Technical Focus

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Tutorial on xDSL technologies

General Aspects | ISDN | ADSL | HDSL | SDSL | VDSL | The xDSL Family

General Aspects

ISDN, HDSL, ADSL, VDSL and SDSL are all DSL modem technologies designed to operate on telephone wires intended originally for voice-band communication (300Hz to 3.4kHz). As a prerequisite to successful operation, all DSL systems require the removal of any loading coils. These were often inserted in some access networks, at regular intervals, to improve the voice-band transmission characteristics. Advances in DSP technology combined with innovation in algorithms and coding methods have allowed access to previously untapped information capacity. Bandwidth utilisation has increased by two orders of magnitude over the last ten years or so; from under 100kHz for narrow-band ISDN to over 10MHz for VDSL.

Most of the DSL modem standards treat the DSL modem as a ‘bit pump’ whose primary task is to transport data quickly and faithfully between end point transceivers, over a specified environment which includes defined loop-sets and noise models. These loop-sets and noise models are designed to be representative of the environment the modem will experience in real access networks. The impairments specified in the DSL modem standards govern the signal-to-noise (SNR) ratio and hence range and achievable bit rate. Generally speaking DSL modems are designed to achieve Bit Error Rates (BER) of less than 1 errored bit in 107, over the test environments specified in the respective standards or reports.

The access network is a hostile environment and most DSL modem physical layer standards will include some or all of the following key requirements in order to provide reliable transmission and vendor interoperability.

- Test loops – makeup and topology (to ensure adequate penetration).
- Cross talk or steady state noise margin (to allow for interactions from other DSL in a multi-pair cable).
- Data rates (both line and payload).
- Impulsive or transient noise margin (to allow for noise spikes e.g. ringing).
- Transmitter power spectral density limits (to ensure spectral compatibility and minimise unwanted RF emissions).
- Return loss (to ensure good line matching and signal power transfer).
- Line interface balance (to prevent EMC problems).
- Framing and data scrambling (to prevent cyclo-stationary effects e.g. line spectra).

- Short Range Devices
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- VPN
- xDSL

- Latency (to minimise delay e.g. for voice traffic).
- Jitter and wander (to minimise data loss).
- Start up protocols (handshaking).
- Warm/cold start limits (time taken to synchronise and achieve reliable bit transport – to minimise circuit unavailability).
- Line coding (to achieve efficiency in terms of bits/s/Hz)
- Duplexing (e.g. time, frequency, echo cancellation).
- Forward error correction (to self-correct physical layer transmission errors and not burden higher layer protocols with data re-transmission.)
- Embedded operations and maintenance (for the transfer of service related information e.g. QoS).

ISDN-BA (DSL)

The acronym DSL was originally used to refer to narrowband or Basic-rate Access transmission for the Integrated Services Digital Network (ISDN-BA).

A 4-level PAM (baseband) linecode known as 2B1Q was pioneered by BT Laboratories. ETSI also adopted it for Europe and also developed the 4B3T linecode (aka MMS43) as an alternative option, primarily for use in Germany.

ISDN-BA modems mostly employ echo cancellation (EC) techniques to enable full duplex transmission at 160kbit/s on a single unloaded telephony wire pair. EC-based ISDN-BA transceivers make use of bandwidth from ~10kHz up to 100kHz, and it is instructive to note that the peak power spectral density of 2B1Q-based DSL systems is around 40kHz with the first spectral null at 80kHz.

ISDN-BA systems tend to have long ranges and good coverage in terms of the percentage of access loops they can operate on. The technology has been around for some time now and there have been significant advances in transceiver performance in recent years.

International ISDN-BA standards tend to specify the physical layer transmission aspects at the ISDN ‘U’ or wires-only interface. In Europe it is usual for the NT to be owned by the Telco and service is provided at the S/T bus, which is a standard digital User Network Interface (UNI).

The DSL payload is usually 2 x ‘B’ or Bearer channels at 64kbit/s each, plus a ‘D’ or signalling channel at 16kbit/s, which can sometimes also be used for packet data. This gives the user access to 128kbit/s plus signalling (144kbit/s). An extra overhead of 16kbit/s is provided for an Embedded Operations Channel (EOC), intended for exchanging information between the LT (Line Terminal) and NT (e.g. link performance statistics). The EOC is not normally accessible to the user.

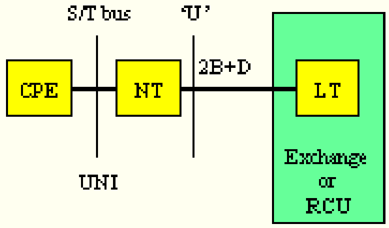

Figure 1 : Basic-rate ISDN-BA concept (DSL)

Several millions of ISDN-BA lines have been installed worldwide and demand for ISDN lines has become significant due to the high demand in higher Internet connection speeds.

ISDN standardization work

ADSL

Asymmetric DSL (ADSL) was again pioneered in North America in the mid-1990s. It was conceived for the delivery of highly asymmetrical services such as Video on Demand, in which large bit-rates were required to be delivered to the Customer but only a small amount back towards the network from the Customer.

Very good quality transmission was required (BER much less than 1 in 109) because of the need to transport highly encoded, low redundancy, MPEG encoded video streams, where single errors produce very noticeable effects on picture quality. This necessitated the use of data interleaving and Forward Error Correction (FEC) techniques, which were never considered for ISDN-BA or HDSL. The price paid for these features was an increase in latency; and this is why early ADSL systems had up to 20ms of delay compared to ISDN-BA or HDSL which were limited to no more than 1.25ms.

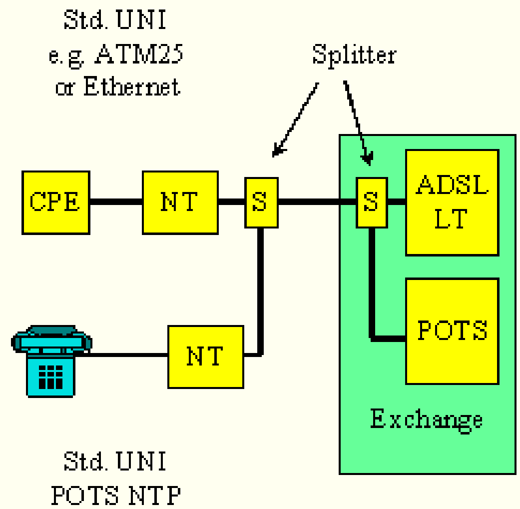

Figure 3 : Asymmetric DSL concept (ADSL)

ADSL has highly asymmetric data rates and is rather different to ISDN-BA/HDSL insofar as it supports coexistence of narrow-band POTS on the same wire-pair via a service splitter (see Figure 3).

ADSL uses Frequency Division Duplexing (FDD) in which a band of tones is allocated to upstream transmission (Customer to Exchange direction) and another band is allocated to downstream (Exchange to Customer). It pushes the usable access bandwidth up to around 1MHz. Some variants of ADSL use echo cancellation techniques to make even better use of available bandwidth by overlapping some of the downstream band with upstream transmission. Figure 7 shows the use of FDD to separate upstream and downstream and the function of the master service splitter.

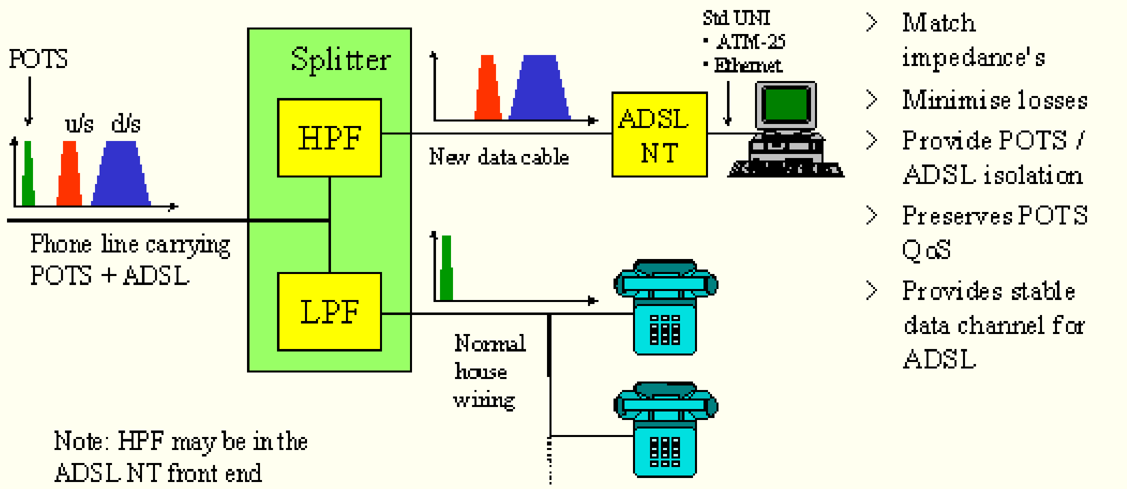

Figure 4 : ADSL showing FDM and service splitter

Downstream and upstream bit-rates are flexible and performance is very dependent on the loop length and noise conditions. ADSL is primarily FEXT limited, whereas ISDN-BA and HDSL are normally NEXT limited. It is this feature of FEXT limitation, which enables bit-rates in excess of 2Mbit/s downstream to be delivered to a large percentage of access network loops. The upstream bandwidth is by its very nature much smaller than the downstream, and ADSL used in network trials around the world is generally achieving around 2Mbit/s downstream with a few hundred kbit/s upstream.

Provision is now made for ATM cell transport and therefore the ADSL transceiver may be thought of as both a bit- and ATM cell pump with multi-service transport capability.

[Standardization work on ADSL] - [Future work on ADSL]

HDSL

High bit-rate DSL modem standards evolved from earlier work on ISDN-BA. The HDSL concept was originally developed in North America when DSL engineers tried to increase the clock rates of ISDN to see how far and fast a high bit-rate system could go, given that Digital Signal Processing (DSP) technology was also rapidly advancing at the same time. Research work led to the discovery that even simple 4-level PAM could be made to work at rates up to 800kbit/s whilst achieving good coverage (known as the Carrier Serving Area in North America). Echo cancellation techniques were again used to enable 784kbit/s duplex over a single wire-pair fulfilling the requirement of reach and adequate Signal-to-Noise margin for good Quality of Service.

HDSL is a bi-directional symmetric transmission system (see Figure 2) that allows the transport of signals with a bit-rate of 1.544Mbit/s or 2.048Mbit/s on multiple access network wire-pairs. Two different options for the linecode are recommended; the Pulse Amplitude Modulation 2B1Q and the Carrierless Amplitude/Phase modulation (CAP). CAP is applicable for 2.048Mbit/s, while for 2B1Q two different frames are defined.

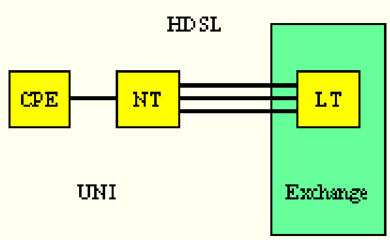

Figure 2 : High bit-rate DSL concept (HDSL)

The 2B1Q standard for 2.048Mbit/s caters for both duplex transmission on a single pair and parallel transmission on two or three pairs. This allows for the distribution of the data to several pairs and for the reduction of the symbol rate in order to increase the line length or transmission reach. CAP is defined for one or two pairs only and the 1.544Mbit/s 2B1Q for two pairs only.

Standardization work on HDSL

SDSL

Symmetric or single-pair DSL (SDSL) is the latest DSL acronym to be coined, and is very much in the requirements capture phase. It is likely to be symmetric and based on older HDSL technology, but using more advanced techniques to enable greater transmission flexibility over a single wire-pair. SDSL will have application to both business and residential sectors, and could therefore have potentially very high volumes.

It is worth noting that some existing narrow-band switch suppliers are viewing this technology as a way of increasing the life of their products. SDSL could be used as an embedded linecard upgrade to enable 2 x B channels of switched traffic to continue to be put through the switch plane. Any access transport capacity left could then be groomed away from the switch plane into an emerging connectionless broadband IP or ATM based broadband core network. Additionally, SDSL capability sits nicely within digital subscriber line access multiplexer (DSLAM) architectures as a complementary access technology to HDSL, ADSL and VDSL.

Standardization on SDSL - Fututre work on SDSL

VDSL

Very high-speed DSL is a natural evolution of ADSL to higher bit-rates and the use of even more bandwidth. This can be contemplated because the effective loop length is shortened due to progress of fibre into the backbone of existing access networks in an FSAN architecture known as Fibre to the Cabinet (FTTCab) as shown in Figure 8 and the VDSL concept is shown in Figure 4.

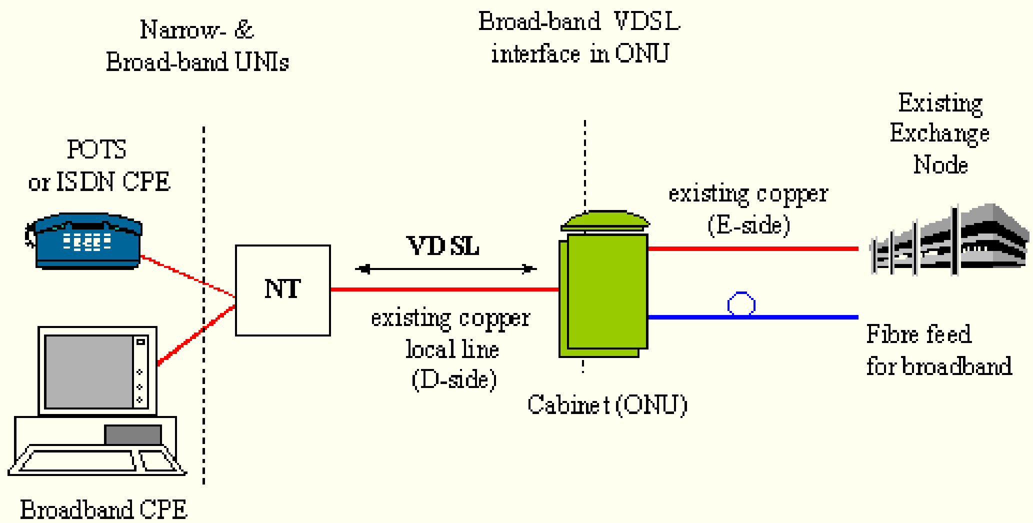

Figure 4 : Fibre to the Cabinet (FTTCab)

Standardization work on VDSL - Future work on VDSL

The xDSL Family

In the following table, one gives a summary of the indicative bandwidthes and bitrates achievable with different members of the xDSL family. Detailed out of band spectra are carefully defined in the corresponding standards. Systems mentioned in Italic are still being discussed.

Member	Frequency Band	Target Bit Rates
ISDN 2B1Q	10 Hz - 50 kHz	144 kbps
ADSL over POTS	25.875 kHz to 1.104 MHz	Up to 8 Mbps DS, 640 kbps US
ADSL over ISDN	138 kHz to 1.104 MHz	Up to 8 Mbps DS, 640 kbps US
HDSL 2B1Q (3 pairs)	0.1 kHz - 196 kHz	2 Mbps
HDSL 2B1Q (2 pairs)	0.1 kHz - 292 kHz	2 Mbps
HDSL CAP (1 pair)	0.1 kHz - 485 kHz	2 Mbps
SDSL	10 kHz - 500 kHz	192 kbps to 2.3 Mbps
VDSL	300 kHz - 10/20/30 MHz	Up to 24/4 DS/US, and up to 36/36 in symmetric mode

Acknowledgments

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Glossary

ADSL	Asymetric Digital Subscriber Line
ATM	Asynchronous Transfer Mode
BA	Basic Access
BER	Bit Error Rate
CAP	Carrierless Amplitude Phase
CPE	Customer Premise Equipment
DMT	Discrete Multitone
DS	DownStream
DSLAM	Digital Subscriber Line Access Multiplexer
DSP	Digital Signal Processing
EC	Echo Cancellation
EOC	Embedded Operation Channel
FDD	Frequency Division Duplexing
FEC	Forward Error Correction
FEXT	Far End Crosstalk
FSAN	Full Service Access Network
HDSL	High bit rate Digital Subscriber Line
IP	Internet Protocol
ISDN	Integrated Services Digital Network
LT	Line Termination
MPEG	Moving Picture Expert Group
NEXT	Near End Crosstalk
NMDS	Narrow-band Multi-service Delivery System
NT	Network Termination
ONU	Optical Node Unit
PAM	Pulse Amplitude Modulation
PMD	Physical Medium Dependent
POTS	Plain Old Telephone Service
PSD	Power Spectral Density

QAM	Quadrature Amplitude Modulation
SDH	Synchronous Digital Hierarchy
SDSL	Symetric Digital Subscriber Line
SHDSL	Symetric High bit rate Digital Subscriber Line
SNR	Signal-to-Noise Ratio
TDD	Time Division Duplexing
TCM	Trellis-Coded Modulation
TCM	Time Compression Multiplexing
TU	Tributary Unit
UAWG	Universal ADSL Working Group
UNI	User Network Interface
US	UpStream
VC	Virtual Container
VDSL	Very high bit rate Digital Subscriber Line

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