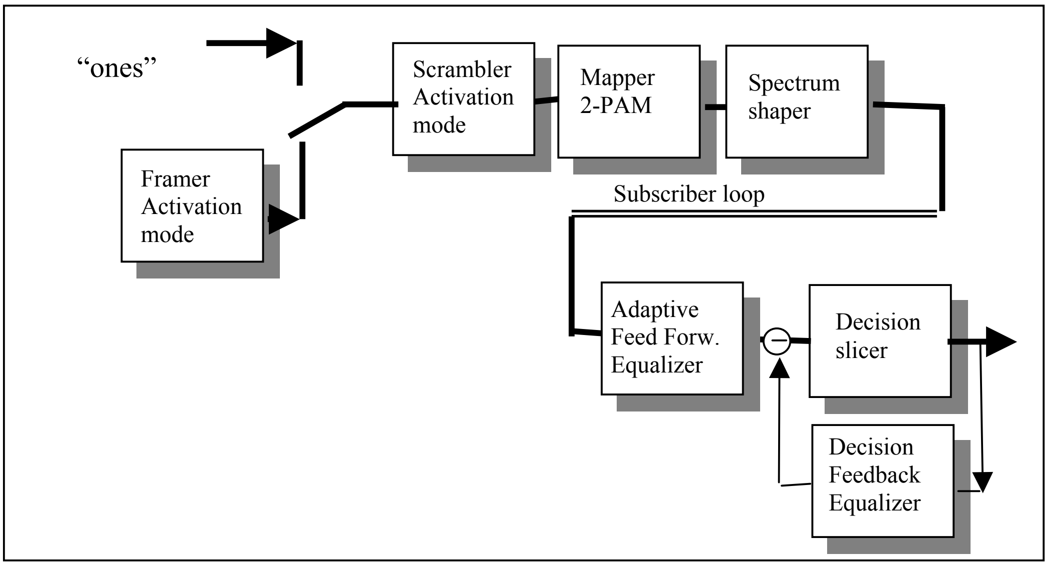


Figure 2.7 – Activation Process



3 HDSL Technology

HDSL (High-Bit-Rate Digital Subscriber Line) has been developed by ATT Bell Laboratories and Bellcore during 1987, a decade later about 450,000 HDSL lines were in service worldwide. The need for HDSL became evident when T1/E1 transmission systems were used as private lines from central office to customer premises. The technology is a further development from ISDN. Figure 3.1 shows a simplified block diagram for a HDSL terminal with 2B1Q coding.

HDSL terminals NTU (Network Termination Unit) and LTU (Line Termination Unit) can be connected with 1, 2 or 3 metallic pairs to match subscriber line quality, distance and required data rates. As an option regenerators (REG), powerfed from the terminals, can be used to increase the distance.

A simplified HDSL transceiver for 2B1Q code consists of:

- CRC-6 coder and decoder
- 2B1Q coder and decoder with amplifiers
- Echo canceller (EC)
- Hybrid circuit (HY)

A simplified HDSL transceiver for CAP code consists of:

- Scrambler and descrambler
- Trellis encoder and decoder
- Tomlinson precoder
- Amplifiers

(Trellis encoding and Tomlinson pre-coding principles are similar to the corresponding functions of SHDSL)

Between HDSL transceiver and Customer or Application interface are the following units:

- Interface Circuitry
- Mapping Circuitry
- Common Circuitry

3.1 Framing functions

The application specific information flow from the Customer or Application interfaces is contained in a specific *Application Frame* layout. As an example, a digital structured 2048 kbit/s signal, which is used e.g. for leased line service, is contained in a 32 byte *Application frame* appearing at the output of the Interface Circuitry. In the Mapping Circuitry payload and management information is arranged in the *Core Frame.* In the Common Circuitry the *Core Frame* and additional management information is placed in one *HDSL Frame* (for single pair transmission) or in two or three parallel *HDSL* Frames (for multi pair transmission).

Figure 3.2 illustrates the different frames for single pair transmission of 2048 kbit/s. The HDSL frame containing 13920 bits is transmitted nominally during 6 ms. The frame carries payload and overhead information for the following functions:

- framing;
- management (e.g. loss of signal, far end block errors, embedded operation channels CRC-6 and bipolar violation indications, power and repeater status).

Corresponding frames are standardized for multi pair transmission.

At the receiver side the incoming *HDSL frames* are converted to *Core Frames* in the Common circuitry, which has the task to counteract delay variations of incoming multi pair *HDSL frames* and extracts management information. Correspondingly the Mapping Circuitry extracts management information and converts the Core Frames into Application Frames for transfer to the Customer or Application interface.

3.2 Line Codes

The 2B1Q code converts 2 bits into one quaternary signal element as shown in Figure 3.3. The Baud rate on the subscriber line is ½ of the bit rate.

CAP codes (Carrierless Amplitude Phase Modulation) are used in two versions:

– 64 CAP Code with 64 signal constellations, each constellation carries 6 bits as illustrated in Figure 3.4.

– 128 CAP Code with 128 signal constellations, each constellation carries 7 bits.

In the HDSL transmitter one bit is required for Trellis coding, i.e.

64 CAP, used for 2 pair transmission, carries 5 bits per signal element, the Baud rate is 1/5 of the bit rate 128 CAP, used for 1 pair transmission, carries 6 bits per signal element. the Baud rate is 1/6 of the bit rate.

The following table lists different HDSL transceiver types.

Table for comparison of various HDSL Types

Number of pairs	Application (Customer) Interface kbit/s	Code	Bit rate per pair kbit/s	Baud rate per pair kBaud/s
3	1544	2B1Q	784	392
	2048	2B1Q	784	392
2	2048	2B1Q	1168	584
	2048	64CAP	1168	233.6
	1544	2B1Q	784	392
1	2048	2B1Q	2320	1160
	2048	128CAP	2320	386.667

Figure 3.5 shows the spectral densities of 2B1Q and 64CAP codes for a two pair HDSL link. CAP codes are more bandwidth efficient, but more complex and more vulnerable to distortion and disturbances.

3.3 Start-up procedures

During activation a duplex communication takes place between LTU and NTU, and between LTU or NTU and REG. The activation requires one pair and particular start-up pattern. Different start-up sequences exist for 2B1Q and CAP transceivers.

Figure 3.1 – HDSL Block Diagram

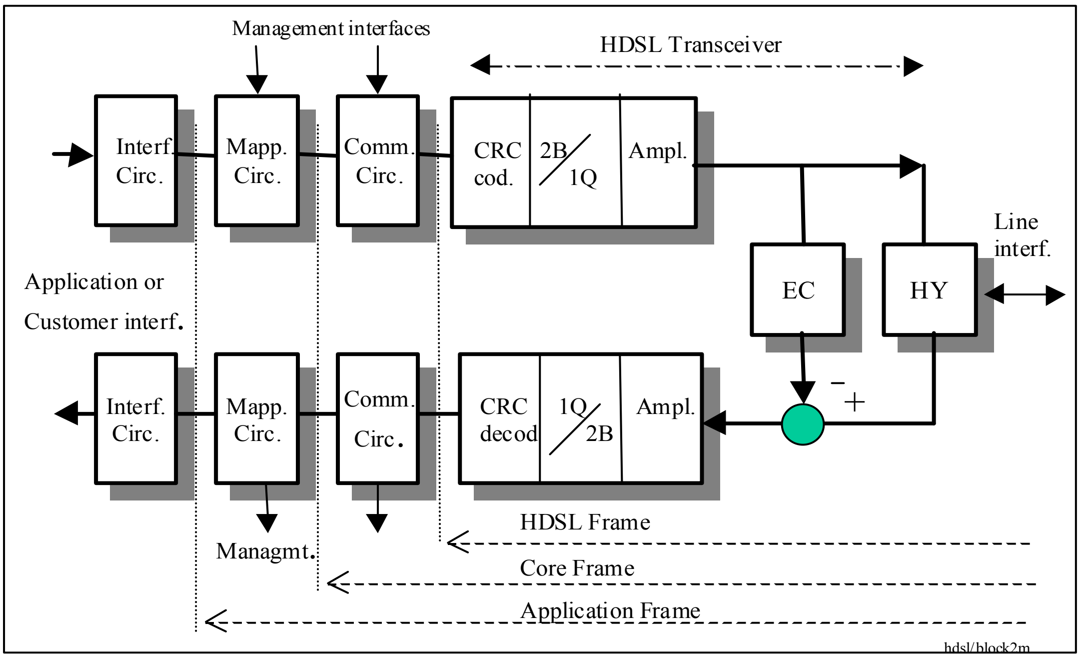


Figure 3.2 – HDSL Framing example

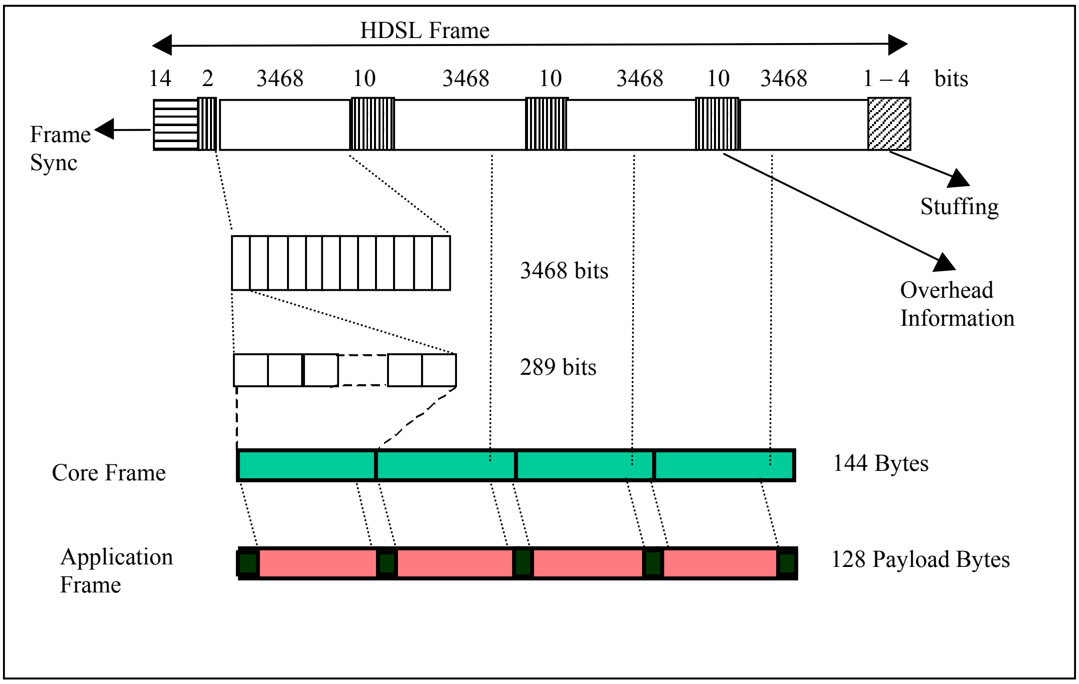


Figure 3.3 – 2B/1Q Coding Table

Binary	Quaternary
1 0	+3
1 1	+1
0 1	–1
0 0	–3

Baud rate = ½ bit rate

Figure 3.4 – 64 CAP Coding Table

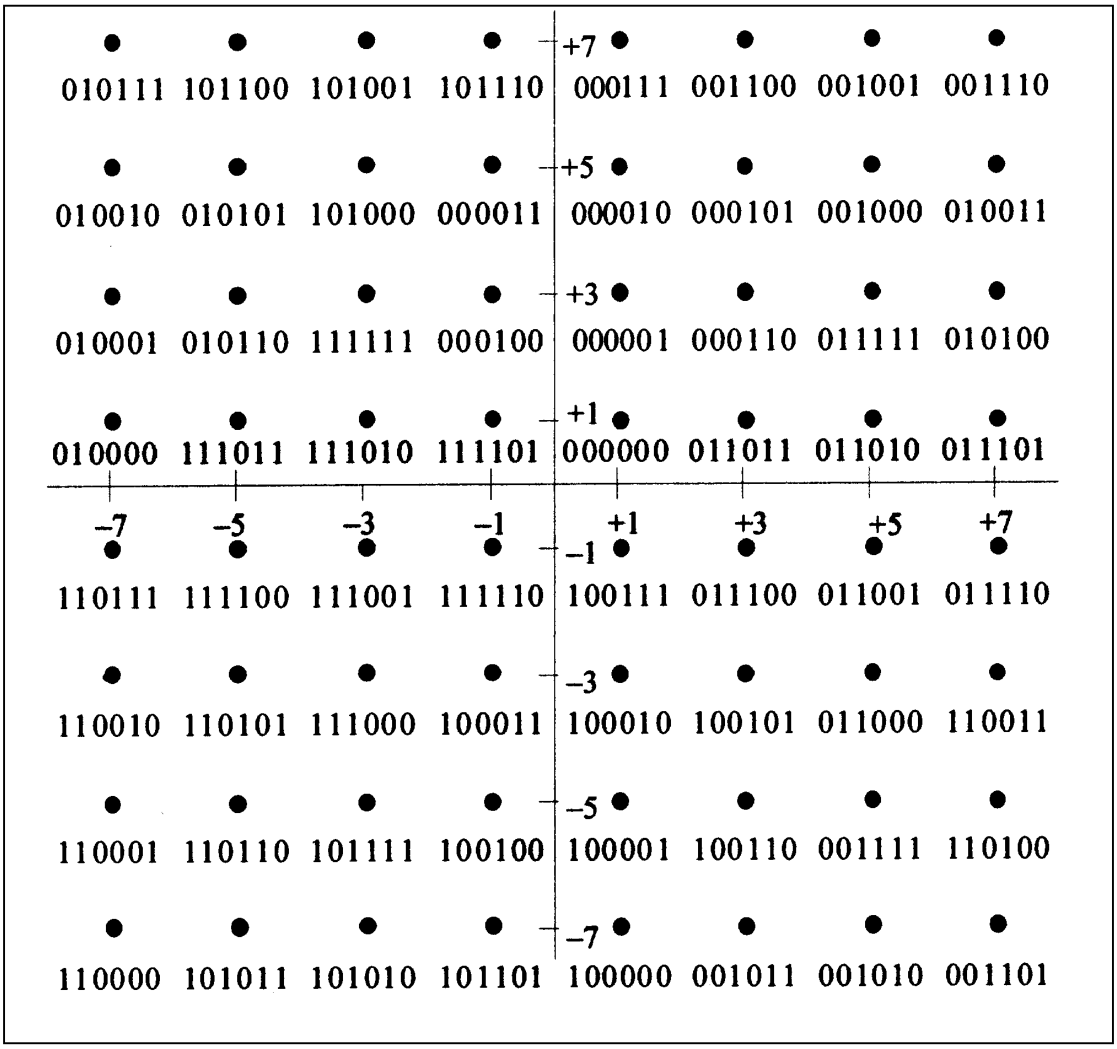
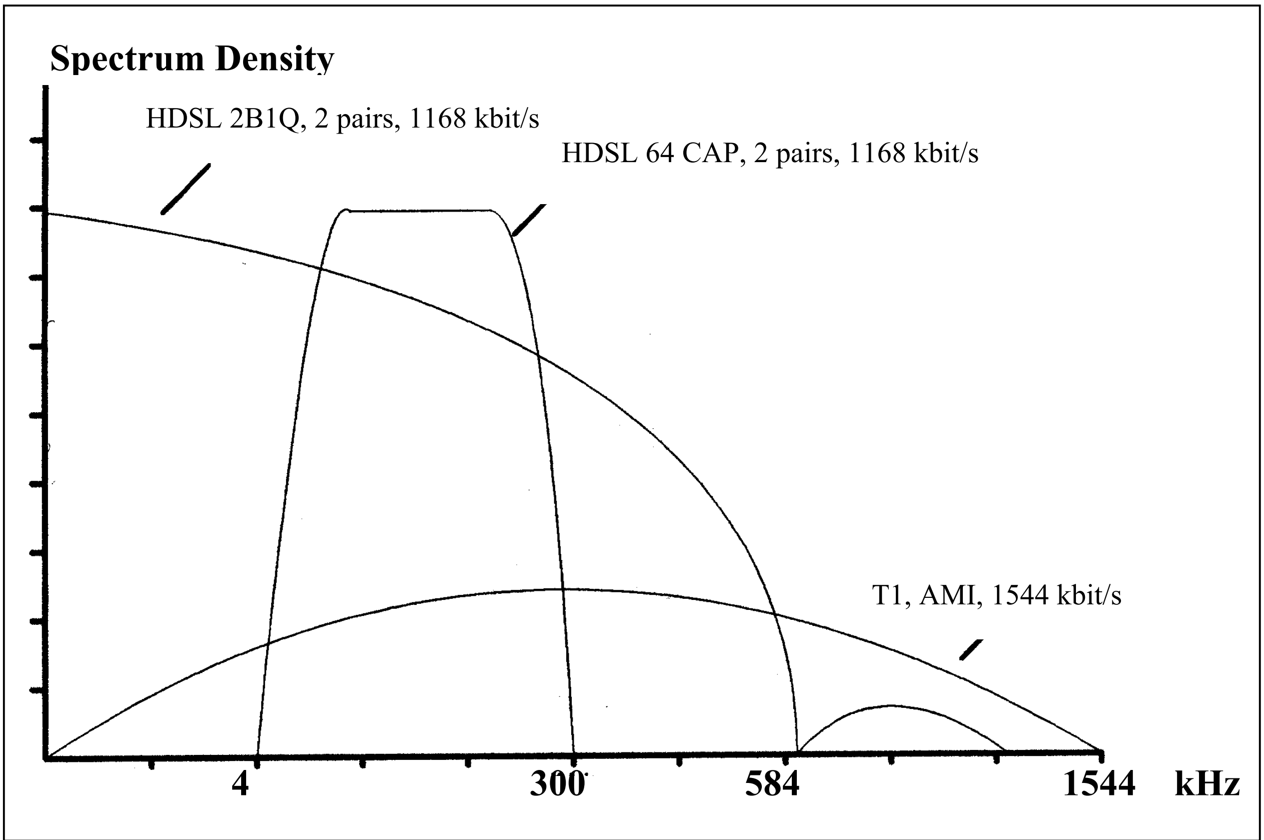


Figure 3.5 – Comparison of 2B1Q and 64 CAP Spectrum Densities



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ANNEX 3

DSL Network Model

1 Introduction

The applicability of DSL Systems depends on the nature of the subscriber loops. Considerable work has been laid down to characterize subscriber loops in the access networks. Based on the derived loop specifications it would be desirable to make predictions about the performance of DSL systems. Test procedures of various DSL Systems over different subscriber loop configurations are described e.g. in ITU Recommendation G.996.1, DSL Forum Technical Report TR-029 and in TIA Report PN 4254-INT (draft 1) prepared by the Telecommunications Industry Association. This annex, which contains a short extract based on the above mentioned TIA Report, shows the impairments influencing the functions of DSL systems in access networks.

2 Access Network Model

The objective of this standard is to define a realistic network access transmission model for comparing DSL modem performance in terms of network model coverage. The goal of the model is to provide a portrait of the real network as it will exist in the year 2002. The model is technology independent. Because some important elements of the model (crosstalk disturber model, for example) are based on projections, it is recognized that the model will need to be revised based on actual rollout of DSL services. The proposed Model is comprised of three elements:

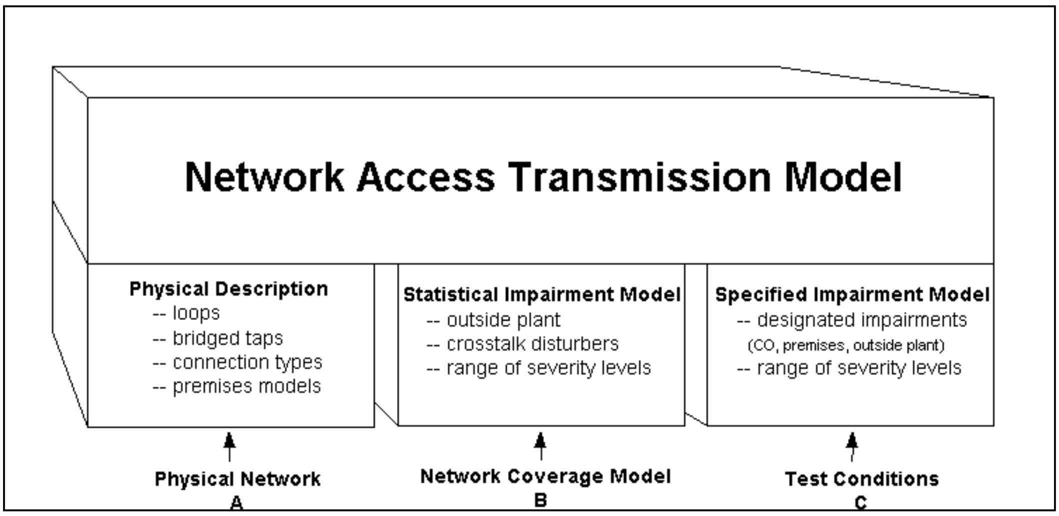
– Physical Description

– Statistical Impairment Model

– Specified Impairment Model

Figure 1 illustrates the content of the Model.

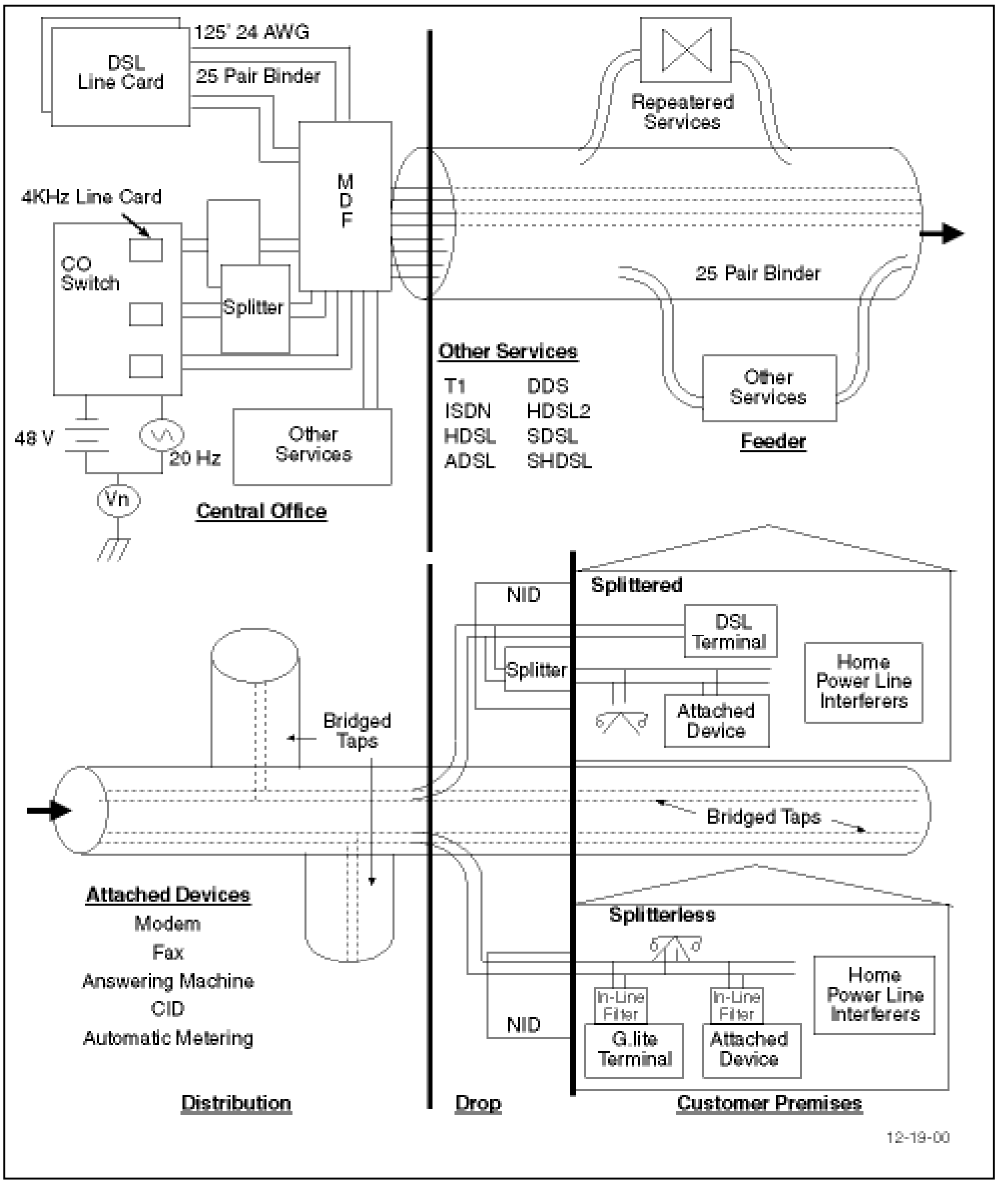
Figure 1 – Network Access Transmission Model



3 Physical Network Description

A block diagram of the access network is shown in Figure 2. The network model has been segmented into four sub networks: Central Office CO, outside plant, customer premises drops or entrance cables and customer premises wiring.

Figure 2 – DSL Network Configuration Block Diagram



4 Statistical Impairment Model

A schematic block diagram of the network showing impairments associated with each sub network element is shown in Figure 3. Each of these impairments is discussed briefly below:

4.1 Crosstalk

Crosstalk is the electromagnetic coupling of a signal from one pair (interferer) onto another (victim) pair in the same cable, causing unwanted interference. A common source of crosstalk interference is coupling from high-speed circuits operating in adjacent cable pairs. Crosstalk whose spectra overlaps the transmit spectra of other DSLs can have a dramatic limiting effect on DSL performance. Sources of crosstalk include DSL transceivers at the CO and premises end of the loop, and also intermediate sources such as repeaters, amplifiers and remote Digital Subscriber Line Access Multiplexers DSLAMS located at digital loop carrier remote terminals.

4.1.1 Near-end crosstalk (NEXT)

Electromagnetic coupling that occurs when the receiver on a disturbed pair is located at the same (near) end of the cable as the transmitter of a disturbing pair. For echo-cancelled systems such as SHDSL, NEXT from self-crosstalk from like systems in the same cable is usually the most limiting crosstalk on performance, regardless of other DSL types that may be in the same cable.

4.1.2 Far-end crosstalk (FEXT)

Electromagnetic coupling that occurs when the receiver on a disturbed pair is located at the other (far) end of the cable as the transmitter of a disturbing pair. For frequency division multiplexed (FDM) systems such as ADSL, FEXT from self-crosstalk is the most limiting crosstalk on performance when there are no other DSL types in the same cable.

4.2 Loop Impairments

Loops impact on DSL performance not only as a result of attenuation due to length and gauge, but also due to other factors such as bridged-taps, loop balance, moisture, and temperature. Below are descriptions of the types of impacts of the loop on DSL performance.

4.2.1 Bridged Taps

A bridged tap is defined as any portion of the telephone access loop that is not in the direct DC path between the telephone instrument and the central office switch. Bridged-taps cause nulls that greatly increase attenuation in the null frequency band and create impedance discontinuities in the loop. DSL performance on long loops is especially susceptible to the effects of bridged taps. The available receive passband of a DSL on a long loop is quite narrow compared to the transmit passband of the circuit. When the bridged taps create nulls in the passband of the receive signal, the throughput can be substantially reduced or diminished.

4.2.2 Amplitude Distortion

Amplitude distortion is a departure of the amplitude versus frequency of a received signal over a telephony circuit from what would normally be expected from uniform loop attenuation characteristics. The most common source of this type distortion is bridged-taps in the loop.

4.2.3 Moisture

Moisture inside the cable jacket or in a splice can cause a disturbing effect on telephone loop characteristics. Moisture can enter the cable as a result of any of a number of anomalies, such as a small hole created by lightning, a nick in the cable due to digging or during cable placement, an opening in aerial cable due to a bullet or an improperly sealed splice case or cable terminal. Disturbing effects could include changes in capacitive and resistive balance of the loop and changes in crosstalk levels. This imbalance can create a source of common mode noise and add additional loop loss that reduces DSL performance.

4.2.4 Temperature

A rise or fall in temperature can cause a significant change in loop attenuation. Changes can be gradual due to such factors as seasonal changes or can be sudden such as the cooling effect of a thunderstorm on a hot summer day or the heating effect when the sun comes out directly after the thunderstorm. The resulting change can be dramatic. For example, a 26 AWG aerial cable has a resistance of 83 ohms/kft at 70 °F, but has a resistance of 93 ohms per kft at 120 °F, a common temperature under direct sunlight. This increased resistance translates to higher attenuation of the DSL signal, reducing throughput to the DSL. (1 kft = 304 m).

4.3 Steady State Impairments

There are many additional factors besides loop and crosstalk impairments that have an effect on DSL performance. Descriptions are provided in the following sections.

4.3.1 Splitter/Distributed Filter

Splitters and distributed filters are used on data over voice technologies such as ADSL to separate the voice spectrum from the DSL signal. Splitters may be used at both ends or may include a splitter at the CO end and a set of distributed filters at the premises end. Splitters and distributed filters impact DSL performance by their frequency response over the DSL band, the impact of intermodulation distortion (IMD) on the noise floor, group delay and the loading effect of multiple distributed filters. Splitters are included in tests where the DSL uses a data over voice technology.

4.3.2 Background Noise

Background noise is a steady-state interference on a telecommunications channel that is not caused by the service installed on the channel. It degrades the signal-to-noise ratio (SNR) of the received signal of the service. This level tends to vary little from one installation to the next, except when crosstalk is present. Crosstalk effects are already accounted for in the loop model. Consequently, a common value of −140 dBm/Hz of white noise is assumed to represent common background noise.

4.3.3 AC Induced Interference

AC-induced interference is common mode noise introduced into the loop due the coupling of 50 or 60 cycle harmonics from power lines paralleling the telecommunications cable. This noise can degrade the signal-to-noise ratio (SNR) of the received signal of the service. This can vary between service installations.

4.3.4 Longitudinal Balance

A difference in capacitive or resistive values in the loop as measured from the tip to ground and from the ring to ground will negatively affect the longitudinal balance of the loop. This imbalance creates additional loss that reduces throughput of DSL.

4.3.5 PC Monitor Interference

Electro Magnetic Impulse from the PC Monitor can couple into a nearby DSL modem, reducing its performance.

4.3.6 AM Radio Interference

AM radio interference is narrow band noise on the loop caused by electromagnetic coupling from nearby AM radio signal sources. When the spectrum of the narrow band interference, including out-of-band frequencies, overlaps the receive signal of the DSL, throughput to the DSL can be severely reduced.

4.3.7 Premises End Crosstalk (PEXT)

PEXT occurs when two DSL services are placed in the same quad drop or premises wiring. Coupling between pairs in quad home wiring is much higher than in telephone cables, causing a significant source of crosstalk to the DSL.

4.4 Transient Impairments

Transient impairments are non-stationary events that commonly occur in the access network. Following are some transient impairments that impact modem performance.

4.4.1 CO Ringing Transients

The CO ringer places an intermittent high voltage AC signal on the line that can be disruptive to a DSL modem.

4.4.2 Ring Trip Transients

Ring trip transients are transient voltages appearing on a transmission channel caused when the telephony circuit is changed from on-hook to off-hook during the time when the ring signal is applied. This can be one of the most damaging sources of transient impairments due to the high voltage on the line when the telephony circuit is changed from on-hook to off-hook. Ring trip transients can severely impact margin, forcing retrains and loss of data being transmitted.

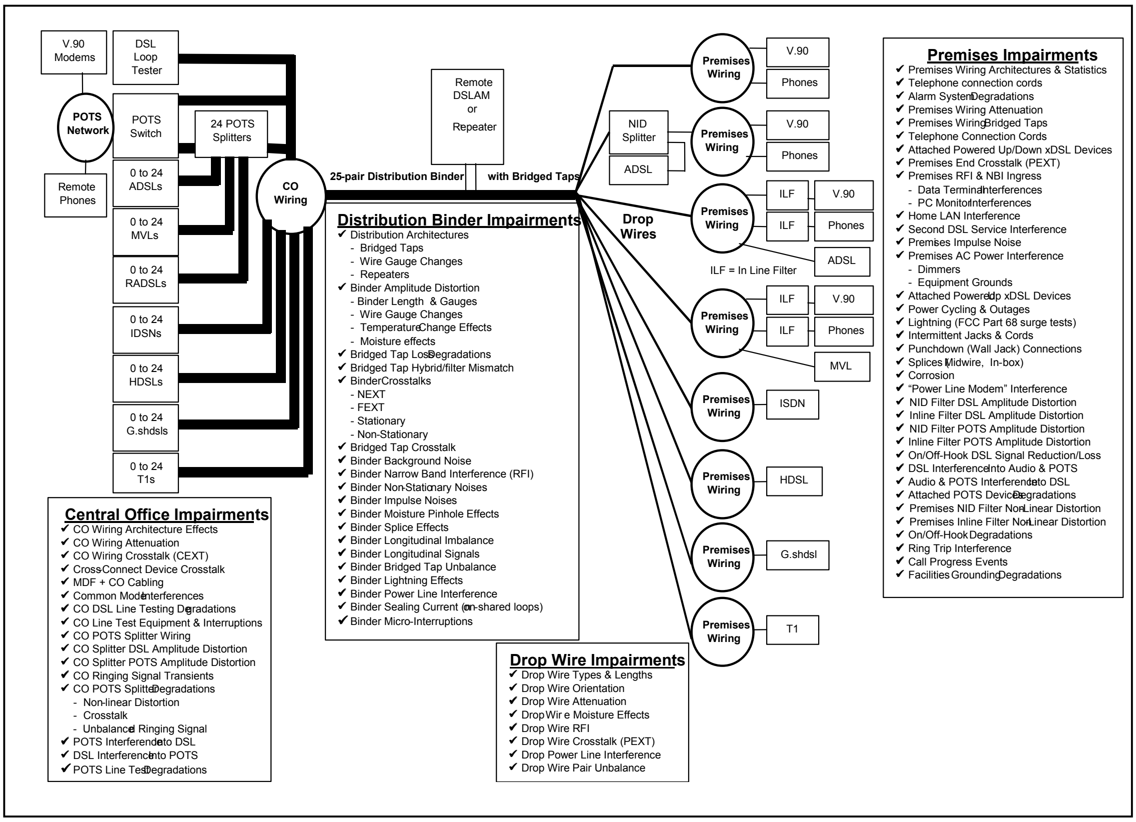
4.4.3 On-Hook/Off-Hook Transients

On-hook/off-hook transients are transient voltages that appear on a transmission channel caused by the impedance change when a telephony circuit is changed from on-hook to off-hook or from off-hook to on-hook. Transients can severely impact margin, forcing retrains and loss of data being transmitted.

4.4.4 Impulse Noise

Impulse noise is a disturbance on a transmission channel caused by a transient voltage higher than the steady-state background noise. Amplitude, duration and rate of occurrence generally characterise impulse noise. A common impulse noise measuring technique is to count the number of transient events above a specified threshold and over a specified time period. Impulse noise can severely impact margin, causing errors on data being received by the DSL. Sustained impulse noise can also force a retrain. Examples of impulse noise in the premises are light dimmers and universal motors.

Figure 3 – Statistical Impairment Model



5 Specified Impairment Model

The Specified Impairment model combines premises and central office models with a catalogue of impairments leading to specified impairment combination tables, which are at present under study.

ANNEX 4

The Annex includes test cases and DSL installations

1 Mali

HDSL was introduced in Mali in 1997. After an introduction of the country the characteristics of the DSL system and the difficulties encountered are described. The description is an extract of Doc. 2/220-F presented by Mali during the Study Group 2 meeting in Caracas, 10-14 September 2001.

1.1 Country overview

The Republic of Mali is situated between latitudes 10° and 26° North and longitudes 4° and 12° West, and has a land area of 1 241 231 km^2 with 7 200 km of borders. At the end of 2000, Mali's population was estimated at 10 206 244 (rural population: 7 650 601, urban population: 2 555 643) The population density is 8.22 inhabitants per square kilometer. The capital city, Bamako, has a population of 1 059 318.

Telecommunications in Mali are administered by the *Société des télécommunications du Mali* (SOTELMA), which is a State corporation established on 9 October 1989. Until February 2001, SOTELMA held a monopoly on the provision of telecommunication services in the country.

SOTELMA has juridical personality and financial autonomy, and reports to the Minister of Communications. It has its own board of directors. SOTELMA's objects are to operate the public telecommunication service and to develop telecommunication services.

As at 31 December 2001, the total number of subscribers is reckoned at 49 726, of whom 39 222 are fixed subscribers and 10 530 are mobile subscribers (6 003 on AMPS and 4 500 on GSM). Of the 39 041 (non-cellular) main telephone lines, 70% are concentrated in Bamako. In addition, the 10 530 mobile lines are all installed in Bamako. For fixed main telephone lines, the density in Bamako is 2.75 (versus 0.40 for the country as a whole).

1.1 HDSL introduction

Mali's telephone network is characterized by a very low level of development (0.45 lines per hundred inhabitants), which means that it ranks below other countries having a similar level of development. The under-development of the national telecommunication network is evident in the lack of connection capacity in the local networks, which are either saturated or antiquated.

Despite various activities undertaken with a view to developing the network, it remains under-equipped and can not keep pace with the continually growing demand.

The problem is particularly acute in certain areas of Bamako, where entire neighbourhoods still lack appropriate facilities. In addition, the lack of network capacity in Bamako serves to stifle a significant volume of demand.

It was in this context that HDSL was introduced in Bamako's network in 1997. By the end of 2000, there were 1 004 subscribers, representing 3.6% of Bamako's main lines connected to HDSL. The HDSL systems that have been installed are operating satisfactorily. The problems identified by the maintenance service have been the result of power outages which have occurred mainly during the rainy season.

Another problem relates to the quality of the copper pairs used. With the network largely being in a state of disrepair in the centre of Bamako, some of the copper pairs in use are not in good condition.

For all these reasons, SOTELMA is considering a plan to modernize the system and plan to extend Bamako's urban network with 30 000 fixed lines.

1.3 Description of HDSL transmission

The equipment used for the HDSL transmission is PG-Flex. PG-Flex is a small capacity universal subscriber carrier system supporting up to 32 subscriber channels, including POTS and ISDN services. The system is based on HDSL transmission technology and the remote power is powered from the Central Office. Using two 24 (0.5 mm) gauge unconditioned copper pairs, the remote terminal may be located up to 3.3 km from the Central Office terminal (COT). Standard 19- or 23-inch shelves contain multiple systems; circuit cards may be hot-swapped without affecting other systems installed in the shelf. POTS channel units use 64 kbit/s A-Law PCM encoding to allow Group 3 facsimile or high-speed modem operation on all channels.

The line is a two-pair, 1 110 kbit/s full-duplex 2B1Q transmission format. The dual HDSL lines provide 32 64-kbps channels with signalling, and an embedded operations channel for management control. No need exists for repeaters, loop conditioning, or pair selection. Adaptive equalization, scrambling, and a four-level 2B1Q line coding scheme increase range and minimize crosstalk. For the system configuration, the maximum distance between the COT and the Remote Terminal (RT) is 3.3 km, assuming the HDSL lines are 24 gauge (0.5 mm). The table below shows the maximum distance between the COT and RT for various gauge wire. Due to the nature of HDSL transmission technology, the HDSL lines do not require any special conditioning and may include unterminated bridge taps, but cannot include load coils.

Table – Typical subscriber loop distances with the PG-FLEX system

Wire gauge	Loop length	
	16/32 Channel system	Resistance
26 AWG (0.4 mm)	2.5 km	686 Ω
24 AWG (0.5 mm)	3.3 km	569 Ω
22 AWG (0.6 mm)	4.2 km	457 Ω
16 AWG (0.9 mm)	5.9 km	322 Ω

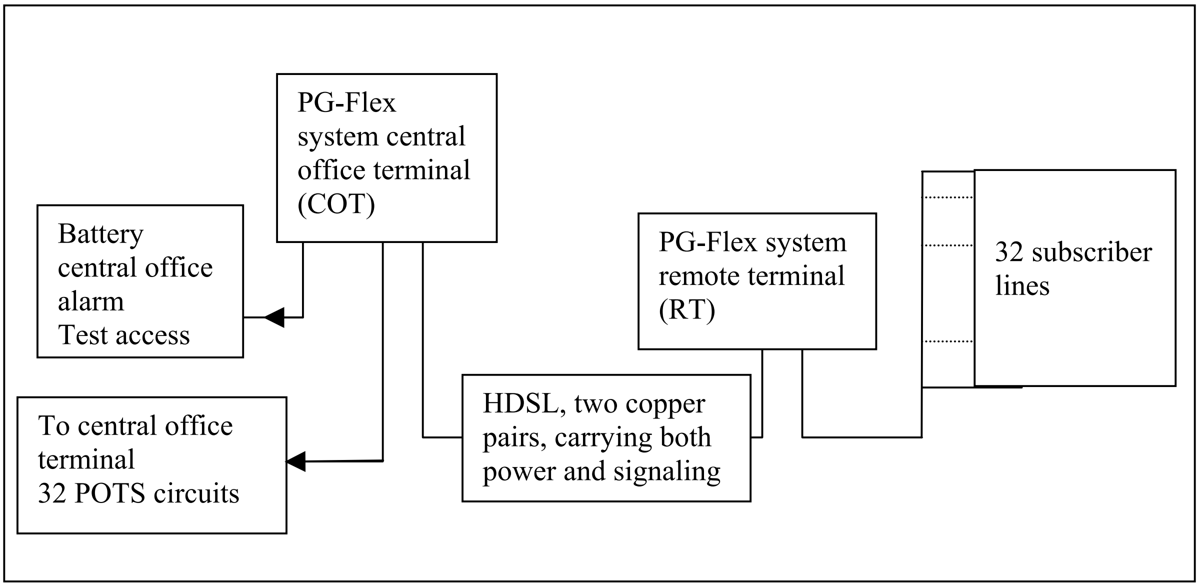
Figure 1 below shows a typical PG-FLEX configuration.

1.4 Conclusion

The HDSL systems that have been installed in Mali have been operating satisfactorily. The problems identified by the maintenance service relate, by and large, to power outages occurring principally during the rainy season.

Another problem relates to the quality of the copper pairs used. With the network having deteriorated generally in Bamako's city centre, some copper pairs are not in good condition.

Figure 1 – Typical PG-FLEX configuration



Terms and Abbreviations

2B1Q	Two binary one quaternary line code
ADSL	Asymmetric Digital Subscriber Line
AGC	Automatic Gain Control
AIS	Alarm Indication Signal
ANSI	American National Standards Institute
ATM	Asynchronous Transfer Mode
ATU	ADSL Transceiver Unit
BER	Bit Error Rate
B-ISDN	Broadband ISDN
BRA	Basis Rate Access
BS	Base Station
CAP	Carrierless Amplitude/Phase Modulation
CATV	Cable Television
CEXT	Central Office crosstalk
CLP	Cell Loss Priority
CO	Central Office
CPE	Customer Premises Equipment
CPN	Customer Premises Network
CRC	Cyclic Redundancy Check
CSP	Competitive Service Provider
DAVIC	Digital Audio Visual Council
DCE	Data Communication Equipment
DDS	Dataphone Digital Service
DMT	Discrete Multitone
DSB	Digital Satellite Broadcast
DSL	Digital Subscriber Line
DSLAM	DSL Access Multiplexer
DSP	Digital Signal Processing
E1	2.048 Mbit/s transmission system
EOC	Embedded Operation Channel
ETSI	European Telecommunication Standards Institute
FDM	Frequency-Division Multiplexing
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FR	Frame Relay
FTTB	Fibre to the Building

FTTC	Fibre to the Curb
FTTH	Fibre to the Home
HDSL	High Speed Digital Subscriber Line
HDSL2	High bit-rate Digital Subscriber Line (single pair), ANSI standard for second generation HDSL
HEC	Header Error Control
HFC	Hybrid Fibre Coax
IETF	Internet Engineering Task Force
IFFT	Inverse Fast Fourier Transform
ILF	In Line Filter
INI	Inter-network Interface
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISP	Internet Service Provider
ITU	International Telecommunication Union
ITV	Interactive TV
LAN	Local Area Network
LFA	Loss of Frame Alignment
LOS	Loss of Signal
LTU	Line Termination Unit
MDF	Main Distribution Frame
MIB	Management Information Base
NID	Network Interface Device
N-ISDN	Narrowband ISDN
NMS	Network Management System
NNI	Network Node Interface
NT	Network Termination
NTU	Network Termination Unit
OAM	Operation Administration and Maintenance
ONU	Optical Network Unit
PBX	Private Branch Exchange
PEXT	Premises End Crosstalk
PHY	Physical Layer
PON	Passive Optical Network
POTS	Plain Old Telephone System
PPP	Point-to Point Protocol
QAM	Quadratur Amplitude Modulation

QAM	Quadratur Amplitude Modulation
REG	Regenerator
RFI	Radio Frequency Interface
RITL	Radio in the Loop
ROBO	Remote Office/Branch Office
SDH	Synchronous Digital Hierarchy
SDSL	Symmetrical Digital Subscriber Line, will be replaced by SHDSL
SHDSL	Single-pair High speed Digital Subscriber Line
SNR	Signal-to-Noise Ratio
SOHO	Small Office/Home Office
SONET	Synchronous Optical Network
STB	Set Top Box
STM	Synchronous Transfer Mode
T1	1.544 Mbit/s transmission system
TC	Transmission Convergence
TDM	Time Division Multiplexing
TMF	Telecommunication Management Forum
TMN	Telecommunication Management Network
U	Loop Interface (Reference Point)
UNI	User Network Interface
URL	Universal Resource Locator
USB	Universal Serial Bus
VAN	Value Added Network
VDSL	Very high rate Digital Subscriber Line
VOD	Video on Demand
VTU	VDSL transceiver
WLL	Wireless Local Loop
WWW	World Wide Web