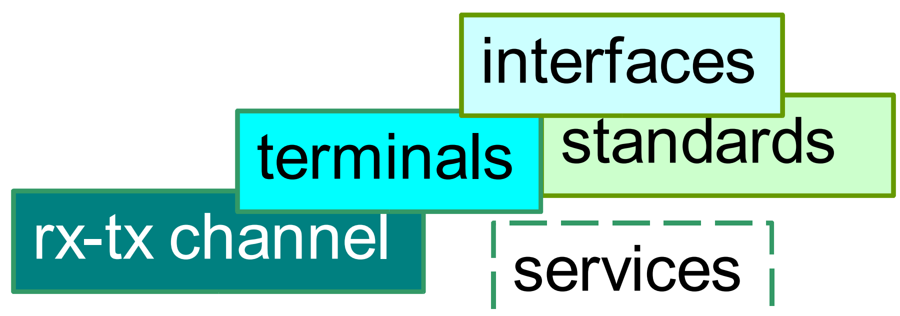
Asymmetrical Digital Subscriber Line (ADSL)

Asymmetrical Digital Subscriber Line

- Physical level (modem technology)
  - Frame structures
  - Modulation
  - Coding
- PSTN local loop as a high-rate digital transmission channel
- Migration issues: Example: Interoperability with ATM
- Flavors of xDSL: performance issues
- Standardization overview



Overview

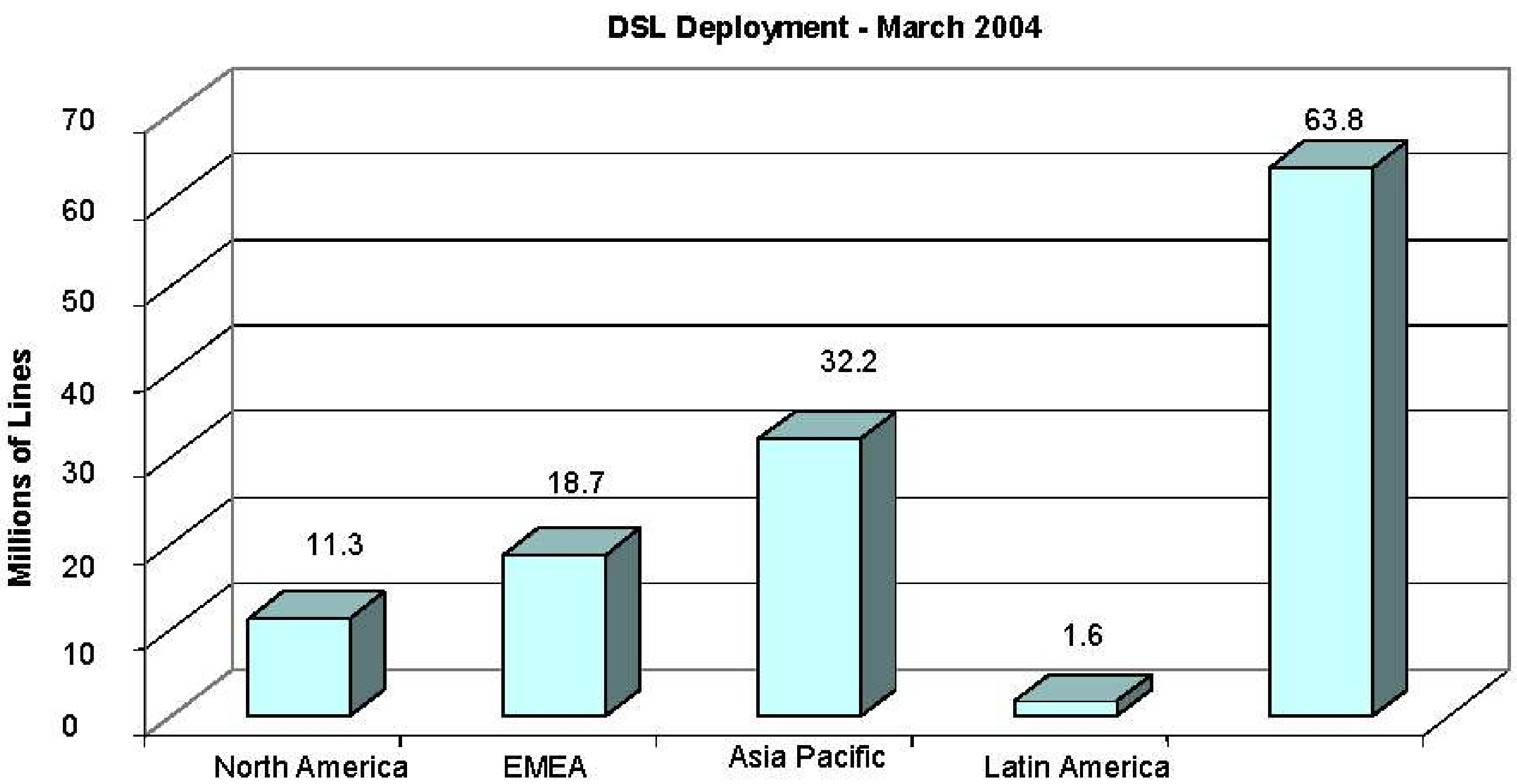
Short history of ADSL

1985 --	Bell Labs develops **OFDM** to make traditional copper wires to support new digital services - especially video-on-demand (VOD)
1990 --	Phone companies start deploying High-Speed DSL (HDSL) to offer T1 service (1.544 Mb/s) on copper lines without the expense of installing **repeaters** - first between small exchanges
	Phone companies begin to promote HDSL for smaller and smaller companies and ADSL for **home internet access**
1993 --	Evaluation of three **modulation technologies** for ADSL: QAM, DMT and CAP. DSL Forum established on 1994
1995 --	Innovative companies begin to see ADSL as a way to meet the need for faster Internet access
1998 --	**DMT adopted** by almost all vendors following ANSI T1.413 - issue 2 (in contrast to CAP)
1999 --	ITU-T produced ADSL standards G.992.1 (G.full: 8M/640k) and G.992.2 (G.lite: 1.5M/512k)

… history

2001 --	Number of DSL subscribers **18.7** million worldwide
2002 --	ITU-T completed G.992.3 and G.992.41 standards for ADSL2
2003 --	ADSL2plus released (G.992.5). It can gain up to 20 Mbps on phone lines as long at 1.5 km. **30** million ADSL users worldwide
2004 --	VDSL2 standards under preparation in DSL forum

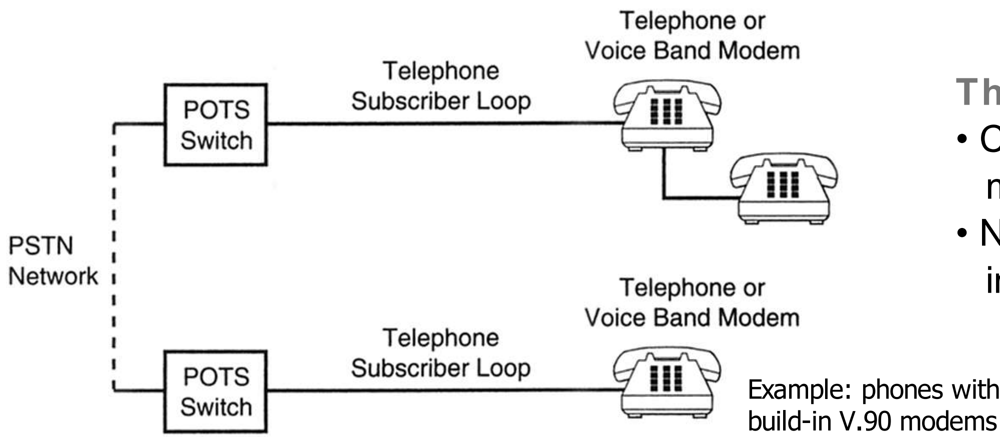
Worldwide deployment of xDSL technologies



Source: Point Topic, March 2004

Reference: DSL Forum: DSL Anywhere - Issue 2, Sep. '04

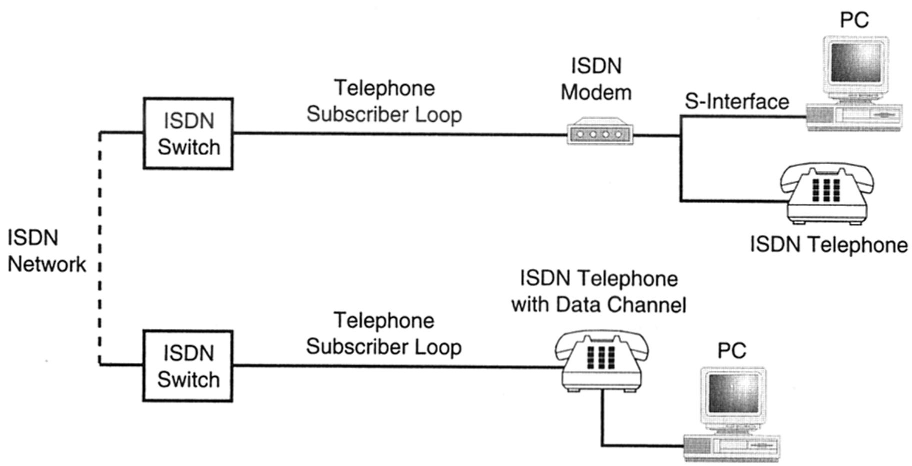
Development of digital access in PSTN



Through analog voice:

- Connecting a voice-band modem (as V.90)
- No switch or network infra changes

The first DSL technique



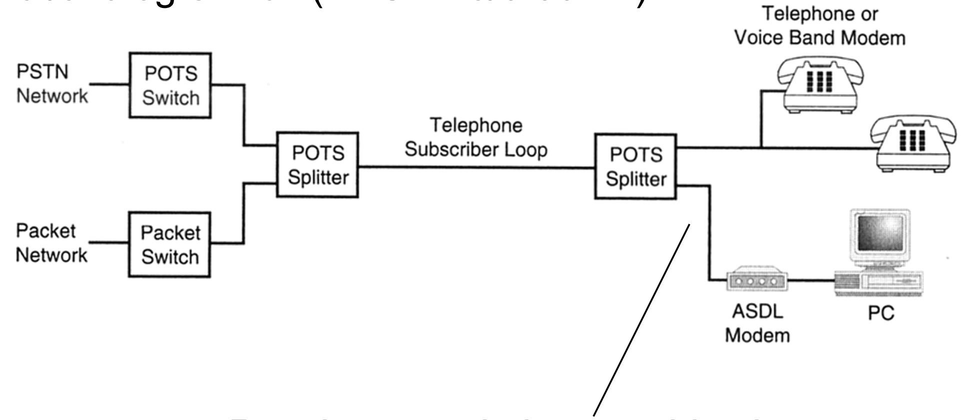
Through ISDN switch:

- Yields basic rate interface (BRI)
- Fixed throughput 2B+D

Digital access in PSTN (cont.)

Digital/analog switch (ADSL lite/9.992.1)

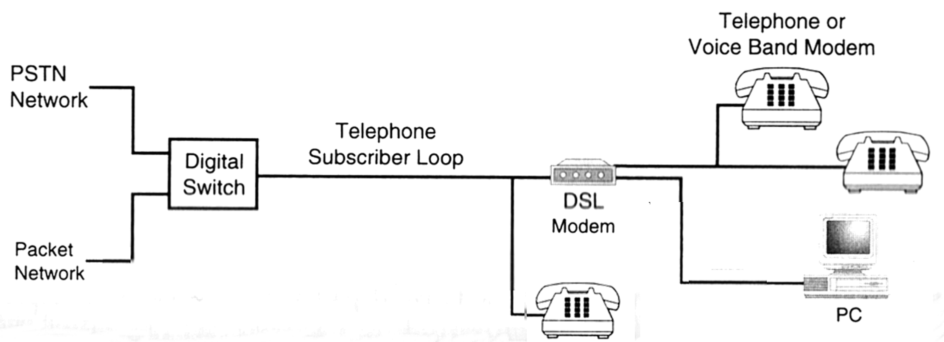
Using POTS splitters



Requires new in-house wiring here

- POTS FDM splitters separate voice and DSL channels

Using digital switch



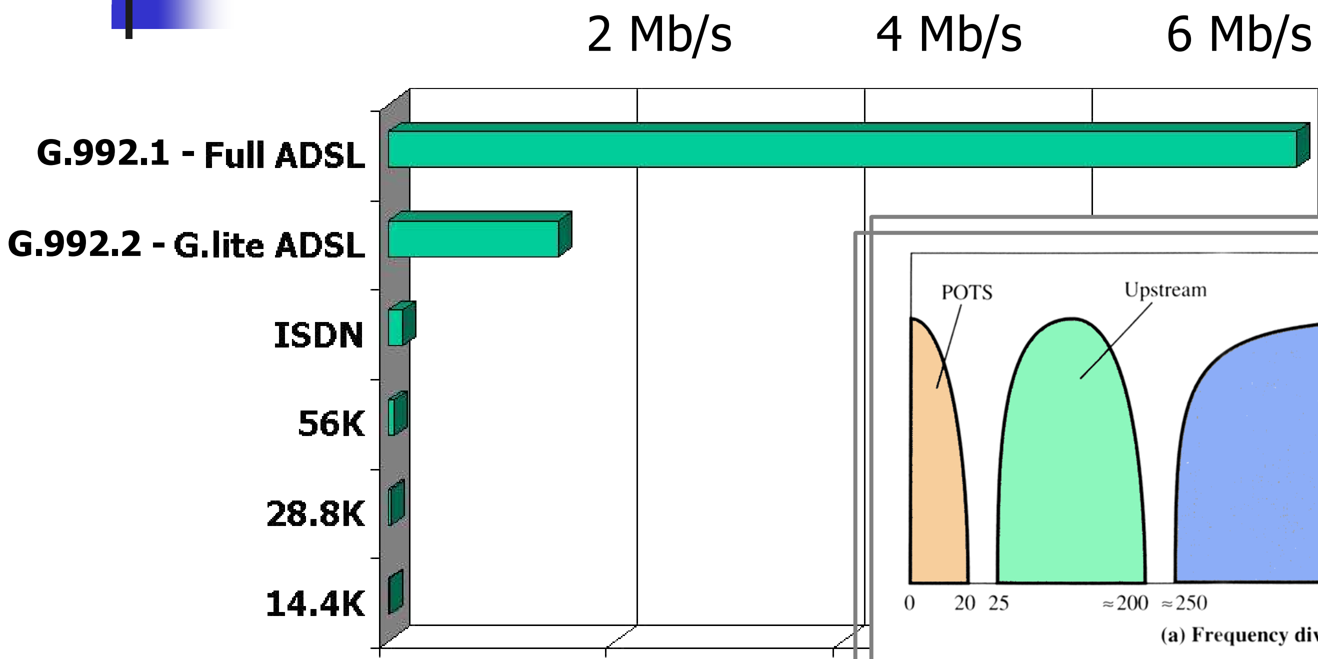
- Intelligent switch recognizes in CO subscriber devices and adjusts its HW parameters (PSTN telephone, voice-band modem, DSL modem) accordingly

Motivation for adaptation of ADSL

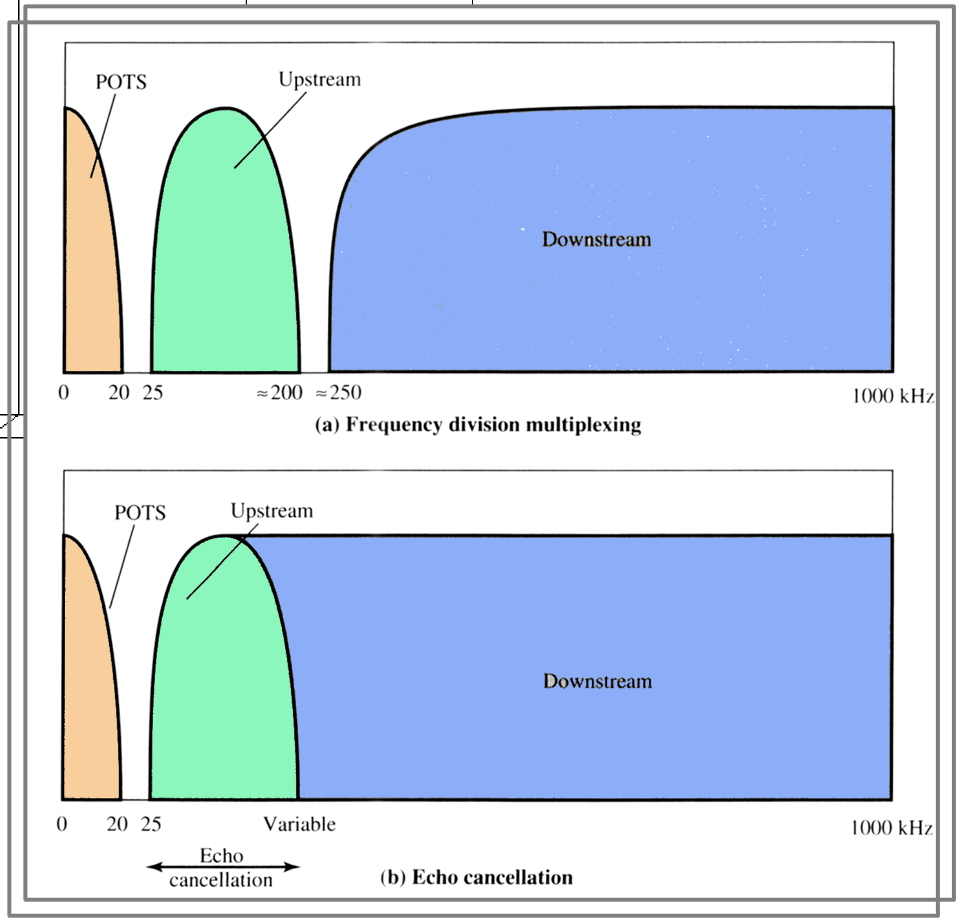
- Need for high-speed Internet access - also telephone modem speeds have peaked and cable modems have turned out to lack speed with many users
- Transmits high speed data to local loop by using unshielded 2-wire twisted pairs (often no repeaters required)
- DSL allows rates varying from 160 kb/s up to 50 Mb/s on down link (DL) depending on technology used!
- In the most popular commercial ADSL (G.992.1) maximum rate 640 kbit/s upstream and 8 Mb/s downstream
- Different xDSL techniques developed to serve symmetric and asymmetric traffic requirements and different rates (STM and ATM supported by G.992.1 ADSL)

STM-n: Synchronous Transfer Module (of SDH): DS-1,2: 1.544 Mb/s, 6.312 Mb/s
ATM: Asynchronous Transfer Mode
DL: Down Link - Down stream

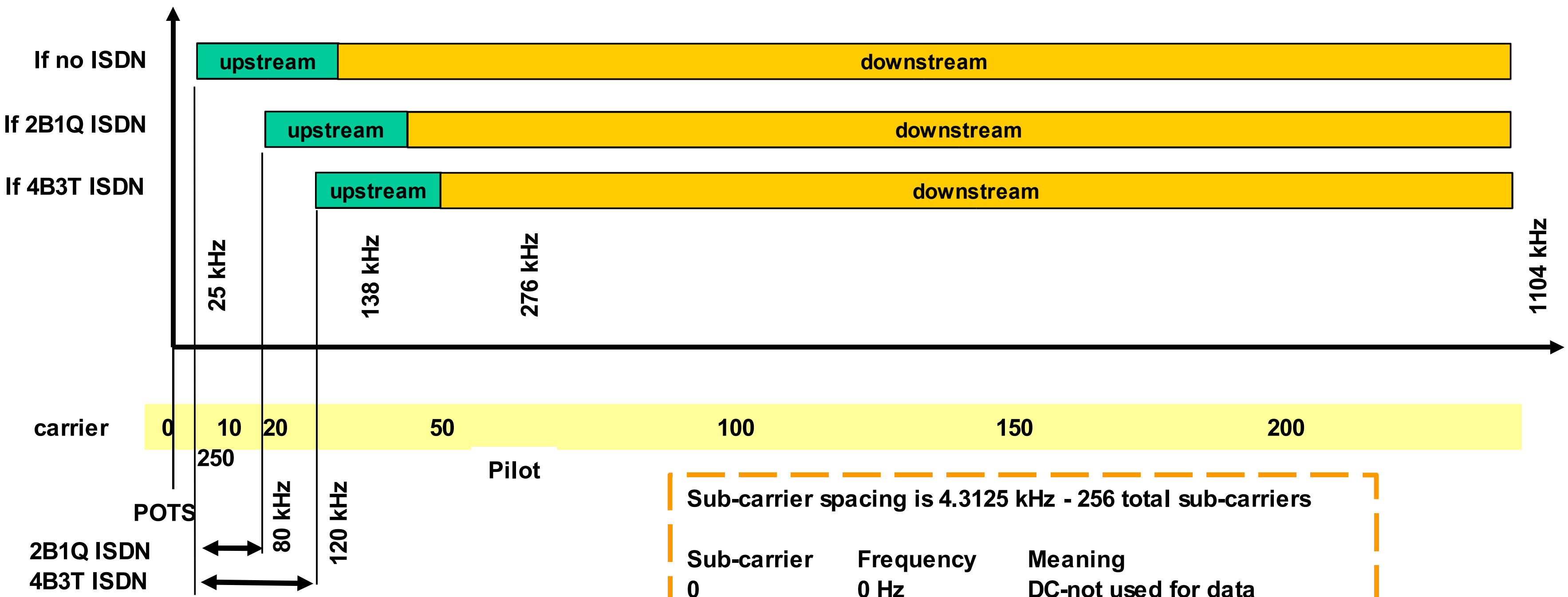
ADSL rates (DL) and channel frequency band allocation in local loop



Two ways to allocate transmission band in PSTN local loop cables
a) Frequency division multiplexing
b) Echo Cancellation assigns the upstream band to over-lap the downstream, and separates the two by means of local echo cancellation (as in V.32 and V.34 modems)



DMT frequency allocation with ISDN [2]



Sub-carrier spacing is 4.3125 kHz - 256 total sub-carriers

Sub-carrier	Frequency	Meaning
0	0 Hz	DC-not used for data
5	25 kHz	lower limit for upstream data
18	80 kHz	Approx limit for 2B1Q ISDN
28	120 kHz	Approx. Limit for 4B3T ISDN
32	138 kHz	upper limit for upstream data
64	276 kHz	Pilot - not used for data
256	1104 kHz	Nyqvist - not used for data

Physical realization and frame structures

ITU-T G.992.1: Asymmetric Digital Subscriber Line (ADSL) Transceivers

- Target: **physical layer** characteristics of ADSL interface to two-wire twisted metallic cable pairs with **mixed gauges** (no loading coils, but bridged taps are acceptable) (min 6.144Mbs/640kbs)
- **A single twisted pair*** of telephone wires is used to connect the ADSL transceiver unit (ATU)-C(central office) to the ATU-R(remote).
- Transmission unit can simultaneously convoy:
  - **downstream** (C->R) simplex (broadcasting) high speed bearers,
  - low speed **duplex** bearers,
  - a baseband **analogue** duplex channel (POTS compatibility),
  - ADSL **line overheads** for
    - framing,
    - error control
    - operations and maintenance (O&M)
- Bearer channels can coexist with voiceband & ISDN (G.961 : Appendices I and II) that is separated with filtering

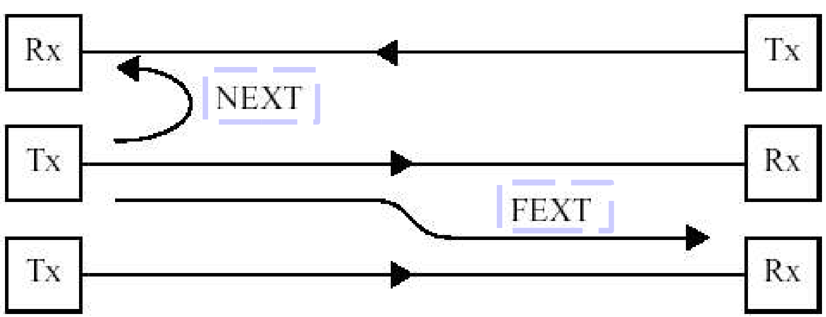
*ADSL2 offers bundling of cables for increased capacity

Topics of ITU-T G.992.1

- Basic capabilities specified in G992.1:
  - combined **options and ranges** of the simplex and full-duplex bearer channels
  - **line code** and the **spectral composition** of the ATU-C and ATU-R signals
  - **electrical and mechanical specifications** of the network interface
  - organization of transmitted and received data into **frames**
  - functions of the operations channel
  - ATU-R to **service module(s)** interface functions
  - **ATM support** (Transmission Convergence Sub-layer)
- Optional capabilities: echo cancellation, trellis coded modulation, transport of a network timing reference, transport of STM and/or ATM, reduced overhead framing modes

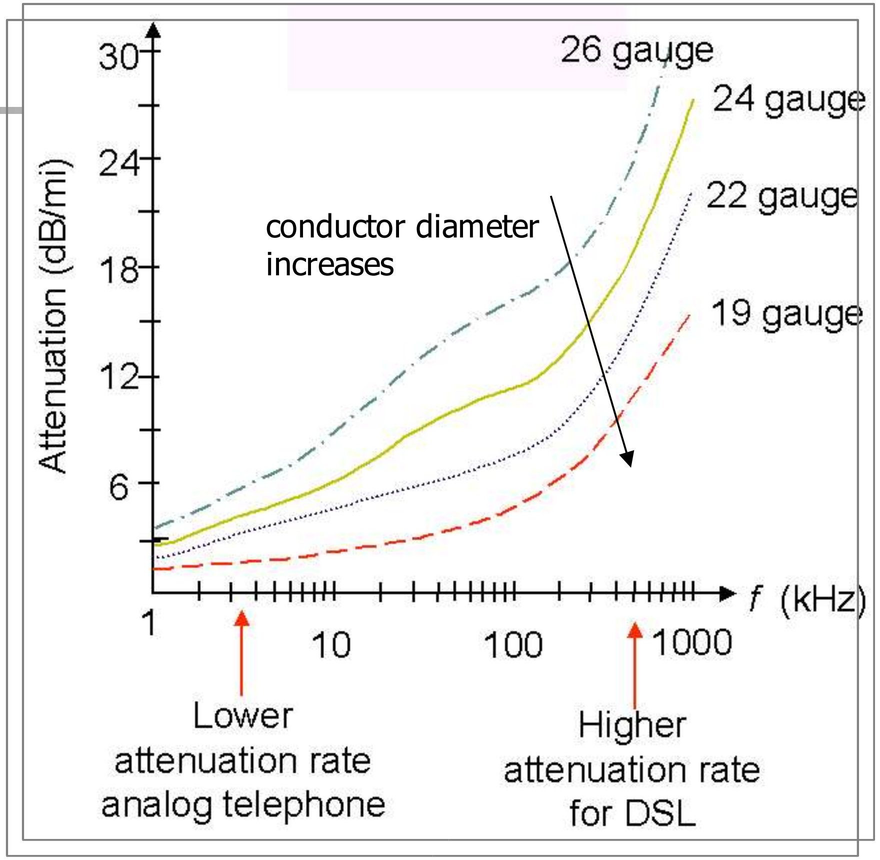
ADSL challenge: local loop cables

- **Crosstalk:**
  - Near-end crosstalk (NEXT) appears between TX and RX of the near-end
  - Far-end crosstalk (FEXT) appears between TX and RX of the far-end
- **Interference**: other lines, overlapping RF-spectra
- **Bridged taps, loading coils**
- **Weather-conditions** (moisture, temperature) affect crosstalk and line impedance
- **Attenuation! -** Frequency dependent (next slides)



Attenuation of twisted cables

- Comes in different wire thickness,
  e.g. 0.016 inch (24 gauge)
- The longer the cable, the smaller the bandwidth



Twisted cable attenuations

Standard	Data Rate	Distance
DS-1	1.544 Mbps	18,000 feet, 5.5 km
DS-2	6.312 Mbps	12,000 feet, 3.7 km
1/4 STS-1	12.960 Mbps	4500 feet, 1.4 km
1/2 STS-1	25.920 Mbps	3000 feet, 0.9 km
STS-1	51.840 Mbps	1000 feet, 300 m

Practical xDSL data rates for 24-gauge twisted pair

DS-1,DS-2: Digital Signal 1,2
Synchronous Digital Hierarchy (SDH) levels
STS-1: Synchronous Transport Signal level-1,
Synchronous Optical Network's (SONET) physical level signal

How ADSL meets local loop challenges?

- Restricted bandwidth?
  - careful allocation of bits for each sub-carrier
- Changing circumstances (whether, bridged taps)?
  - Adaptive setup phase (next slide)
- High attenuation?
  - Usage of relatively high bandwidth for transmission
- Compatibility to old POTS?
  - Own band for POTS by FDM (splitters)
- Interference and cross-talk?
  - Coding
  - Interleaving
  - Modulation (OFDM/DMT)
  - Echo cancellation

Note: loading coils must be removed from cables in order to ADSL to work!

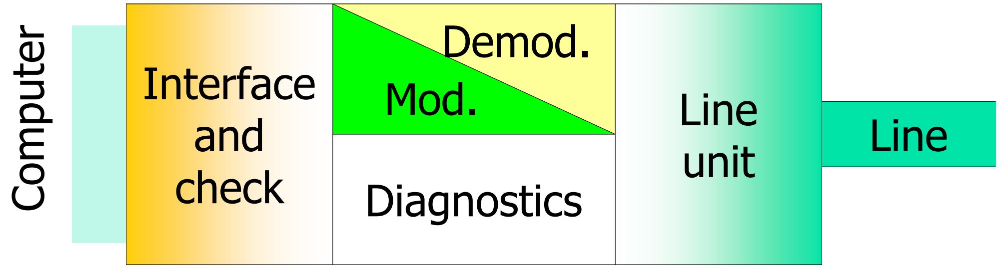
Data Rate	Wire Gauge	Distance	Wire Size	Distance
1.5 or 2 Mbps	24 AWG	18,000 ft	0.5 mm	5.5 km
1.5 or 2 Mbps	26 AWG	15,000 ft	0.4 mm	4.6 km
6.1 Mbps	24 AWG	12,000 ft	0.5 mm	3.7 km
6.1 Mbps	26 AWG	9,000 ft	0.4 mm	2.7 km

Performance of G.992.1

Start-up phases of Rate Adaptive ADSL (RADSL)

- RADSL modems apply sophisticated **hand shaking** to initiate transmissions that include
  - **Activation**: notice the need for communications
  - **Gain setting/control**: Adjust the power for optimum transmission and minimum emission
  - **Channel allocation / bit rate assignment (DMT)**
  - **Synchronization**: Clocks and frames to the same phases
  - **Echo cancellation**: (if used, required for both ends)
  - **Channel identification and equalization**

ADSL modem technology

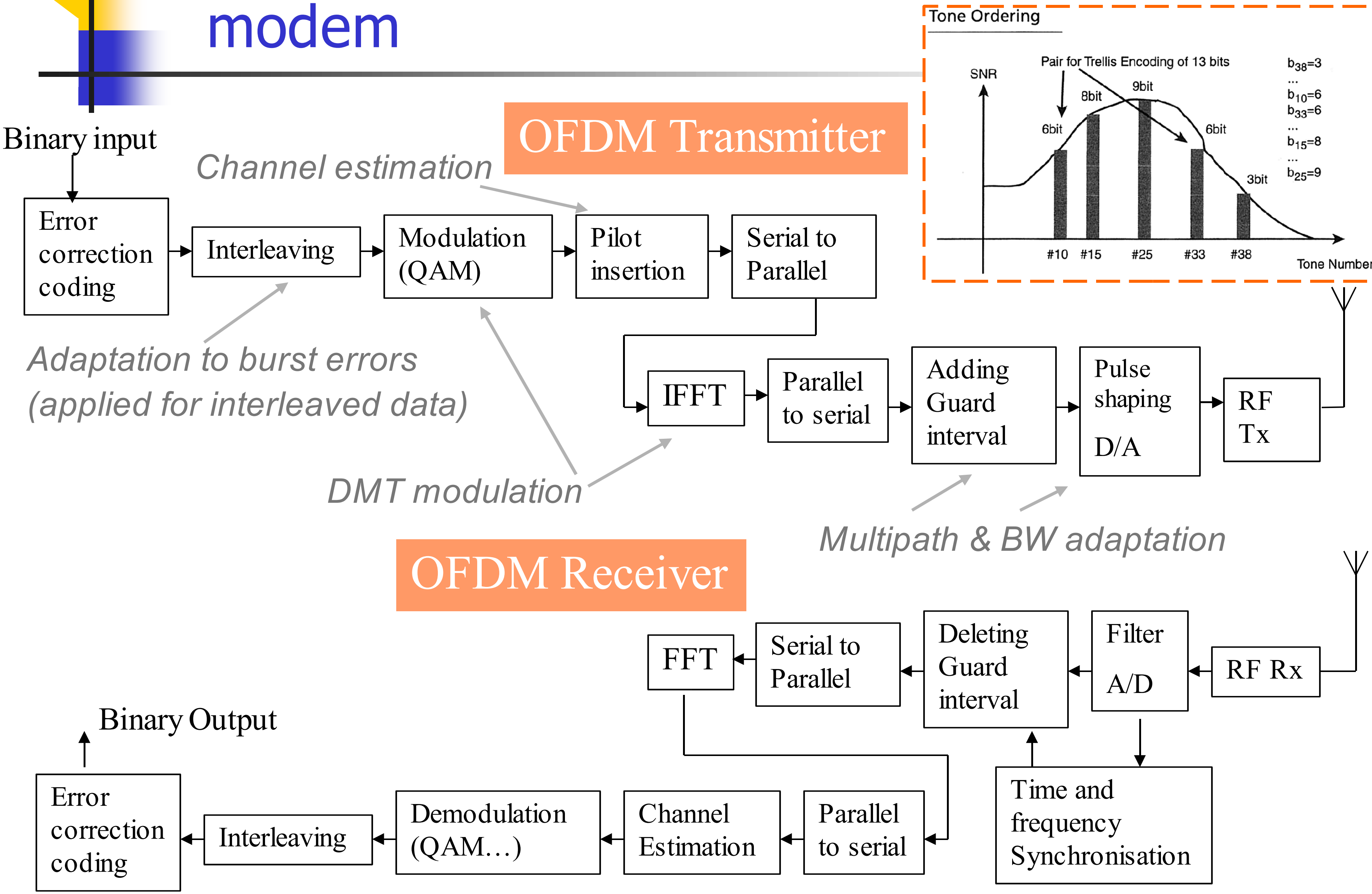


- ADSL provides fast point-to-point connections by modem (modulator/demodulator technology)
- All modems (including xDSL modems) have many common features
  - Analog parts
    - analog transmit and receiver filters
    - DAC, automatic gain control, ADC
  - Digital parts
    - modulation/demodulation, constellation mapping
    - coding/decoding
      - Reed-Solomon
      - Trellis
    - bit packing/unpacking (compressed transmission)
    - framing
    - interleaving
    - scrambling

ADSL- modem technology (cont.)

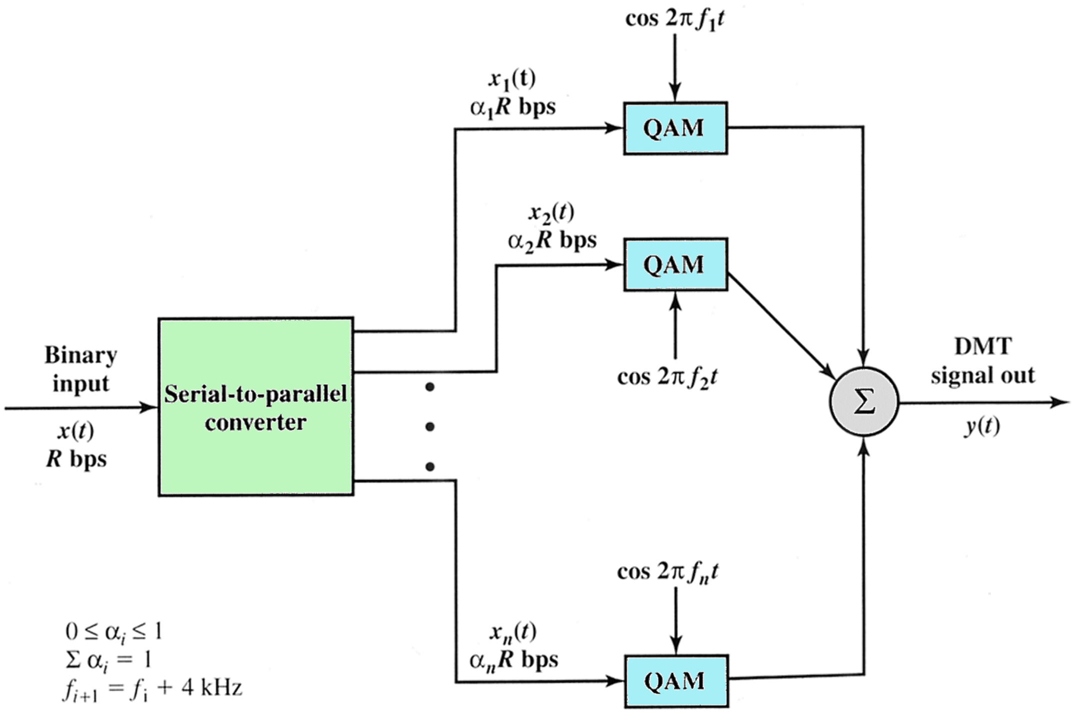
- xDSL modems apply also more advanced techniques:
  - Carrierless AM/PM (CAP) or QAM line codes (97% of USA installations apply this method)
  - Fast Fourier Transforms for Discrete Multi-Tone Modulation (DMT) - the dominant method
    - tone ordering -> water pouring bit allocations (adaptation to transfer function) & peak-to-average ratio (PAPR) decrease
    - channel equalization (tone-by-tone different rates)
    - guard intervals (adaptation to channel delay spread)
  - Turbo - coding
  - Adaptive echo canceller

Block diagram of an ADSL modem

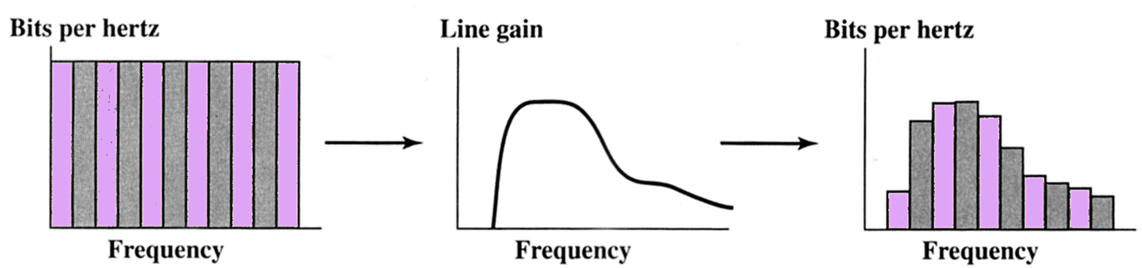


The principle of DMT* modulation [4]

- Transmission band divided into 4 kHz subchannels
- Tone ordering: On initialization test-tone determines number levels in QAM for each subchannel (each can carry 0 - 32 kb/s)
- Number of subchannels 256
- Current downstream rates 256 kb/s ... 8 Mb/s depending on line conditions and operator specifications in ADSL



Discrete Multi-tone (DMT) modulation

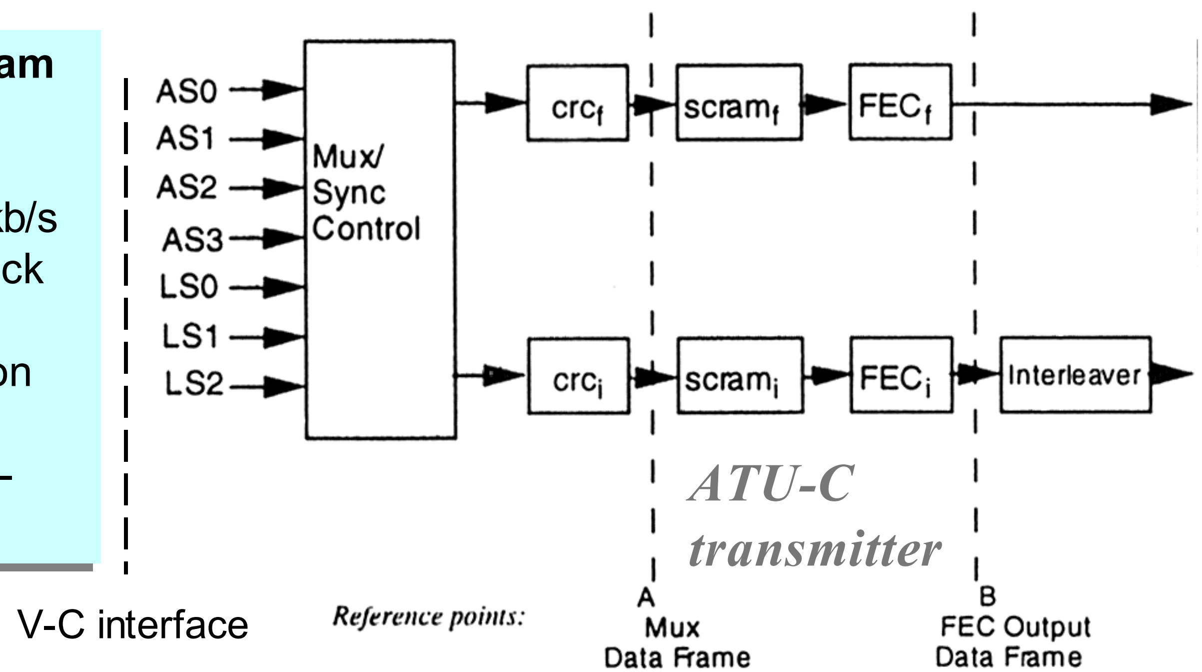


Tone ordering (bit-loading)

ADSL subchannels [3]

- **G.992.1** specifies DMT modem for ASDL applications
- Downstream:
  - 2.208 MHz sampling rate, 256 subchannels at 0 … 1.104 MHz
  - DMT symbol rate 4000 symbols /s. Each sub-channel is 4.3 kHz wide
  - max rate 32 kb/s per subchannel (compare to V.90 modem!)
- Upstream:
  - 275 kHz sampling rate, 32 tones 0 … 138 kHz

ASx: high-speed, **downstream simplex** nx1.54 Mb/s
LSx: low-speed, **duplex channels** 160…576 kb/s
crc: cyclic redundancy check
FEC f,i: (fast,interleaved): forward error correction
scram f,i: scrambling
ATU-C: ADSL transmitter unit - central office

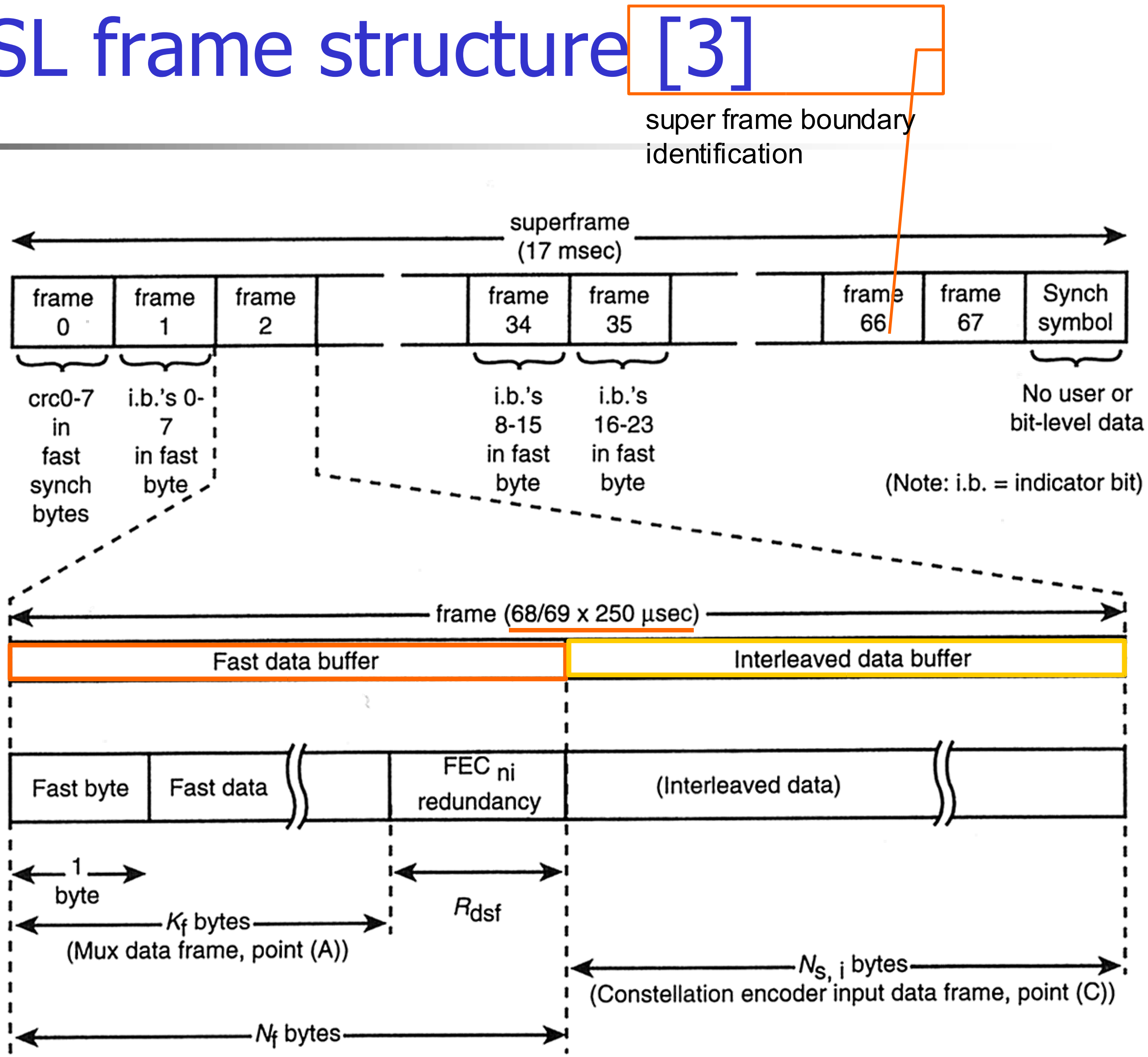


Multi-tone modulation (cont.)

- In channel activation phase different sub-channels are allocated for their optimum rates (by changing number of levels in modulation)
- DMT-ADSL supports both synchronous transfer modules (STM) of SDH and asynchronous transfer mode (ATM, AS0 used for primary cell stream)
- ADSL modems offer **two data paths**:
  - Fast
    - low latency (2ms)
    - real-time traffic
  - Interleaved
    - low error rate
    - Reed-Solomon encoding (concatenated convolutional codes) at the expense of increased latency

ADSL frame structure [3]

68 DMT data symbols, -> symbol rate ~4000/sec



- bearer channel allocation during initial setup determines ratio of interleaved and fast data frames (Nf,Ns)
- fast bytes take care of CRC, O&M and sync. control:
  - 8 crc bits (crc0-7) supervise fast data transmission
  - 24 indicator bits (ib0-ib23) assigned for O&M functions

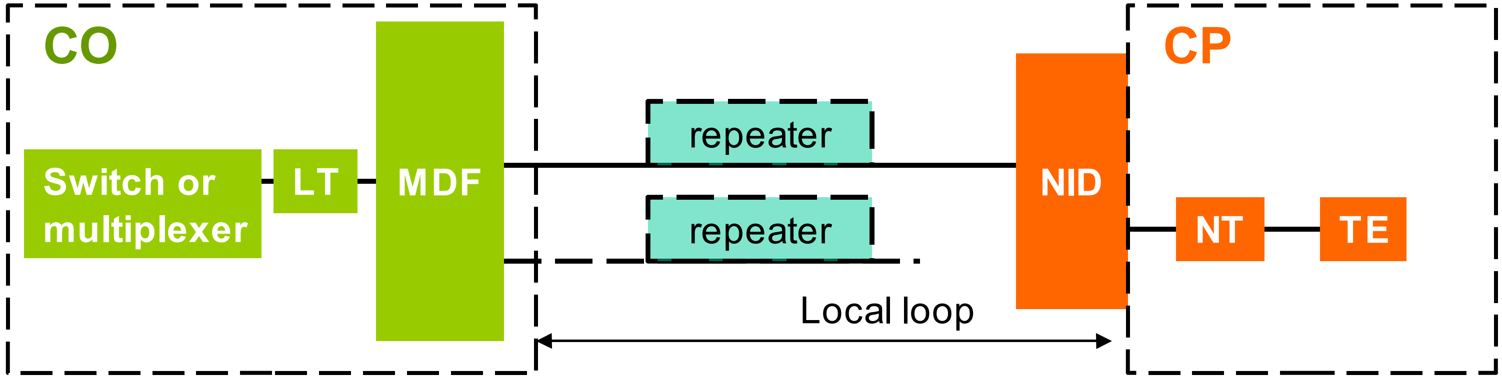
ADSL system total data rate

- Total data rate=Net data rate + System overheads
- The net data rate is transmitted in the ADSL bearer channels
- ADSL system overheads
  - an ADSL embedded operations channel, eoc (O&M)
  - an ADSL overhead control channel, aoc
  - crc check bytes
  - fixed indicator bits for O&M*
  - Reed-Solomon FEC redundancy bytes
- These data streams are organized into ADSL frames and super-frames for the downstream and upstream data

O&M: error detection, corrected errors, loss of signal, remote defects ...

Reference models

Generic DSL reference model



ADSL transceiver units

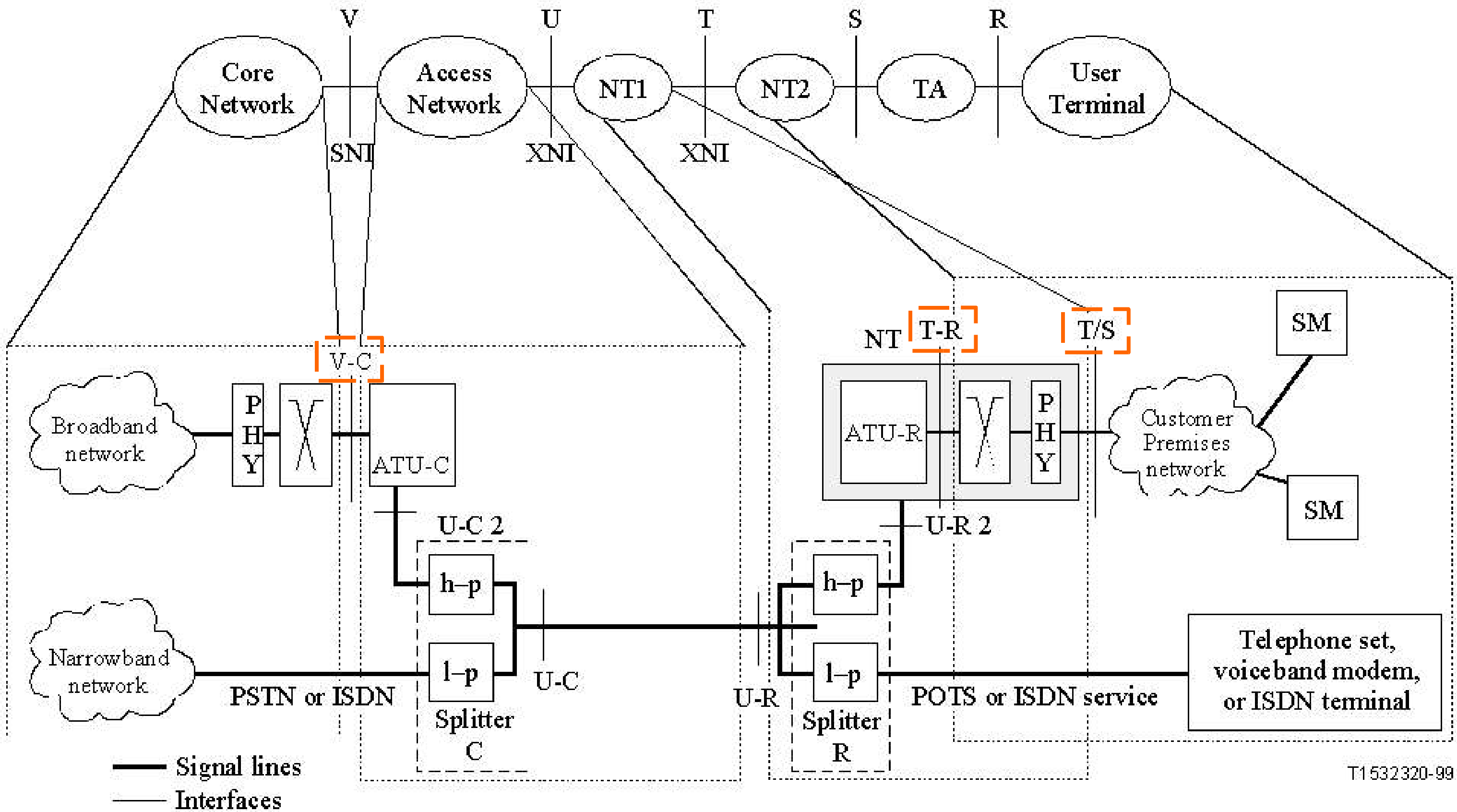
ATU-R

ATU-C

- CP: Customers premises - local loop connects to switch (CO)
- TE: Terminal equipment - PC or telephone
- NT: Network terminal - DSL modem at CP
- NID: Network interface device - all customer’s installation reside right from this point and telephone company's to the left in the diagram
- CO: Central office
- MDF: Main distribution frame - wire cross-connection field connects all loops to CO
- LT: Line termination eg DSL modem
- repeater: signal regeneration for transmission introduced impairments
- local loop: in ADSL 2-wire connection between CO and CP

ATU: ADSL transceiver unit, -C : Central office, -R: Remote unit

G.992.1 (ITU-T)/T1.413 (ANSI) reference model



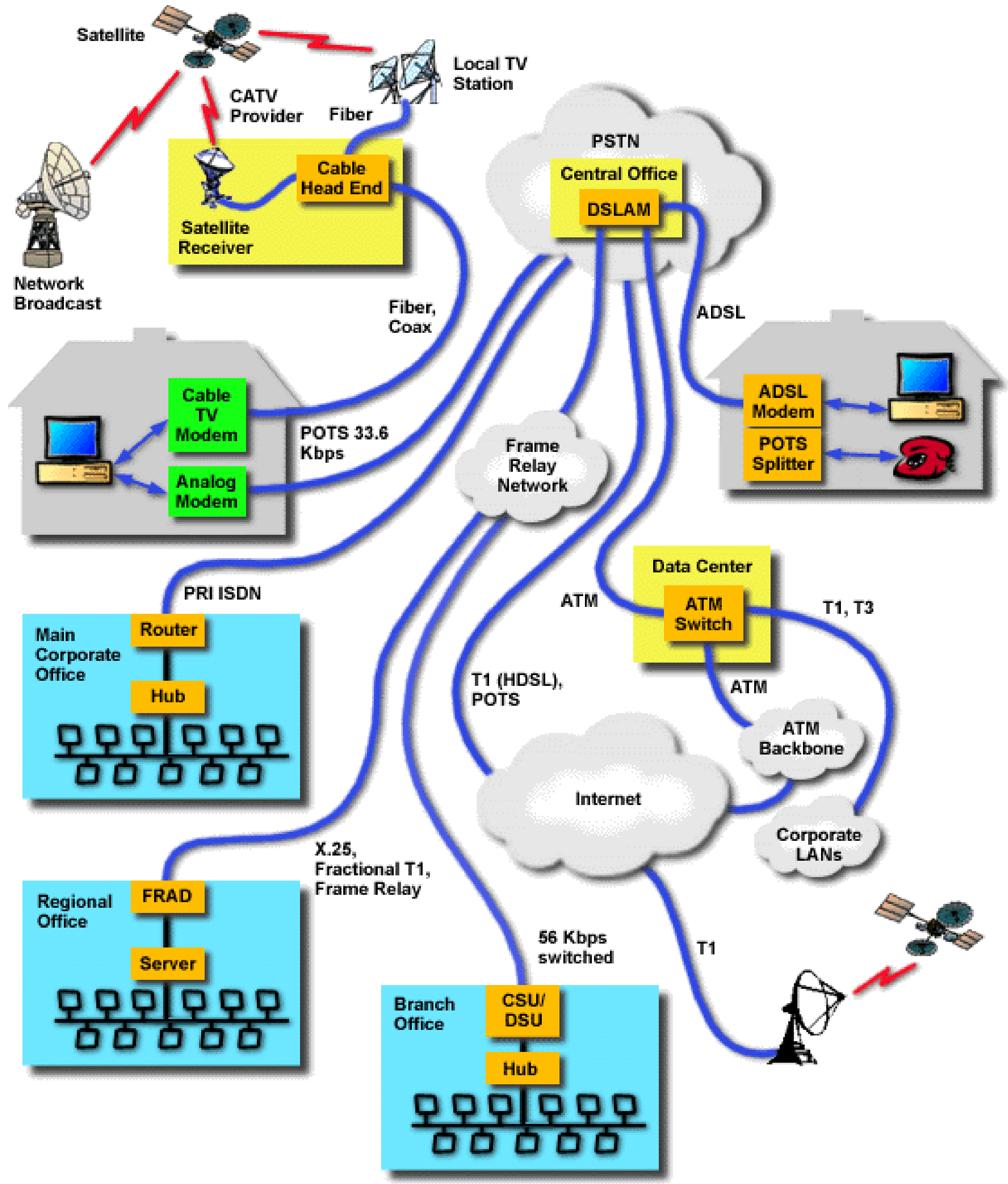
ATU	ADSL Transceiver Unit
ATUC	ATU at the central office end (i.e. network operator)
ATUR	ATU at the remote terminal end (i.e. CP)
ATU-x	Any one of ATU-C or ATU-R
NT1,2	Network terminals (ISDN)
TA	Terminal adapter
SM	Service module

-The V-C and T-R interfaces are defined only in terms of their functions but they are not technically specified
- T/S not defined

Interoperability issues

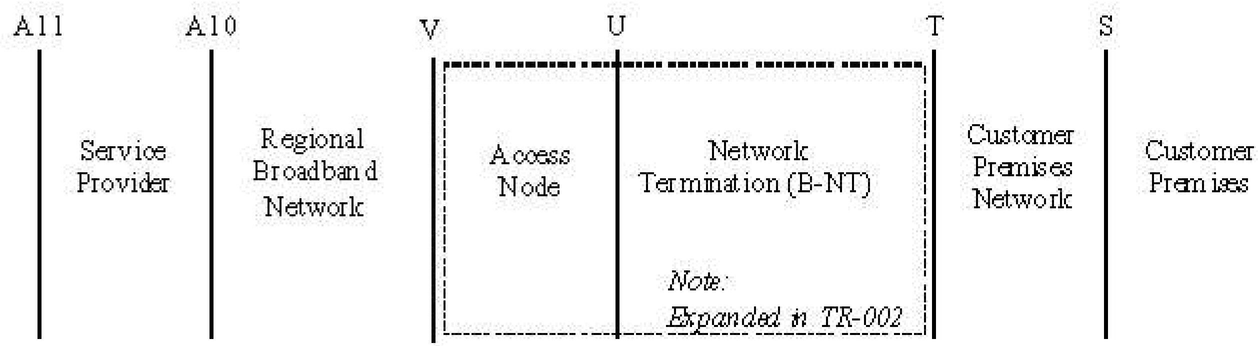
Using ADSL

- DSLAM provides access to LANs, WANs and other services at CO
- ADSL (G.992.1) supports traffic over
  - ATM
  - STM
  - ISDN
- Indirect support for example for
  - X.25
  - Frame relay
  - Internet core



DSL Forum’s End-to-end Reference Model

ADSL modem = B -NT (B-ISDN network termination)

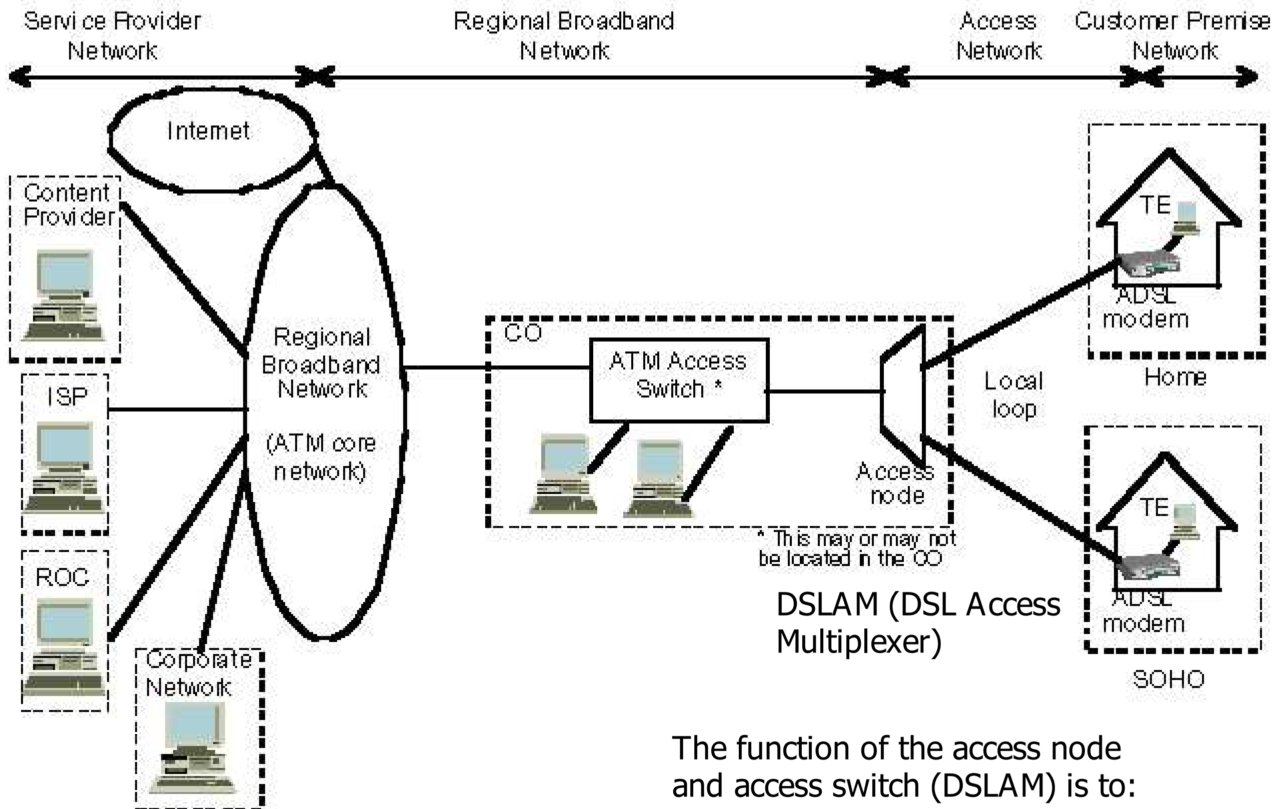


NOTE: V, U, S and T correspond to ITU practice
A10 and A11 are borrowed from DAVIC as there are no ITU equivalents

- Includes the following subnetworks:
  - customer premise network
  - access network
  - regional broadband network
  - service provider networks

Reference: DSL Forum: TR-012-Broadband Service Architecture for Access to Legacy Data Networks over ADSL (PPP over ATM)

ATM over ADSL for broadband networking



ADSL modem = B-NT (B-ISDN network termination)

NOTE: DSL Forum's report TR-002 identifies and defines the functional blocks of ATM-based ADSL access network

The function of the access node and access switch (DSLAM) is to:
- provide **physical port concentration**
- provide bandwidth concentration in the form of **statistical multiplexing** of non-CBR traffic classes
- to possibly provide **logical port concentration** in **service interworking** function
- to support the ability to offer **differentiated services** in the network

Reference: DSL Forum: TR-012-Broadband Service Architecture for Access to Legacy Data Networks over ADSL (PPP over ATM)

Standardization

Standardization bodies

ADSL standards

Company based

International/national standardization

Similar to IETF

Standards Body	Working Group	Standard	Purpose
ADSL Forum	Many, including UAWG SNAG	TR-00x	Industry Advisory Papers
ANSI T1	T1E1.4	T1.413, Issue 2	Basic ADSL Standard
ETSI	TM6		Close interworking with ANSI
ITU-T	Study Group 15	G.992.1	International Standards
		G.992.2	
		G.994.1	
		G.995.1	
		G.996.1	
		G.997.1	

G.full
G.lite

UAWG: Universal ADSL working group - strives to make ADSL more commercially adaptable
SNAG: Service network architecture group

Hierarchy of standards

nal level -examples: ITU: International Telecommunications Union - yields recommendations that may be adapted by companies

evel -examples: ANSI (American Standards Institute) /ETSI (European Technical Standards Institute)

Multi-corporate level -examples: ADSL forum/ATM forum

Corporate level -open or proprietary standard created by a company

See also:
http://www.ktl.com/testing/telecoms/xdsl-standards.htm

Recently ratified ITU-T DSL standards

				SERVICE	
FAMILY	ITU	NAME	RATIFIED	RESIDENTIAL	BUSINESS
ADSL	G.992.1	G.dmt	1999	✓	✓
ADSL	G.992.2	G.lite	1999	✓	
ADSL2	G.992.3	G.dmt.bis	2002	✓	✓
ADSL2	G.992.4	G.lite.bis	2002	✓	
ADSL2	G.992.5	ADSL2 PLUS	2003	✓	✓
ADSL2	G.992.3	Reach Extended	2003	✓	
SHDSL	G.991.2	G.SHDSL Single-pair High-speed DSL	2001		✓
VDSL	G.993.1	Very-high-data-rate DSL	2004	✓	✓

Reference: DSL Forum: DSL Anywhere - Issue 2, Sep. '03

xDSL flavors and performance comparison

Overview to xDSL techniques

ADSL	**Asymmetric Digital Subscriber Line**	Asymmetric: Downstream: 1.5Mbps -> 8Mbps Upstream: 16Kbps -> 640Kbps Range : 5400 m - 1.544Mbps 4800 m - 2.048Mbps 3600 m - 6.312Mbps 2700 m - 8.448Mbps	Internet access VoD and video access services Remote LAN access Interactive multimedia
VDSL	**Very High Data Rate Digital Subscriber Line**	Asymmetric: Downstream: 13Mbps -> 52Mbps Upstream: 1.6Mbps -> 2.3Mbps Range: 1350 m - 12.96Mbps 900 m - 25.82Mbps 300 m - 51.84Mbps	Same as ADSL and HDTV

-ATM / STM compatible
-2-wire compatible
- G.992.2 requires splitter and separate phone line from box to wall

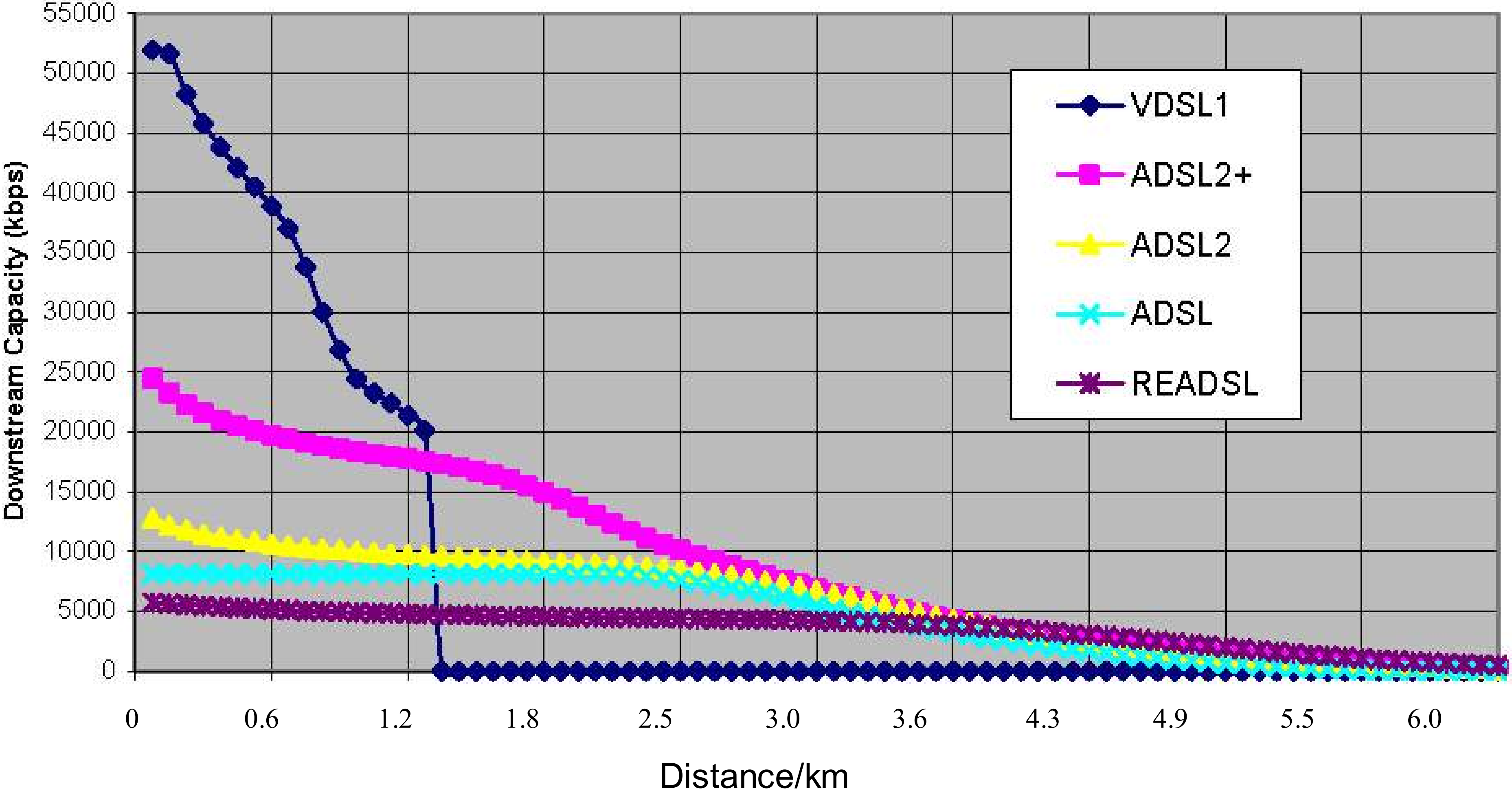
For short distances, applies ATM

Overview to xDSL techniques (cont.)

DSL	**Digital Subscriber Line**	Duplex: 160K (2B+D+Management)	ISDN service Voice and data communications
HDSL	**High Data Rate Digital Subscriber Line**	Duplex: 2 x T.1 (1.544Mbps) / 2 x E.1 (2.048Mbps) 2 to 4 pairs of copper-wire Range : 3600 meter	T.1 and E.1 service
SDSL	**Single Line Digital Subscriber Line**	Duplex:2 x T.1 (1.544Mbps) / 2 x E.1 (2.048Mbps) 1 pair of copper-wire Range : 3000 meter	Premises access for synchronous services

-Channel associated signaling
-2- or 4-wire connections
-performance increase by cable bundling

Performance comparison



Reference: DSL Forum: DSL Anywhere - Issue 2, Sep. '04

References

[1] T. Starr, J.M. Cioffi, P.J. Silverman: Understanding Digital Subscriber Line Technology, Prentice-Hall

[2] W.Y. Chen: DSL Simulation Techniques and Standards - Development for Digital Subscriber Line Systems, MacMillan Tech. Publishing

[3] C.K. Summers: ADSL - Standards, Implementation and Architecture, CRC Press

[4] William Stallings: Data and Computer Communications (7th Ed), Prentice Hall

[5] ANSI T1.413, issue 2 standard