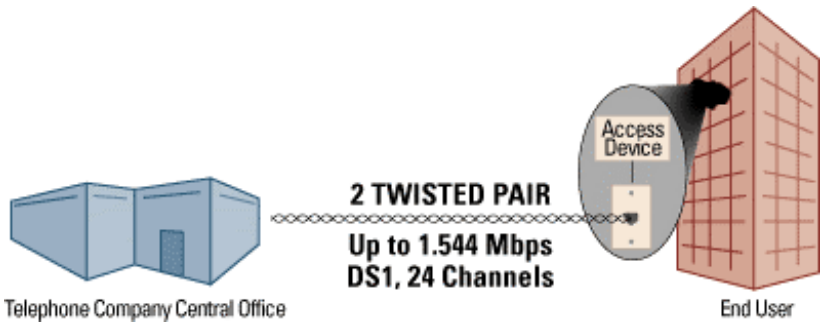
Introduction to
Digital Subscriber's Line (DSL)

Professor Fu Li, Ph.D., P.E. ©

xDSL Overview: T1 & E1

- DSL PrecursorsSome argue: T1, E1, and DDS (Digital Data Service) are first DSLs.
- T1 (1.544 Mb/s AMI) is used primarily in North America, first used by AT&T in 1962,
- E1 (2.048 Mb/s HDB3) was intended between COs but proved useful to customer sites,
- T1/E1 are not used for their original purposes, but still as subscriber lines. They are expensive and hard to install.

xDSL Overview: T1 & E1



xDSL Overview: T1 & E1

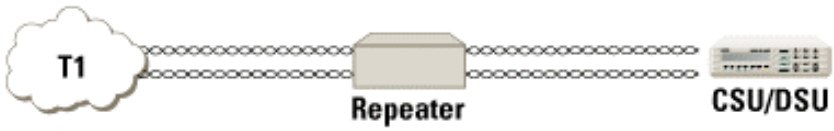
Origin

- In 1961, the Bell System deployed the first digital T-1 circuit.
- The T-Carrier System is a 2-way path, one cable pair for each direction of transmission.
- This T-1 replaced analog carriers that were being deployed.

xDSL Overview: T1 & E1

Reach Limits:

- Repeaters are required at about every 6000 feet for the intermediate repeater sections.
- The first repeater from the Central office is usually no more than 3000 feet away.
- The repeater closest to the customer location is usually no more that 3000 feet away.



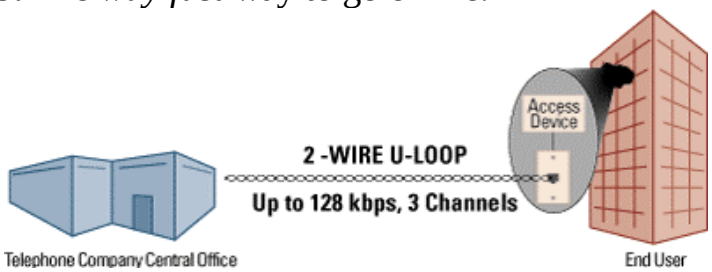
xDSL Overview: T1 & E1

- A T1 consists four wires: two each direction.
- To reduce NEXT, all outbound wires and inbound wires are cabled separately in T1.
- T1 is designed for
  - 15 (2-3 kft) dB line loss t 772 KHz for CO to first repeater,
  - 36 (3-6 kft) between repeaters,
  - 22.5 between last repeater to customer premises.
- T1: unloaded, no bridged taps, and DC power (+/- 130 V).
- Operates over existing phones but requires extensive re-engineering.

xDSL Overview: BRI-ISDN

What is ISDN? **ISDN** [I*SD'N] *n.*

- **1.** Integrated Services Digital Network.
- **2.** A digital telephone service that provides fast, accurate data transmission over existing copper telephone wiring.
- **3.** The *way fast* way to go online.



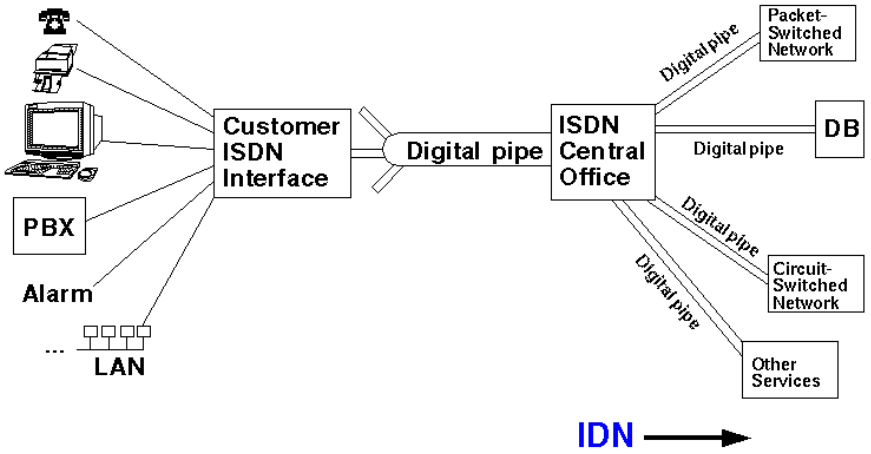
xDSL Overview: BRI-ISDN

ISDN: Integrated Services Digital Network

- Origins: conceived in 1975, tested since 1985, costs $50B
- Vision: a uniform global network for data communications and telephony.
- 100 Million BRI lines
- Available to 90% of phone customers.

xDSL Overview: BRI-ISDN

Conceptual view



xDSL Overview: BRI-ISDN

- Integrated Services
  - Voice
  - Video
  - Image
  - Data
  - Mixed media at a number of standard data rates
- Digital
  - Digital terminal equipment
  - Digital local loops
  - Digital trunks
  - Digital switching
  - Digital signaling
- Network

xDSL Overview: BRI-ISDN

BR-ISDN: Capabilities and applications:

- 160 kb/s of symmetrical transmission
- loops up to 18 kfs (5.5 km) 42 dB of loss at 40 Khz
- Two 64 kb/s B channels (circuit or packet switched), one 16 kb/s D channel (signaling and user data packets), and 16 kb/s for framing and line control. eoc (embedded operation channel and indicator within 8 kb/s overhead.

xDSL Overview: BRI-ISDN

Two communication paths:

- **B-channel** The Bearer ("B") channel is a 64 kbps channel which can be used for voice, video, data, or multimedia calls. B-channels can be aggregated together for even higher bandwidth applications.
- **D-channel** The Delta ("D" or "Demand") channel can be either a 16 kbps or 64 kbps channel used primarily for communications (or "signalling") between switching equipment in the ISDN network and the ISDN equipment at your site.

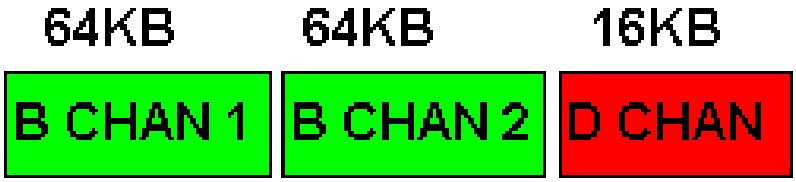
xDSL Overview: BRI-ISDN

- **H Channel**
  - An H channel is a special, high-speed clear channel.
  - H channels, designed primarily for full-motion color video, are not yet in common use.
  - There are currently three kinds of H channel:
    - H0 ("H-zero")
    - H11 ("H-one-one")
    - H12 ("H-one-two")

xDSL Overview: BRI-ISDN

Two pre-defined configurations (Access Types):

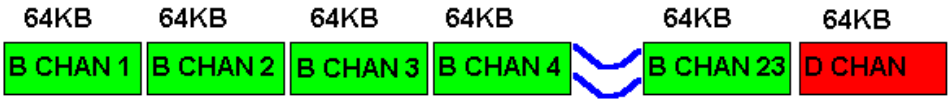
- **Basic Rate Interface (BRI)** connection supports two 64 kbps B-channels and one 16 kbps D-channel over a standard phone line. BRI is often called "2B+D" referring to its two B-channels and one D-channel. The D-channel on a BRI line can even support low-speed (9.6 kbps) X.25 data



xDSL Overview: BRI-ISDN

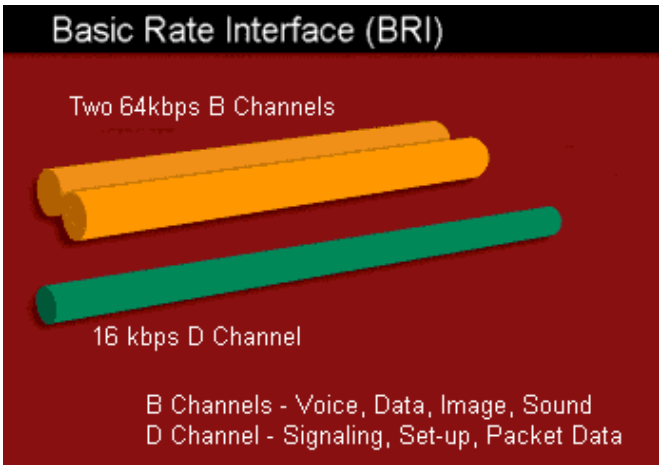
Two pre-defined configurations (Access Types):

- **Primary Rate Interface (PRI)** connection supports 23 64 kbps B-channels and one 64 kbps D-channel (or 23B+D) over a high speed DS1 (or T-1) circuit. The European PRI configuration is slightly different, supporting 30B+D.



xDSL Overview: BRI-ISDN

Two pre-defined configurations (Access Types):

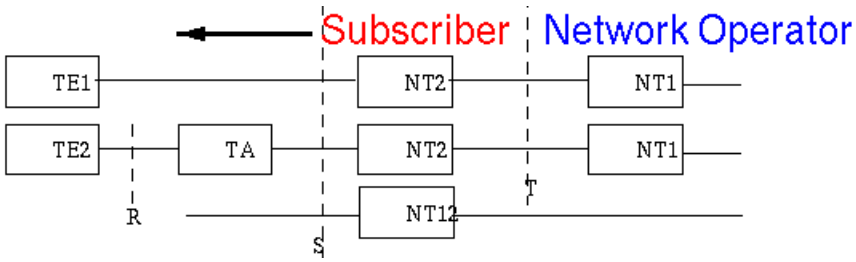


xDSL Overview: BRI-ISDN

- BRI is the most common ISDN for Internet access.
- Single line can support up to three calls at same time due to three channels (2B+D). Two voice, fax, or data "conversations," and one packet switched data "conversation" can take place at the same time.
- Multiple channels or multiple lines can be combined into a single faster connection upon equipment. Channels can be combined as needed for a specific application, then broken down and reassembled into individual channels for different applications.

xDSL Overview: BRI-ISDN

Subscriber's interfaces



xDSL Overview: BRI-ISDN

Types Of Equipment

- **NT1**: Network Termination type 1. This is the end of the line for the local phone company, and the beginning of your house's phone network.
- **NT2**: Network Termination type 2. In most homes, this won't exist. If you were a big company with your own private telephone system, then this would be the guts of that telephone system.
- **TA**: Terminal Adaptor. This lets old, TE2 stuff talk to the ISDN network. It also adapts other kinds of equipment, like ethernet interfaces , to ISDN.

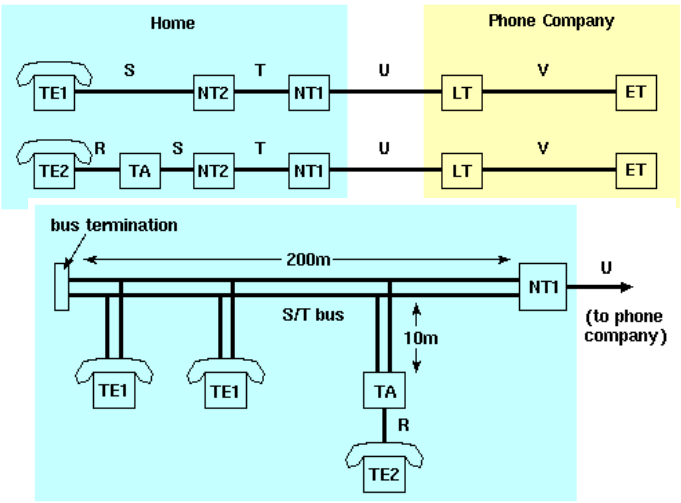
xDSL Overview: BRI-ISDN

Types Of Equipment

- **LT**: Line Termination. This is the physical connection to the phone company.
- **ET**: Exchange Termination. This is the local phone company's logical connection from your telephones to "the phone network".
- Power Supply - plugs into a standard wall outlet and provides power to the ISDN line.
- ISDN Routers - multiple computers on a LAN can share single ISDN BRI connection.

xDSL Overview: BRI-ISDN

Common reference configurations



xDSL Overview: BRI-ISDN

Physical Interfaces - wiring interfaces

- **U-Interface** is the 2-wire interface your phone company delivers for connection to the NT1.
- **S/T Interface** is the 4-wire interface between the NT1 and the ISDN networking equipment such as an ISDN TA or router.
- **Other interfaces** is usually one of the standard industry interfaces. For example, an External TA will use the computer's serial COM port such as RS232.

xDSL Overview: BRI-ISDN

- **Protocol**

OSI	**D–channel**			**B–channel**		
Application	Customer signaling			CCITT or ISO protocol		
Presentation						
Session						
Transport						
Network	Call Control I.451/Q.931	X.25 packet level	(Future Study)			X.25
Data link	LAP–D (I.441/Q.921)			lFrame Relayl		LAP–B
Physical	I.430 basic interface + I.431 primary interface					
Type	**Signal**	**Packet**	**Telemetry**	**Circuit**	**Semiperm**	**Packet**

xDSL Overview: BRI-ISDN

Advantages:

- speed and quality
- flexibility
- Multiple Call Appearance
- No Distance or Size Limitation

xDSL Overview: BRI-ISDN

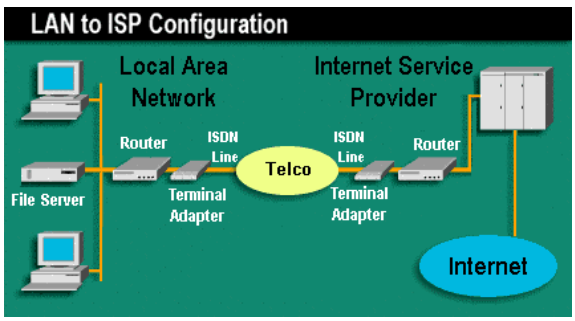
Advantages:

- Incoming Caller Identification
- End-to-End Digital Connectivity
- Visual Message Waiting Indication
- Data Applications

xDSL Overview: BRI-ISDN

Popular ISDN applications include:

- Internet access

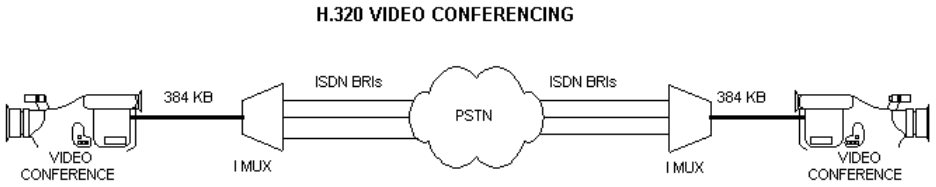


- Telecommuting/remote access to corporate computing
- Small and home office data networking

xDSL Overview: BRI-ISDN

Popular ISDN applications include:

- Video conferencing



xDSL Overview: BRI-ISDN

Popular ISDN applications include:

- Screen Sharing
- **File Transfer**
- **Access on Demand to Local-Area-Networks**

Additional ISDN data applications include:

- PC-to-PC Interactive Host
- Remote Access to ISDN at the Desktop (telecommuting)
- LAN-to-LAN Connectivity

xDSL Overview: BRI-ISDN

BRI-ISDN: Rate Transmission

- Transmission: 2B1Q for most countries, use one four-level pulse to represent two binary bits ; 4B3T for some countries.
- send 160 kb/s over 80 kHz of bandwidth
- echo cancellation and adaptive equalization
- unloaded but with bridge tap

xDSL Overview: H-DSL

High-bit-rate DSL (HDSL) -- Origin:

- Conceived in 1986 Bell Lab and BellCoRe.
- Prototyped in 1989
- Placed in service 1992
- Nearly all phone companies provide HDSL, about 1 million lines are in service.
- Benefit over BRI: no mid-span repeater
- Benefit over T1/E1 system with more extensive SNR diagnostic feature and less cross talk.

xDSL Overview: H-DSL

HDSL is

- a physical layer data communications standard
- that allows bi-directional symmetrical data transmission
- over pairs of metallic wires (such as copper telephone cables) at bit-rates of up to 2.340 Mbps.
- This allows HDSL to support services traditionally offered by more expensive T1 (1.544 Mbps)/E1 (2.048 Mbps) connections.

xDSL Overview: H-DSL

- the oldest of the DSL technologies, and the most heavily deployed. HDSL evolved from research in attempting to increase the bit-rates provided by basic rate interface (BRI) ISDN.
- By using digital signal processors (DSP), and using advanced coding and modulation techniques, HDSL can achieve bit-rates of 2.340 Mbps over one pair of wires, or 1.168 Mbps each over two pairs in parallel, and 784 Kbps each over three pairs of wires in parallel. **HDSL** is
- HDSL has a maximum serviceable range of about 15000 ft or just less than 4.6 Km by using standard 0.5 mm or 24 Gauge wire.

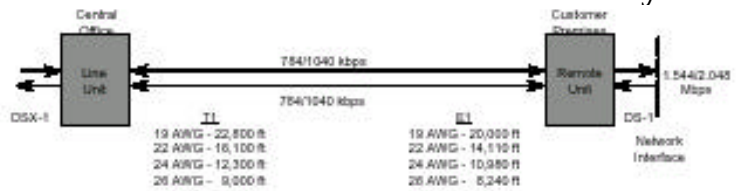
xDSL Overview: H-DSL

HDSL: The New Way to T1 (xDSL)

- High-bit-rate Digital Subscriber Line
  - 4-PAM, 2 pairs, 772 kbits/pair full duplex
- High-performance adaptive digital signal processing
  - Feedback Equalization
  - 250 MIPS Echo cancellation
  - Decision VLSI
- No segregation, no bridged-tap removal
- Full CSA distance (9000-12000 ft), repeaterless

xDSL Overview: H-DSL

HDSL ACCESS NETWORK: New Way to T1



High-bit-rate Digital Subscriber Line

- 2B1Q: 4-PAM, 2 pairs, 772 kbits/pair full duplex
  - High-performance adaptive digital signal processing

xDSL Overview: H-DSL

High-bit-rate Digital Subscriber Line

- Echo cancellation, Decision Feedback Equalization, 250 MIPS VLSI
- Repeaters are not required
- Operate with loops of mixed gauge wire, Bridged tap removal not required
- Pairs may be in same binder group & no interference to existing services

xDSL Overview: H-DSL

HDSL's Applications and Benefits

- designed to transfer data rapidly from one location to another using existing telephone cabling.
- is symmetric - upstream speed is the same as down-stream speed, to provide bi-directional connectivity.
- With the advent of HDSL, the same bandwidth can be obtained at a fraction of the cost of T1/E1
- HDSL does not require repeaters to be installed every 1 Km, does not require stringent line conditioning, installation time is reduced from months to hours.
- As a result, many telcos deploy HDSL systems to carry traditional T1/E1 services.

xDSL Overview: H-DSL

Capacities

- Two way transport at 1.544 or 2.048 Mb/s up to 3.7 km (12 kft) without Mid-span repeater (twice distance with one repeater, 95% of time no) of 0.5 mm (24 AWG)
- Allows bridged taps, no loading coils.
- no line re-conditioning and binder group segregation is needed (single or dual duplex).
- Reliable service to all Carrier Service Area (CSA) with BER at 10exp –(9 ~10)

xDSL Overview: H-DSL

Capacities

- DS1 HDSL (1.544 Mb/s) uses two pairs of wires each of 784 kb/s payload in both directions (dual duplex transmission).
- E1 HDSL (2.048 Mb/s) uses either two or three pairs with full duplex transmission. Three-pair transmission uses same transceiver as DS1.

xDSL Overview: H-DSL

Repeater and Reach

- Repeaters may be used for beyond the reach (line powered from CO):
- No repeater: 2.75 to 3.7 km (9-12 kft),
- One repeater: up to 7.3 km (24 kft)
- Two repeater: 11 km (36 kft)

xDSL Overview: H-DSL

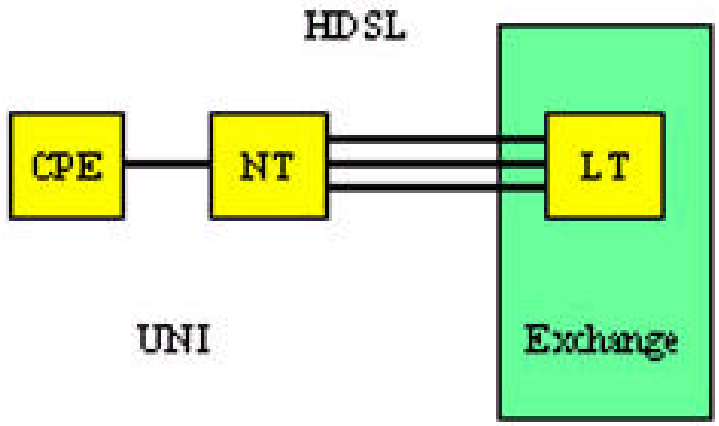
Subsystems

- HDSL lines are not used to connect central offices because their bandwidth cannot compete with levels offered by optical fiber carriers (OC-x).
- However, to the end consumer, their performance and price make them an excellent choice.

xDSL Overview: H-DSL

CPE=Customer Premise Equipment NT=Network Termination

LT=Line Termination UNI=User Network Interface

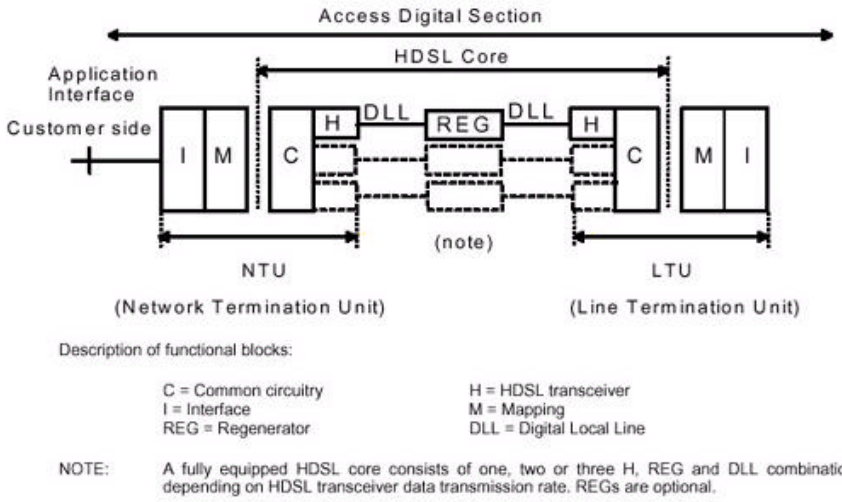


xDSL Overview: H-DSL

- The CPE or Customer Premise Equipment is essentially the customer's network interface card (NIC), or a hub, or a router, etc.
- The CPE connects to the NT/NTU or Network Termination Unit via a network cable.
- The NT connects to the LT/LTU or Line Termination Unit at the telco's local exchange via Digital Local Lines (ie, telephone cables).

xDSL Overview: H-DSL

Detailed block diagram



xDSL Overview: H-DSL

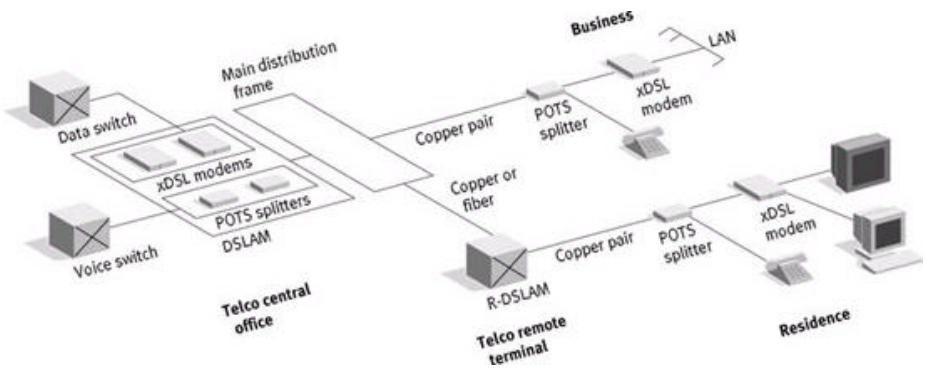
- The NT (NTU) is on the customer side, it is analogous to a modem. It connects to the LT (LTU), which is on the telco's local exchange (or CO) side, through one to three pairs of Digital Local Lines (DLL). It also connects to the customer's network equipment.
- The LT (LTU) is at the telco's local exchange, where thousands of cables connect to racks of line cards. They are then multiplexed into the telco's main fiber-optic backbones and thus to the global communication network.

xDSL Overview: H-DSL

- The DLL (Digital Local Lines) are simply metallic lines connecting the NTU and LTU, copper is the transmission medium of choice for HDSL systems
- A variety of sizes of cables can be used for the various sections of a HDSL system,
- industry standard 24 AWG (American Wire Gauge) cable is most widely used.
- With 24 Gauge cable, HDSL has a range of about 15000 ft.

xDSL Overview: H-DSL

Physical model of DLL connection from NTU to LTU



xDSL Overview: H-DSL

- HDSL systems do not support simultaneous voice and data operations.
- Hence, no Splitters in a HDSL system. This is because traditional voice communications uses frequencies below 20 KHz, however, HDSL uses frequencies from 0.1 to 196 KHz (for 3 pair DLL operation), and 0.1 to 292 KHz (for 2 pair DLL operation) and 0.1 to 485 KHz (for single DLL pair).

xDSL Overview: H-DSL

Applications:

- Primary rate private line circuits from user to network.
- Connect private branch exchange (PBX) and Packet/ATM equipment to net
- Connect small digital loop carrier (DLC) to CO

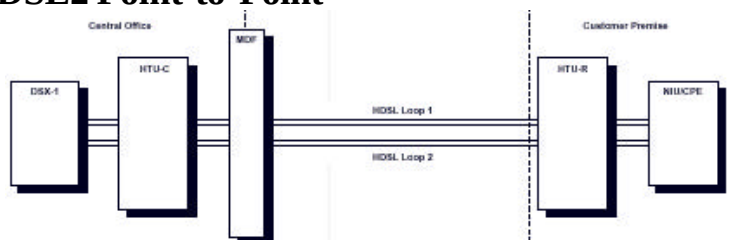
xDSL Overview: H-DSL

Economics

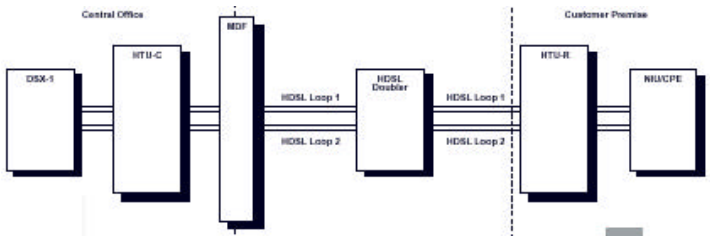
- Installation cost went lower than T1/E1 since 1994
- Maintenance is lower than T1/E1 as well.

xDSL Overview: H-DSL

HDSL2 Point-to-Point



HDSL2 Extended



xDSL Overview: H-DSL

HDSL systems support two line codes:

- 2B1Q (2 binary and 1 quaternary) is used generally in North America as the standard line code for DSL systems.
- CAP (Carrierless amplitude/phase modulation) is also used in Europe as the standard line code for DSL systems (European Telecommunications Standards Institute).

xDSL Overview: H-DSL

2B1Q a 4 level PAM signal

Dibit	00	01	11	10
Amplitude	-3	-1	1	3

xDSL Overview: H-DSL

2B1Q

- It is clear that if "0"s and "1"s are equally probable, then, the 2B1Q has zero energy at DC on average.
- it offers excellent performance in reducing near-end crosstalk and intersymbol interference.

xDSL Overview: H-DSL

CAP can also be used in a HDSL system.

- Trellis coded 64-CAP system can be used to achieve 1.168 Mbps and
- a Trellis coded 128-CAP system can achieve 2.320 Mbps.
- The details of the CAP systems are beyond the scope at this point.

xDSL Overview: H-DSL

Timing -- Stuff Quats:

- Quaternary symbols represents two bits
- Need to synchronize payload bit-rate with HDSL line rate.
- Allow slight difference between up- and down- stream payloads.

xDSL Overview: H-DSL

Delay (Latency) -- End-to-end delay for signal transfer:

- T1: 100 micro-seconds
- HDSL: 400 micro-seconds one way due to DSP (standard: less 500)
- Repeater doubles delay.

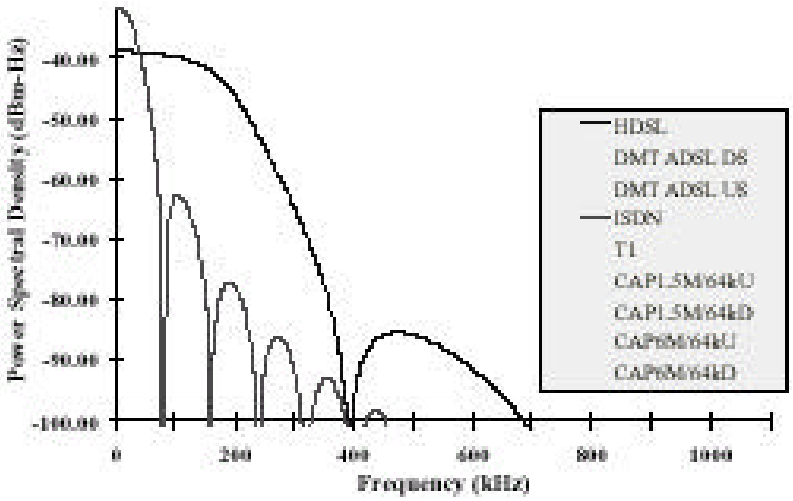
xDSL Overview: H-DSL

BER

- BRI, HDSL, ADSL all are designed for better than 10 exp-7 BER on worst case loop with Cross Talk power 6 dB greater than theoretical worst case cross talk model.
- 99% HDSL are in fact operated at 10 exp-9 BER.
- 6-dB design margin seems over-engineered for the worst case but fits for all situations (water in cable, bad slice, poor quality, and longer line).

xDSL Overview: H-DSL

Symmetric Echo-Cancelled Transmission:HDSL & ISDN



xDSL Overview: H-DSL

The Future of HDSL

- because of the abundance of copper cabling buried, HDSL will still play a strong role in connecting consumers and businesses to network backbones because of its
  - low cost,
  - high performance, and
  - low maintenance requirements.
- Further, a new emerging standard is called HDSL2, its design goal is to allow 18000 ft connections with standard 24 Gauge cable.

xDSL Overview: H-DSL

Standardization

- ETSI built on the good foundation work and initially adopted and standardized the 2B1Q 784kbit/s HDSL for providing structured and unstructured 2.048Mbit/s access using three wire-pairs.
- Subsequently, with improvements in HDSL technology, a 2-pair variant was standardized by ETSI followed by a 1-pair variant, each delivering 2.048Mbit/s over progressively shorter loops.

xDSL Overview: H-DSL

Standardization

- ETSI has also specified Carrierless Amplitude/Phase variant for operation over one and two wire-pairs.
- ETSI has also specified HDSL for use in SDH applications where VC-12 or TU-12 can be transported in a 2.3Mbit/s payload.
- These evolutions and improvements have been brought in the successive version of **ETSI TS 101 135**, the last one being V1.5.3.

xDSL Overview: H-DSL2

High-bit-rate Digital Subscriber Line 2 (**HDSL-2 or SDSL --** Second generation): is a technology that

- transmits a T1 on 2 wire (one pair) 24 AWG copper wire w/o repeaters for 12,000 feet .
- (In comparison, HDSL uses 4 wires to do the same job HDSL2 does with 2 wires.)
- reduces to one pairs with more complex modulation and coding technology
- is rate adaptive

xDSL Overview: H-DSL2

- Symmetric at 1.544 MBPS
- Applications:
  - T1 Replacement
  - Telecommuting
  - Internet access
- Advantages over T1:
  - Much easier to deploy
    - Bridged Taps OK
    - 12,000 ft range
    - Spectral compatibility
  - Single Twisted Pair

xDSL Overview: H-DSL2

Requirement

- Loop reach: same as two pairs
- Impairment: minimum 5 dB of performance margin with 1% worst case cross talk from more interfering services
- Spectral compatibility: no more than what is tolerated today.
- Latency: no more than HDSL

xDSL Overview: H-DSL2

Impairments:

Severe worst case combination:

- NEXT as in T1 Standard
- FEXT as in T1 Standard
- FDM split point
- Impulsive noise is not considered.

xDSL Overview: H-DSL2

Spectral Compatibility -- A big challenge to determined between difference services.

- With T1: 15-dB loss on the first segment not 30 dB as other segments must operate over with.
- With ADSL: 1 dB degradation
- With HDSL: unnecessary.

xDSL Overview: H-DSL2

Modulation Format -- Key Elements:

- The up- and down- stream transmitters will each have a unique spectral shape;
- The up- and down- stream transmitter spectra will partially overlapped in frequency
- The shape of spectrum will be decoupled from symbol rate to allow the flexible use of excess bandwidth.
- The transmit modulations will be pulse amplitude modulation (PAM).
- Coded modulation will be used.

xDSL Overview: H-DSL2

Line Coding:

- HDSL2uses the Trellis Coded PAM (Pulse Amplitude Modulation) line code.
- This yields 3 bits per baud. Trellis Coded PAM along with POET (Partially Overlapped Echo Canceled Transmission) allows HDSL2 to deliver all 24 channels using 2 wires , while maintaining a loop distance of 12,000 feet on 24 AWG.

xDSL Overview: H-DSL2

HDSL2

- can tolerate bridged taps,
- but cannot tolerate load coils.
- A single bridged tap can be no more than 2000 feet and total length of all bridged taps cannot exceed 2500 feet.
- HDSL2 can reach 12,000 ft on 24-AWG cable non-loaded, non-bridged tapped cable.
- This distance is 9,000 feet if the cable is 26-AWG

xDSL Overview: H-DSL2

Complexity Differences Relative to HDSL

- Transmit power 3 dB higher than HDSL
- Channel equalizer precoder is 12-16 bit wide instead of two bits
- Trellis code on the order of 512 states will be needed to meet Viterbi decoding
- Fractionally spaced equalizer and echo-canceler, more complex than the baud-spaced equivalents in HDSL

xDSL Overview: ADSL

Definition and Reference Model

- *Definition*: A local loop transmission technology that simultaneously transports via on pair of wires:
- Downstream (towards customer) bit rates up to about 9 Mb/s
- Upstream (toward network) bit rate up about 1 Mb/s
- POTS, analog voice
- *Asymmetric* in bit rates.

xDSL Overview: ADSL

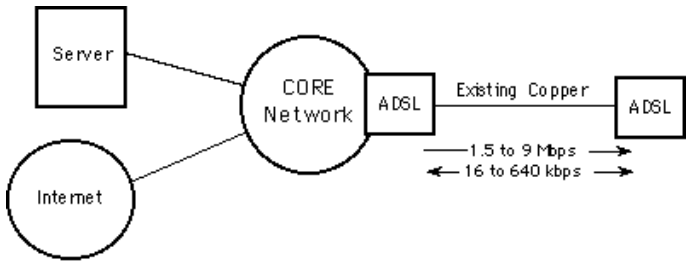
Origins

- Conceived 1989 primarily by Joseph W. Leichleider and others at BellCoRe.
- Derived from Voice Band Modem, ISDN, and HDSL.
- Developed 1990 at Stanford & AT&T Bell Labs.
- Tested in 1992.
- Deployed in 1995.

xDSL Overview: ADSL

Origins

- Standardized in 1998 by ITU as G.922.1
- Expanded in ANSI T1.413,G.992.2, G.994.1, G.995.1, G.996.1, G.997.1.



ADSL Connection

xDSL Overview: ADSL

Capabilities -- ADSL-1, 2,3

- ADSL-1: downstream at 1.5 Mb/s and upstream at 16 Kb/s for video dial tone (DVT) MPGE-1
- ADSL-2 downstream at 3 Mb/s and upstream at 16 Kb/s
- ADSL-3 downstream at 6 Mb/s and upstream at 64Kb/s for MPEG-2

xDSL Overview: ADSL

Capabilities --

Data Rate	Wire Gauge	Distance	Wire Size	Distance
1.5 or 2 Mbps	24 AWG	18,000 ft	0.5 mm	5.5 km
1.5 or 2 Mbps	26 AWG	15,000 ft	0.4 mm	4.6 km
6.1 Mbps	24 AWG	12,000 ft	0.5 mm	3.7 km
6.1 Mbps	26 AWG	9,000 ft	0.4 mm	2.7 km

xDSL Overview: ADSL

Capabilities -- RADSL

- Rate-Adaptive DSL: capable of automatically determine the transport capacity of the individual local loop then operate at highest possible rate.
- Rate adaptation occurs up line state-up, with adequate signal quality margin.
- RADSL borrowed the concept form voice-band modem.
- Maximum downstream 7 to 10 Mb/s and upstream 512-900 kb/s.

xDSL Overview: ADSL

Transmission:

- Fundamental concepts:
- NEXT is reduced by having upstream bit rate and bandwidth much lower than those of downstream
- Simultaneous transport of POTS and data by transmitting data in frequency band much high than voice telephony

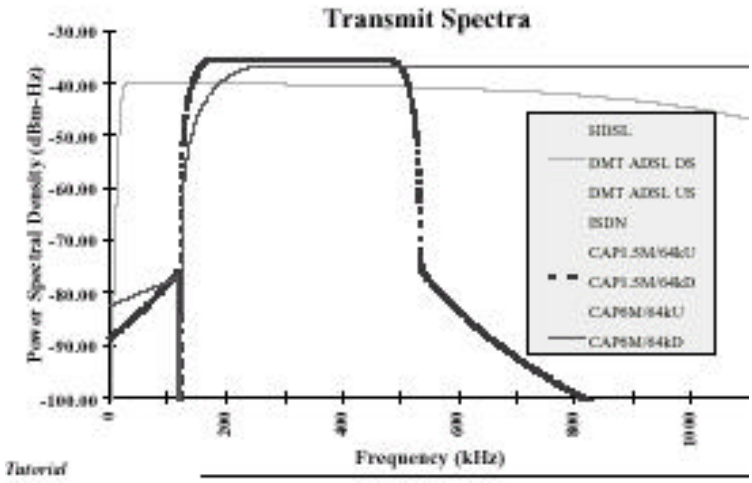
xDSL Overview: ADSL

Transmission:

- For two-way transmission, Received Signal attenuates and Cross-Talk increases as frequency goes higher. ADSL uses high frequency for one-way.
- Many ADSL use FDM for up- and down-streaming with a guard band in between with voice-band.
- Some ADSL overlaps up- and down-streaming using Echo Cancellation Hybrid technique.

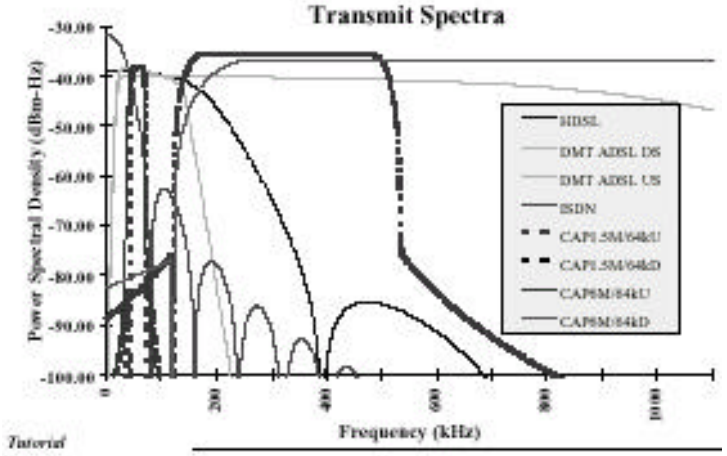
xDSL Overview: ADSL

ADSL Downstream



xDSL Overview: ADSL

ADSL tolerates xDSL & ISDN Disturbers



xDSL Overview: ADSL

Why does ADSL go so fast?

- Fact 1: Communications works on signal & noise
- Fact 2: Unlike earlier systems, e.g., T1, xDSLs (HDSL, ADSL, VDSL...) can move around interferers in frequency
- Fact 3: Except for T1 signals, the DSL spectrum above 200 kHz is unclaimed

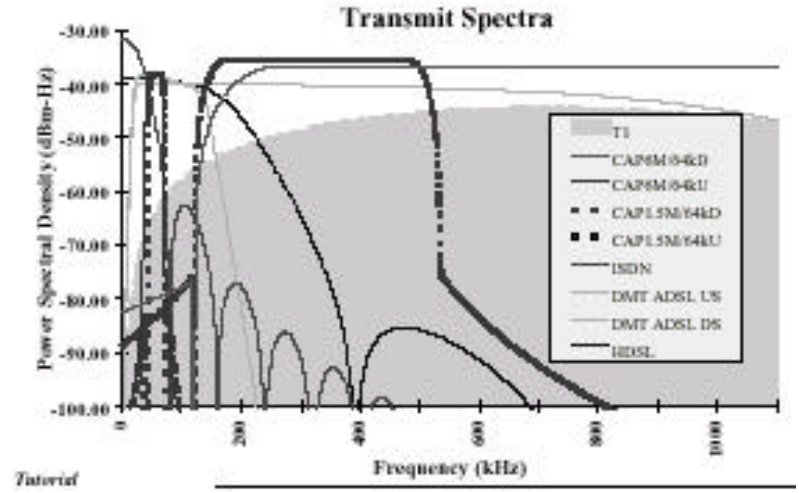
xDSL Overview: ADSL

Why does ADSL go so fast?

- Result 1: In the absence of T1, a 1-way signal can achieve high data rates (or long reaches) - hence ADSL
- Result 2: ADSL can only go fast 1-way, not symmetrically
- Result 3: “Reverse ADSL” ruins ADSL reach or rate for everyone in the same binder group

xDSL Overview: ADSL

ADSL impaired by (AMI) T1



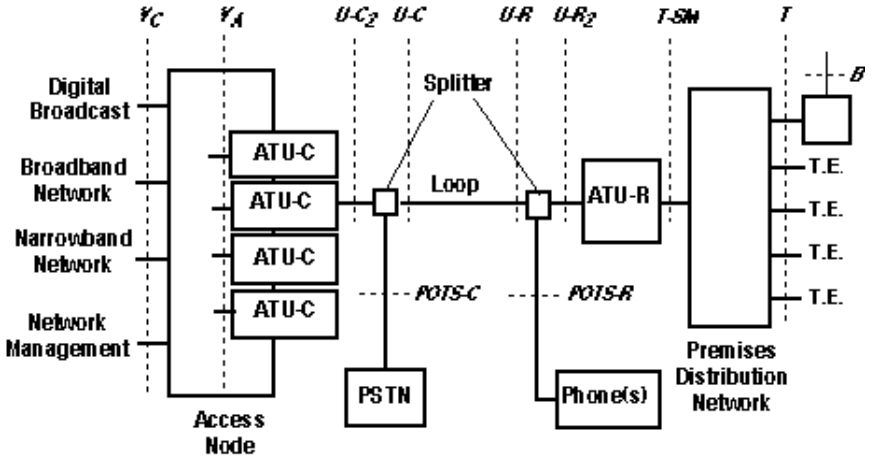
xDSL Overview: ADSL

ADSL impaired by (AMI) T1

- the downstream ADSL is in the same binder as T1 signals transmitting in the upstream direction.
- T1 adds substantially more interference (noise) into the downstream ADSL signal.
- Therefore ADSL reach is decreased.
- Note that since higher data rates generally require more bandwidth, reach is especially degraded for ADSL rates above 1.5 Mbits.

xDSL Overview: ADSL

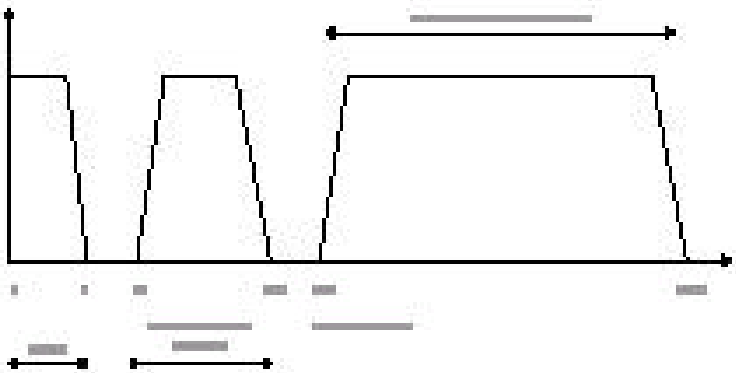
ADSL Architecture



xDSL Overview: ADSL

ADSL FDM System

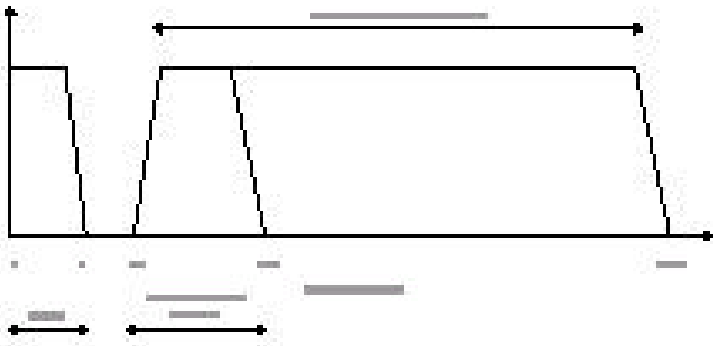
- Divides the 1+ MHz bandwidth into 3 disjoint regions using filters.



xDSL Overview: ADSL

ADSL ECH System

- Upstream and downstream bandwidths overlap, requiring the use of echo cancellation to separate channels



xDSL Overview: ADSL

Transmission:

- Pros/Cons:
  - FDM ADSL performs better in upstream due to less self cross talk;
  - ECH ADSL performs better in downstream due to wider bandwidth in for shorter loop.

xDSL Overview: ADSL

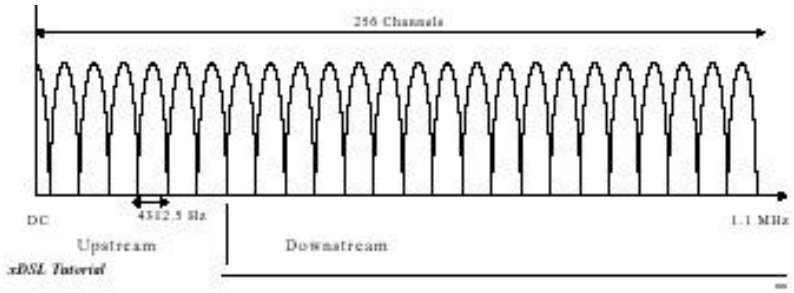
History about ADSL Line Codes

- 1.QAM, or Quadrature Amplitude and Phase Modulation, a line coding technique used in modems for over 20 years
- 2.CAP, which was introduced earlier for HDSL and is actually a variant of QAM
- 3.DMT, or Discrete MultiTone, a line coding technique that was patented (but not implemented) by AT&T Bell Labs over 20 years ago

xDSL Overview: ADSL

DMT for ADSL

- DMT (Discrete Multi-tone) is the worldwide standard for ADSL transmission.
- For full-rate ADSL (T1.413), DMT is a multi-carrier system with 256 carriers (or subchannels) spaced 4.3125 kHz apart.



xDSL Overview: ADSL

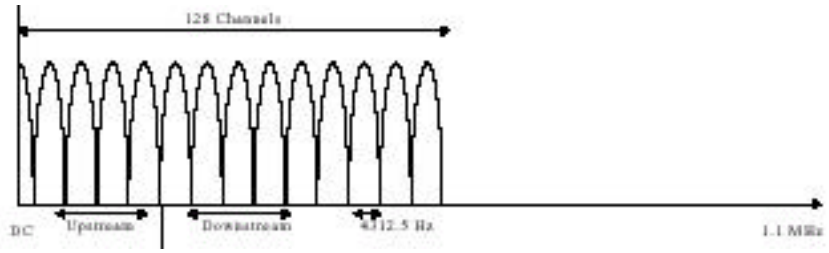
CAP or DMT?

CAP	DMT
Inherently – Lower analog power – Lower latency (μ msec) – Less flexible on rates – Fixed frequency plan	Inherently – Higher analog power – Higher latency **(msec)** – Variable rate
Current state – More field experience – Single technology source – Non-standard	Current state – ANSI standard (T1.413-1995) – Multiple technology sources – Less field experience

xDSL Overview: ADSL

DMT for G.lite (UADSL)

- G.lite/Universal ADSL (UADSL) systems are to be interoperable with full-rate T1.413 ADSL with extensions:
  - Splitterless operation
  - Reduced bandwidth/power



xDSL Overview: ADSL

ADSL vs. HDSL - Which one do I need?

When ADSL:
– When downstream bandwidth is the priority
– When long reach without doublers is required
• No access to loop plant
– Key Application: Web surfers

When HDSL:
– Doublers: When high data rates are required at long reaches
• 768 kbps, 36,000 ft
– When spectral compatibility is a concern (T1 circuits in loop)
– When Telco 'owns' remote
• (desire for line powering)
– When upstream bandwidth is the priority
– Key Application: Businesses

xDSL Overview: ADSL

- **DMT has been recently chosen for use in the G.lite** (ADSL-lite, UADSL, "splitterless" ADSL) standard from the ITU.
- G.lite systems, also called ADSL-lite, Universal ADSL (UADSL), and "splitterless" ADSL feature the ability to coexist on the same wire with telephone service, without the installation of a special filter at the entrance to the home.
- G.lite ADSL uses less bandwidth than full-rate ADSL, using only a 128 point FFT to get bandwidth up to 552 kHz.

xDSL Overview: ADSL

Splitterless ADSL

- Conventional ADSL uses splitter at NID in customer's premise to extract voice band signals to red and green wires and leave wide-band signal to yellow and black wires.
- But yellow and black might not be always possible, might have been used, may impair operation.
- Splitterless ADSL let all go through red and green (ADSL in every phone jacket on the wall.

xDSL Overview: ADSL

Future

- Will be integrated into fiber-fed digital loop carrier (DLC) systems to address those loops that are not served directly from CO.
- Become the access technology of Asynchronous Transfer Mode (ATM) to homes and small offices for 45 Mb/s and above (work underway for error rates, latency, asymmetry, and dynamic rate change).
- Being further developed to include multiple digital derived oice circuits in addition to high-speed data.

xDSL Overview: VDSL

VDSL- Very-high-bit-rate DSL,

- an extension of ADSL to 53 Mb/s downstream.
- primarily for Optical Network Unit (ONU) which connects CO and can be found less than 1 km away from customers premises.

xDSL Overview: VDSL

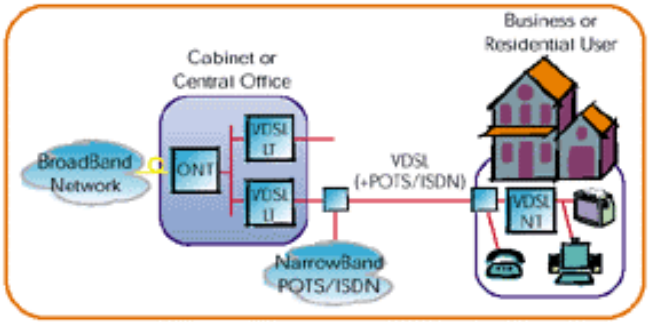
Why VDSL?

- VDSL is the ultimate solution for broadband services over copper telephone lines, transforms the existing telephone twisted pair access network into an information superhighway.
- VDSL gives telecom operators the opportunity to offer existing and emerging services at unequalled speeds, up to 58 Mbit/s, over the existing twisted pairs.
- Symmetrical and asymmetrical services are supported.

xDSL Overview: VDSL

Origin

- Conceived in 1994 by standard committees;
- Standardized in ETSI TM6 and T1E1.4



xDSL Overview: VDSL

Applications

- Full service network for voice, data, video, and
- ultimately for HDTV (High definition Television) and
- high-performance Computing.

xDSL Overview: VDSL

Other applications examples are

- fast Internet access for users and content providers,
- digital video broadcasting,
- interactive video,
- LAN interconnection,
- teleworking,
- high quality videoconferencing.

xDSL Overview: VDSL

VDSL in the network

- VDSL is deployed from the cabinet or from the central office exchange.
- VDSL is a fiber to the node architecture with an optical network unit sited in the access network.
- The VDSL Line Terminations (LT) are grouped so that they share the same optical interface to the broadband network.
- At the customer's premises, the VDSL Network Termination (NT) provides a set of standardized user network interfaces.

xDSL Overview: VDSL

VDSL in the network

- VDSL allows shared use of the telephone pair for broadband and narrowband services such as POTS ISDN.
- Simultaneous operation of VDSL with legacy narrowband services requires a splitter filter at both ends of the line.
- Alternatively, the narrowband services can be carried in-band, as part of the digital data.

xDSL Overview: VDSL

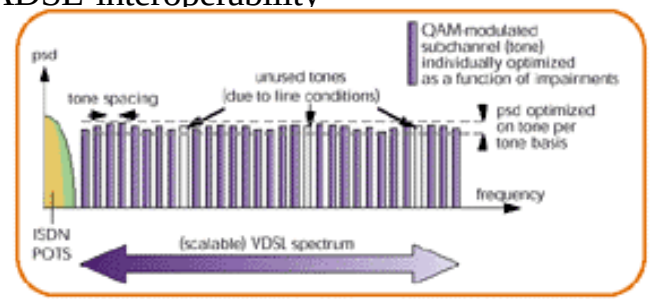
Capacities

- DAVIC VDSL type specification employs Carrierless Amplitude Phase Modulation (CAP) for
- 51 Mb/s upstream and
- 1.6 Mb/s upstream via an unshielded twisted wire pairs.

xDSL Overview: VDSL

Capacities

- Alcatel's VDSL solution is based on DMT (Discrete MultiTones), ensuring
  - spectral compatibility with existing services,
  - robustness to radio interference and
  - ADSL interoperability



xDSL Overview: VDSL

Capacities -- VDSL passive hub architecture:

- permits direct connection of multiple VDSL transceivers at the customer end of line,
- requires the OUN to be less than 100 meters from customer VDSL unit thus more suitable for fiber-to-the-pedestal and in-premises application.

xDSL Overview: VDSL

Capacities --VDSL active hub architecture:

- permits a greater (rate) X (reach) product by using a point-to-point configuration for loop transmission,
- consists of a single VDSL transceiver, and a separate short-haul link within the premises to each terminal, or a short-haul bus with the premises.

xDSL Overview: VDSL

VDSL system features

- A VDSL transceiver can transport
  - ATM (Asynchronous Transfer Mode) or
  - STM (Synchronous Transfer Mode) services

with associated network timing references.

- Furthermore, it can offer
  - delay-sensitive services as well as
  - services with less stringent latency requirements but that are sensitive to impulsive noise .

xDSL Overview: VDSL

VDSL system features

- Symmetric and
- asymmetric

modes of operation are possible.

- The up- and down- stream rates depend on
- the loop length,
- the noise environment and
- the selected downstream-to-upstream ratio.

xDSL Overview: VDSL

Typical VDSL rates

Reach	Downstream data rate	Upstream data stream
300m	52 Mbit/s	6.4 Mbit/s
300m	26 Mbit/s	26 Mbit/s
1,000m	26 Mbit/s	3.2 Mbit/s
1,000m	13 Mbit/s	13 Mbit/s
1,000m	13 Mbit/s	1.6 Mbit/s

xDSL Overview: VDSL

Typical VDSL rates

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xDSL Overview: VDSL

Power

- The transmit power is limited to 11.5 dBm (14 mW) over a band from DC up to l 30 MHz.
- For the power spectral density (psd) limit, options exist upon the topology and the environment.
- Key parameters characterizing the mask options:
  - ADSL compatibility,
  - psd enhancement and
  - radio interference emission notching.
- In addition, regional differences exist.

xDSL Overview: VDSL

VDSL spectral compatibility with existing xDSL systems

- ADSL,
- ISDN-BRA (Basic Rate Access),
- ISDN-PRA (Primary Rate Access) and
- HDSL (High-speed DSL).

xDSL Overview: VDSL

- VDSL system should not interfere with wireless communication systems within its bandwidth.
- Without precautions, such interference would be caused by poor cable balance resulting in unwanted emission and susceptibility to radio interference.
- Concern is egress into and ingress from radio amateurs (HAM radio).

xDSL Overview: VDSL

VDSL standardization is in progress

- in ITU (International Telecommunication Union), study group SG15/Q4, as well as
- in the regional bodies ANSI/T1E1.4 (American National Standards Institute) and ETSI/TM6 (European Telecommunications Standards Institute).