SAPIENZA
UNIVERSITÀ DI ROMA

Network Infrastructures

A.A. 2023-24
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XDSL

- DSL (or xDSL), is a family of technologies that provide digital data transmission over the wires of a local telephone network.
- DSL originally stood for digital subscriber loop, although in recent years, many have adopted digital subscriber line as a more marketing-friendly term

xDSL Faminly

- ISDN Digital Subscriber Line (IDSL)
- High Data Rate Digital Subscriber Line (HDSL)
- Symmetric Digital Subscriber Line (SDSL), a standardized version of HDSL
- Asymmetric Digital Subscriber Line (ADSL), a version of DSL with a slower upload speed
- ADSL “lite” (or g.lite)
- Rate-Adaptive Digital Subscriber Line (RADSL)
- Very High Speed Digital Subscriber Line (VDSL)
- Very High Speed Digital Subscriber Line 2 (VDSL2), an improved version of VDSL

Reasons for xDSL market

- More than 600 million copper wires worldwide
- Growing requests for data transmissions (mainly access to IP networks)
- Competition
- Deregulation
- Growing needs fro POTS in developing countries

An example: copper wired access network Telecom Italia

- Number of network terminations: 33.576.600
- Numebr of Central Offices: 11.000
- Number of Street Cabinets: 150.000
- Amount of cables: above 105.700.000 km–pairs
- Mean distance from a CO and a user: 1,5 Km (1,2 Km in urban areas)

Some history

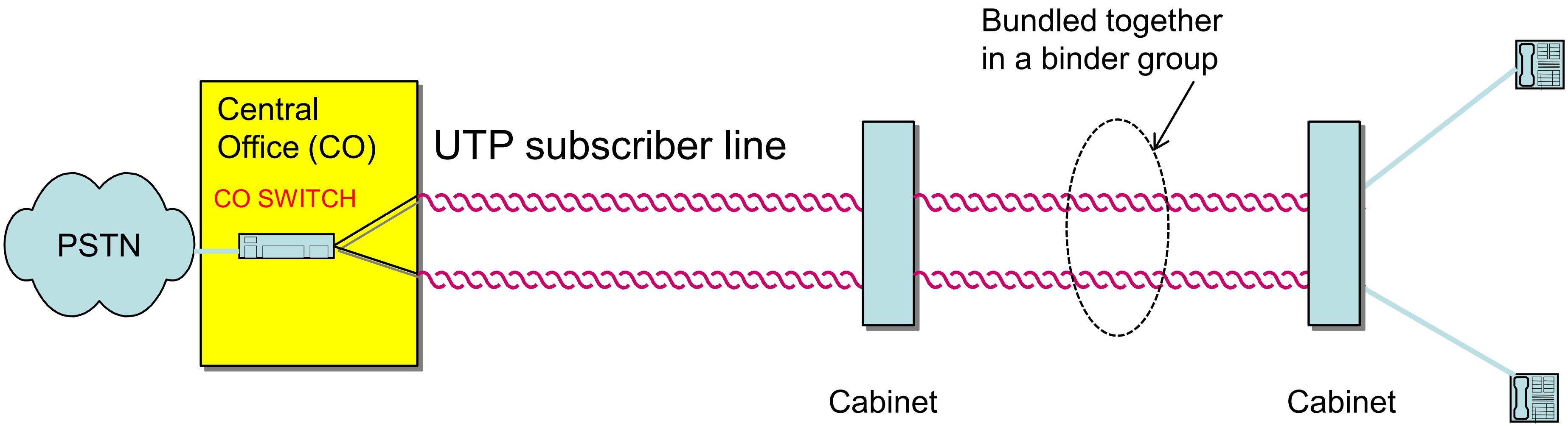
- In the early 1980s, the idea of a digital subscriber line to provide access to an integrated services digital network (ISDN) was initiated
  - The initial throughput requirement was 160 kbit/s
  - Investigate even higher transmission throughputs approaching T1 speeds
  - The project was named High bit rate DSL (HDSL)
- Lately the interest towards asymmetry arose (for Video on Demand services)
- Joe Lechleider at Bellcore (now Telcordia Technologies) developed ADSL in 1988 by placing wideband digital signals above the existing baseband analog voice signal carried between telephone company central offices and customers on conventional twisted pair cabling

Current telco services

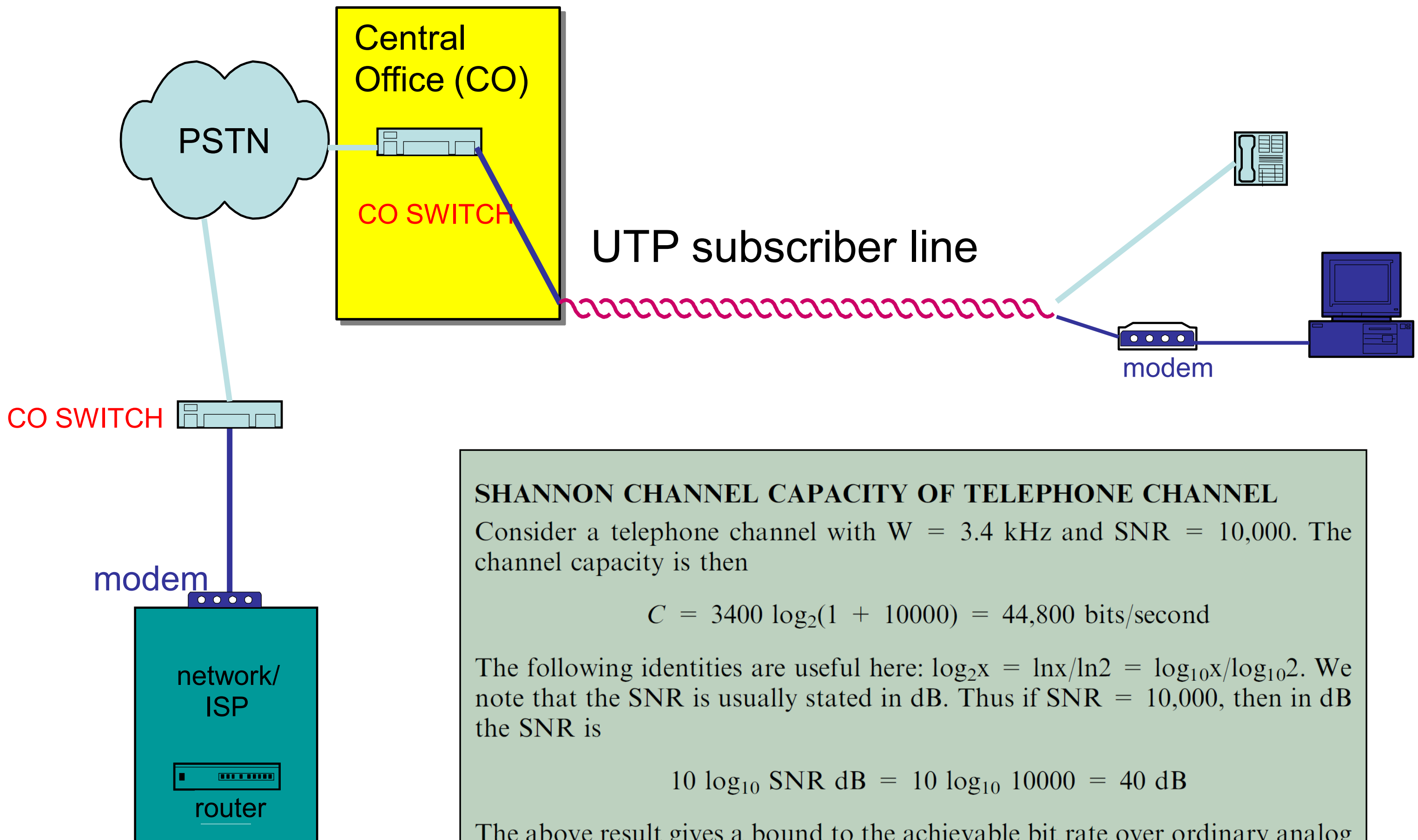
- Bandwidth comparisons with phone wire

Service	Upper limit bandwidth
Voice service	3400Hz
ISDN(USA)	80kHz
ISDN(Germany)	120kHz
T1 Using 2B1Q	400kHz
ADSL	About 1MHz

Wiring Schematic pre-DSL



Analog (or V.90) modems



SHANNON CHANNEL CAPACITY OF TELEPHONE CHANNEL

Consider a telephone channel with $W = 3.4$ kHz and SNR $= 10{,}000$. The channel capacity is then

$$C = 3400 \log_2(1 + 10000) = 44{,}800 \text{ bits/second}$$

The following identities are useful here: $\log_2 x = \ln x/\ln 2 = \log_{10} x/\log_{10} 2$. We note that the SNR is usually stated in dB. Thus if SNR $= 10{,}000$, then in dB the SNR is

$$10 \log_{10} \text{SNR dB} = 10 \log_{10} 10000 = 40 \text{ dB}$$

The above result gives a bound to the achievable bit rate over ordinary analog telephone lines.

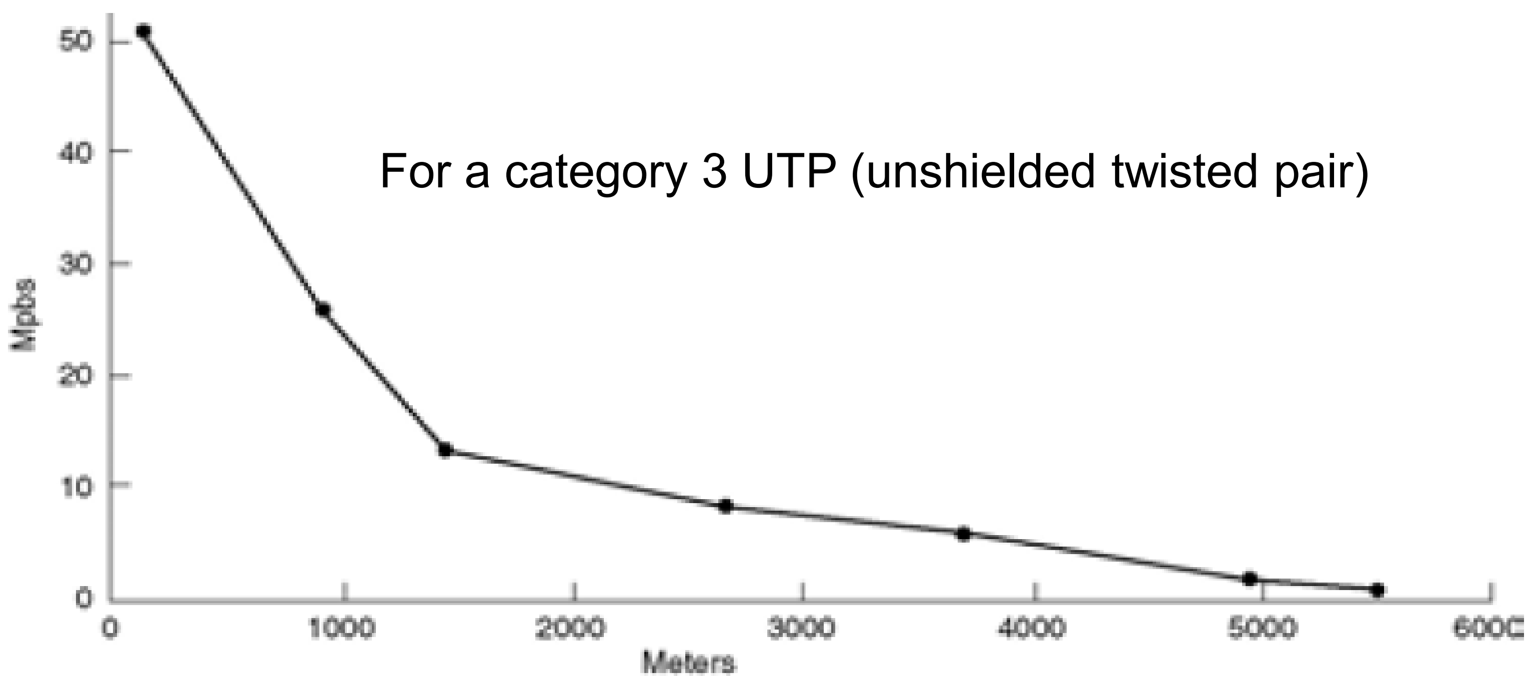
Current telco services

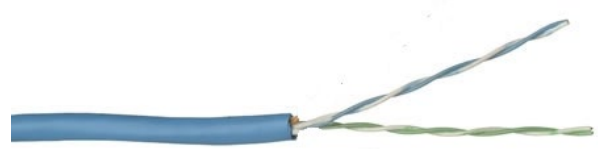
- Limitations of current telco networks to upgrade service:
  - Space of CO
  - Distance of user from CO
  - Internet problems for POTS and ISDN
  - Both types of data services use existing CO voice switch, not optimized for data
- Need to put data services to be handled by Data Communication equipment

xDSL variations

- X = Variations:
  - Speed and distance
  - Symmetry
  - Support for POTS
  - Location of equipment

Bandwidth as a function of meters





High Data Rate DSL: HDSL

- Most widely deployed form of DSL
- Created to provide leased-line T1 service
- Adaptive line equalization and 2B1Q (2 binary,
- 1 quaternary)
- Heavily used in cellular telephone buildouts
- Drawbacks:
  - No provision exists for analog voice
  - HDSL has crosstalks at both ends for symmetric
- HDSL-2 with a single wire pair is a promising alternative to HDSL with 2 or 4 wire pairs

Asymmetric DSL

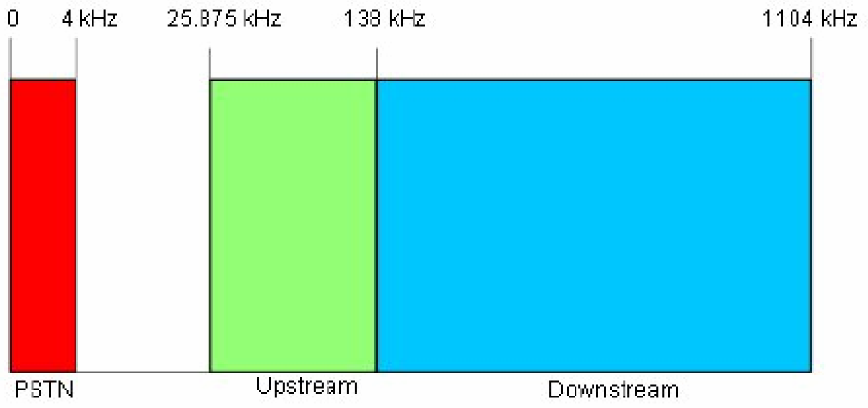
- Original market driver: distribution of video on demand (VoD) (failed for this target)
- An ADSL local loop is for the exclusive use of he subscriber, with no contention for bandwidth on that local loop
- ADSL provides for passive transmission of analog voice service
- The distinguishing characteristic of ADSL over other forms of DSL is that the volume of data flow is greater in one direction than the other
- Providers usually market ADSL as a service for consumers to connect to the Internet in a relatively passive mode
  - able to use the higher speed direction for the "download" from the Internet but not needing to run servers that would require high speed in the other direction

Speed

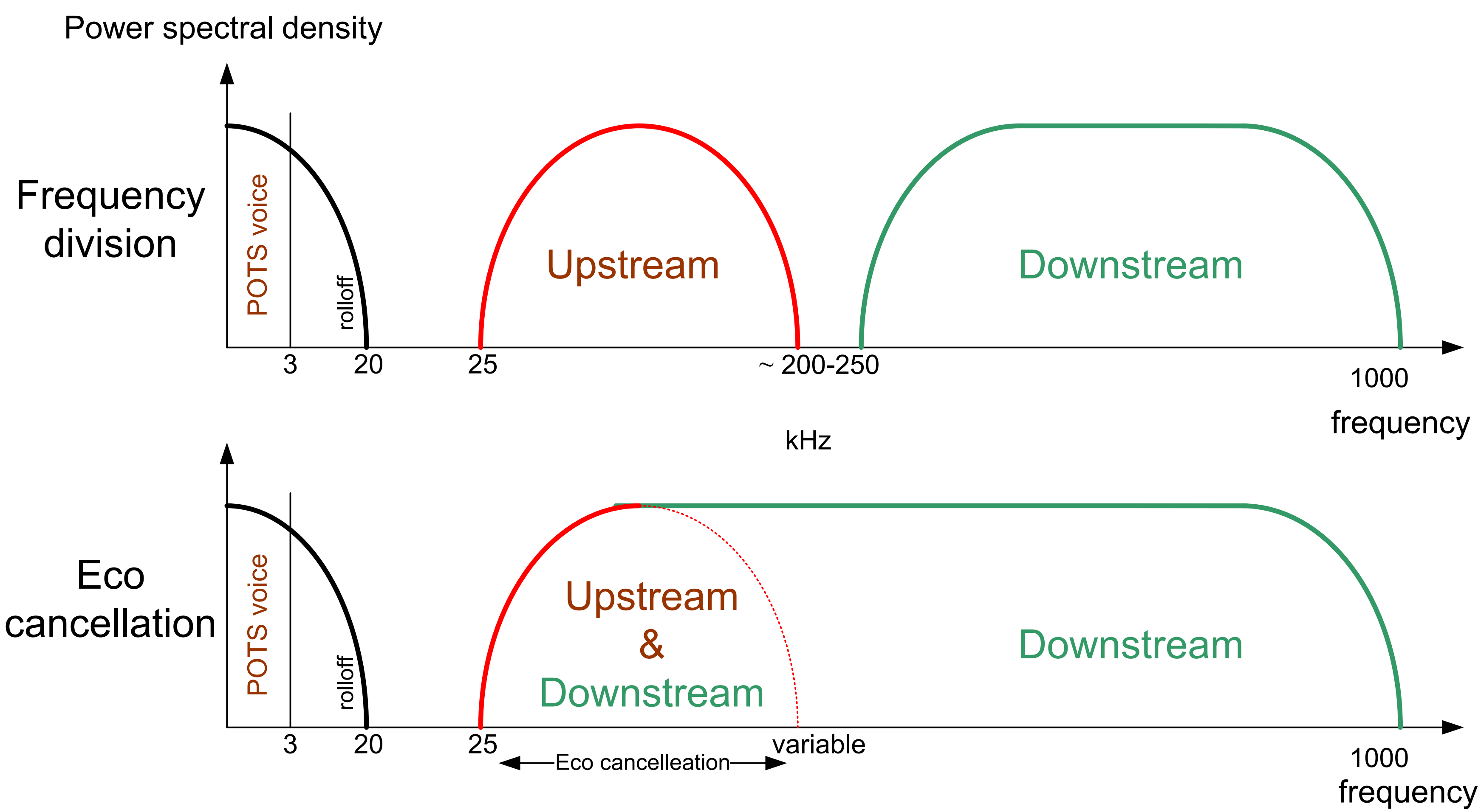
- Older ADSL standards can deliver 8 Mbit/s to the customer over about 2 km of unshielded twisted pair copper wire
- The latest standard, ADSL2+, can deliver up to 24 Mbit/s, depending on the distance from the central office

ADSL frequency bands

- ADSL uses two separate frequency bands, referred to as the upstream and downstream bands
- The upstream band is used for communication from the end user to the telephone central office
- The downstream band is used for communicating from the central office to the end user.
- With standard ADSL, the band from 25.875 kHz to 138 kHz is used for upstream communication, while 138 kHz –1104 kHz is used for downstream communication

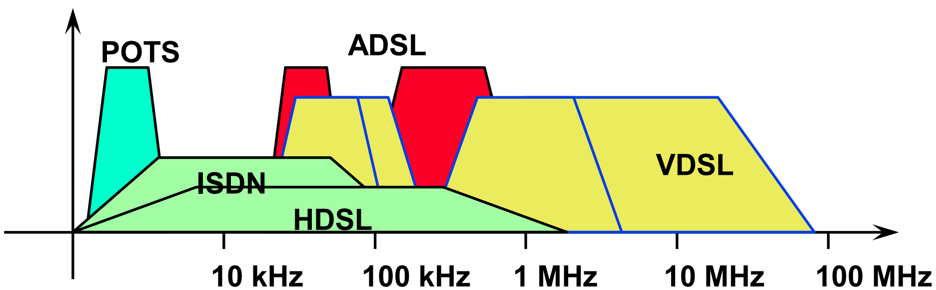


ADSL frequency allocation

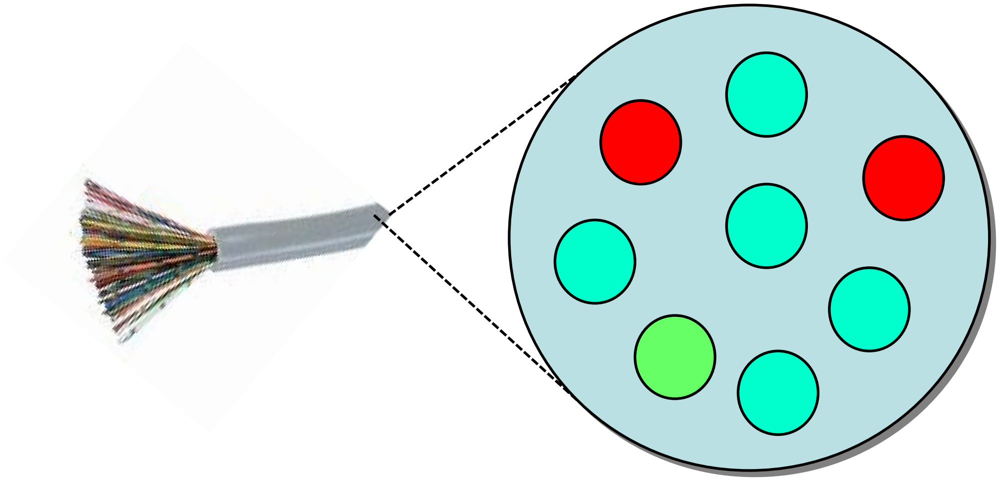


Cross-talks

- Wires sharing the same cable interfere one each other



Binder group



ADSL and cross-talks

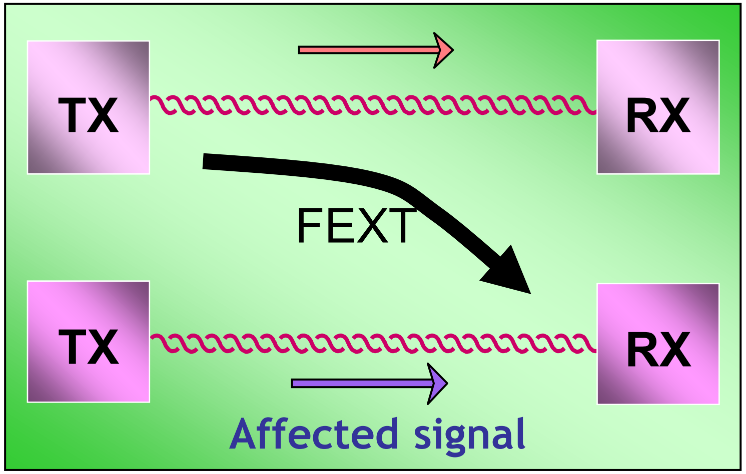
- Two kinds of cross-talk noise exist: far-end cross-talk (FEXT) and near-end cross-talk (NEXT).

- Depend on:
  - The power spectral density of the transmitted signal
  - The number of twisted pairs in the same cable
  - The overlapping of bandwidths of the useful signal and the interfering ones

- Crosstalk typically increases with frequency→ significant impairment for high speed DSL

FEXT

- FEXT is the cross-talk between a transmitter and a receiver placed on opposite sides of the cable
- FEXT signals travel the entire length of the channel
- Since for ADSL “short” cables are used, the signal carried on other pairs, even though coming from far away, are not strongly attenuated and create interferences that affect other pairs.
- To reduce this kind of noise a cable usually doesn't contain more than a dozen twisted pairs.

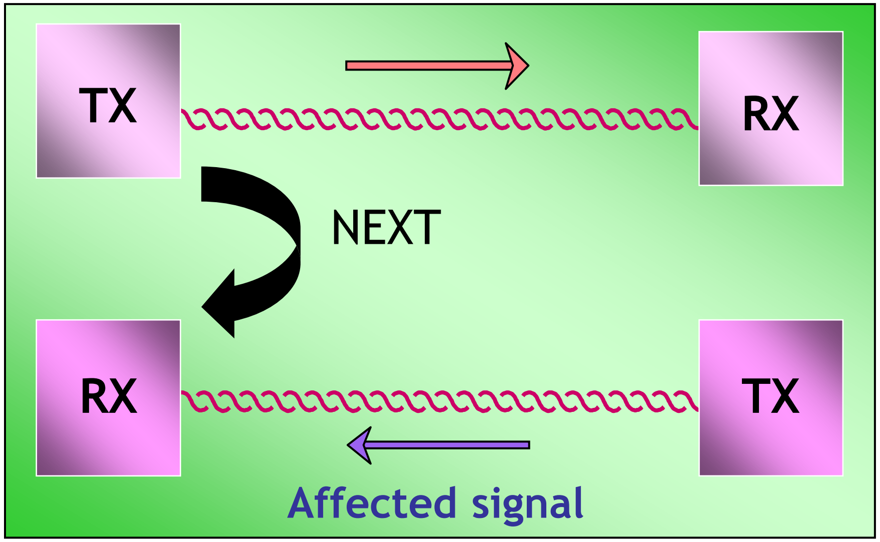


NEXT

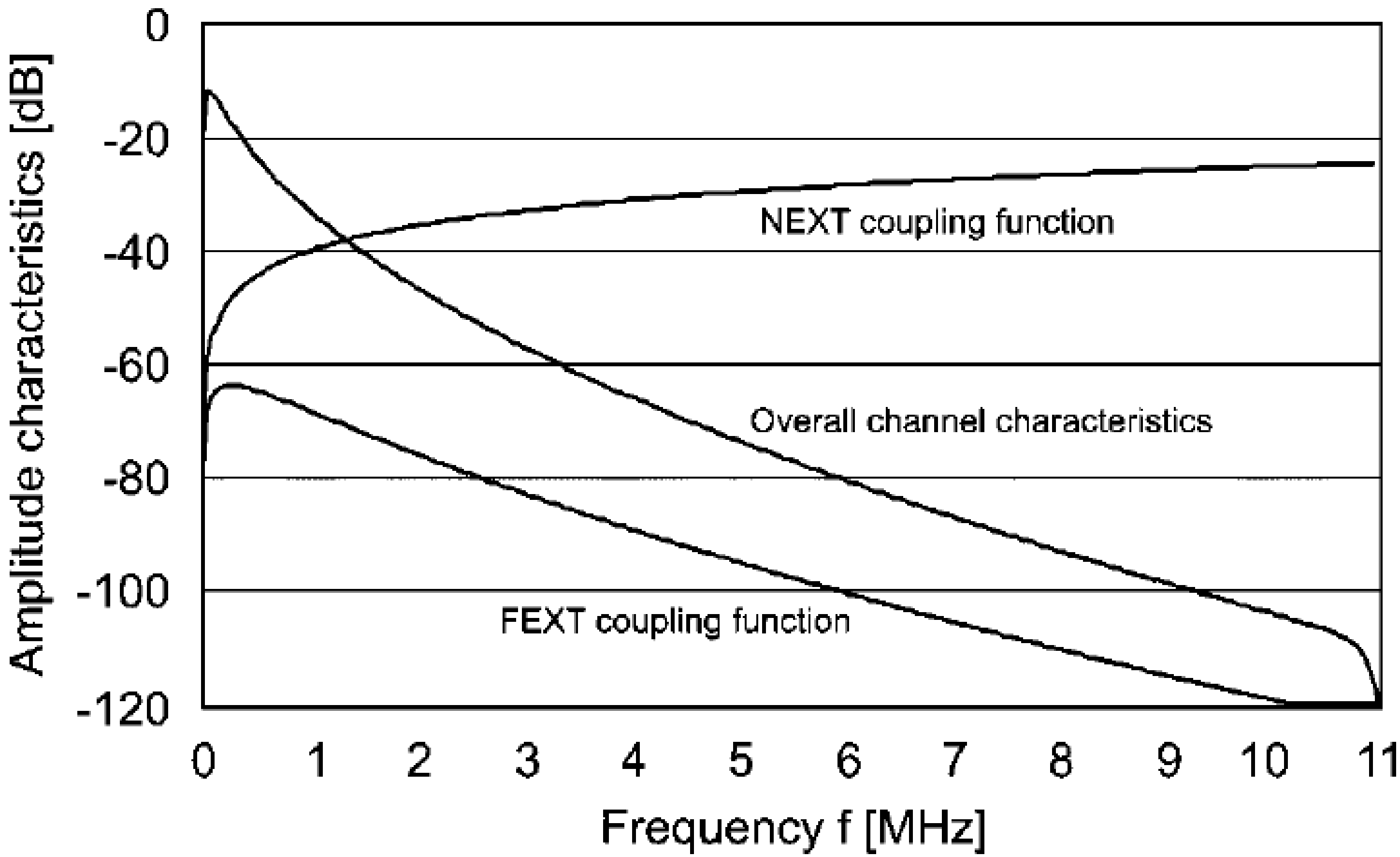
- NEXT is the cross-talk between a transmitter and a receiver placed on the same side of the cable;

Receiver's signals are softer than transmitter's one, since come from far away and thus there is a strong interference which reduces quality of useful received data.

NEXT is one of the reason of the frequency division for upstream and downstream in ADSL.

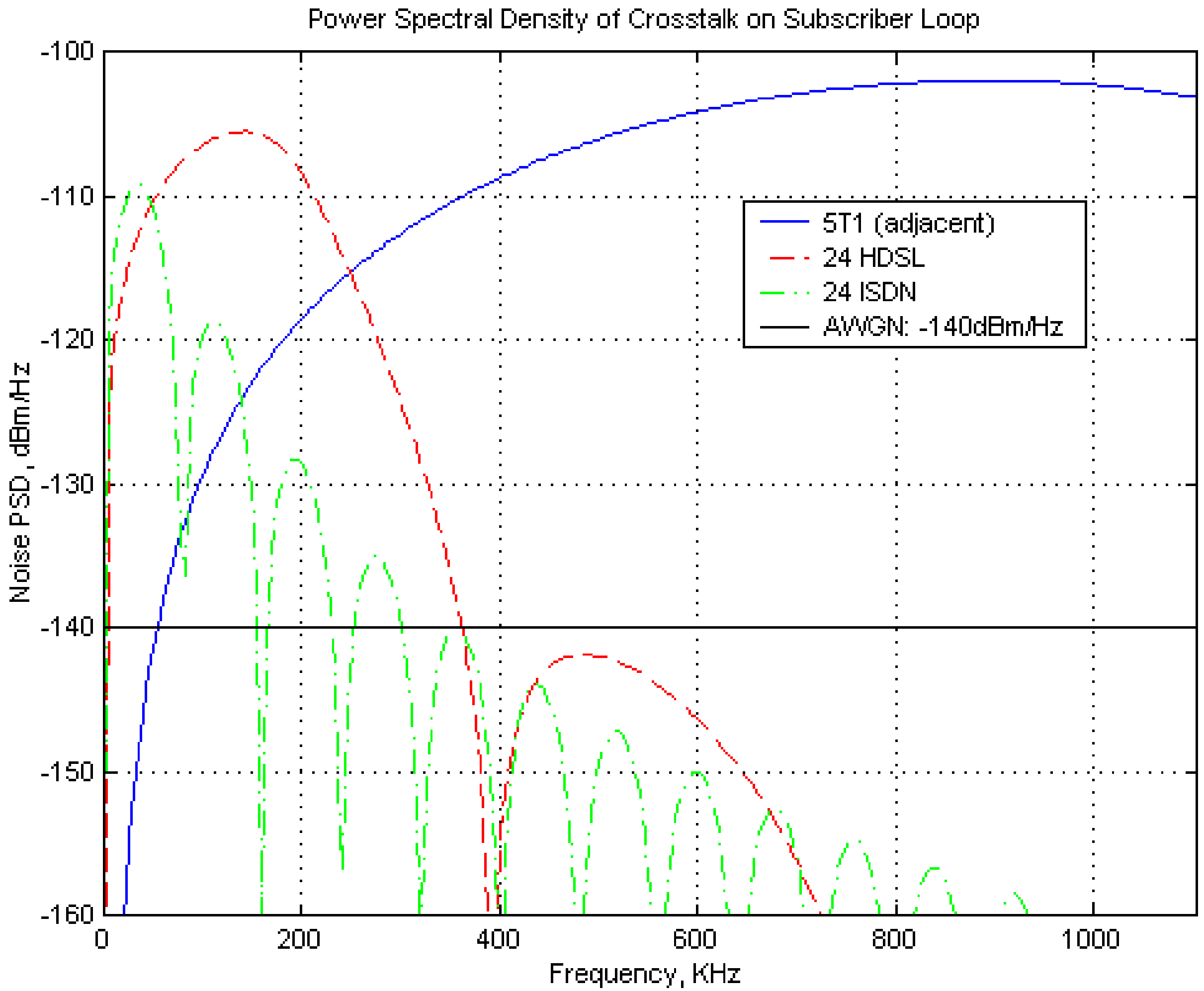


Average NEXT and FEXT coupling functions



Local loop lenght= 1 Km

Crosstalk on Line



Status at an ADSL modem

- **Home**
- **Technicolor Gateway**
- **Connessione a banda larga**
  - **Connessione DSL**
  - Servizi Internet
  - WAN-Sensing
- **Casella degli strumenti**
- **Rete domestica**
- **Guida**

Home > Connessione a banda larga > Connessione DSL

Connessione DSL

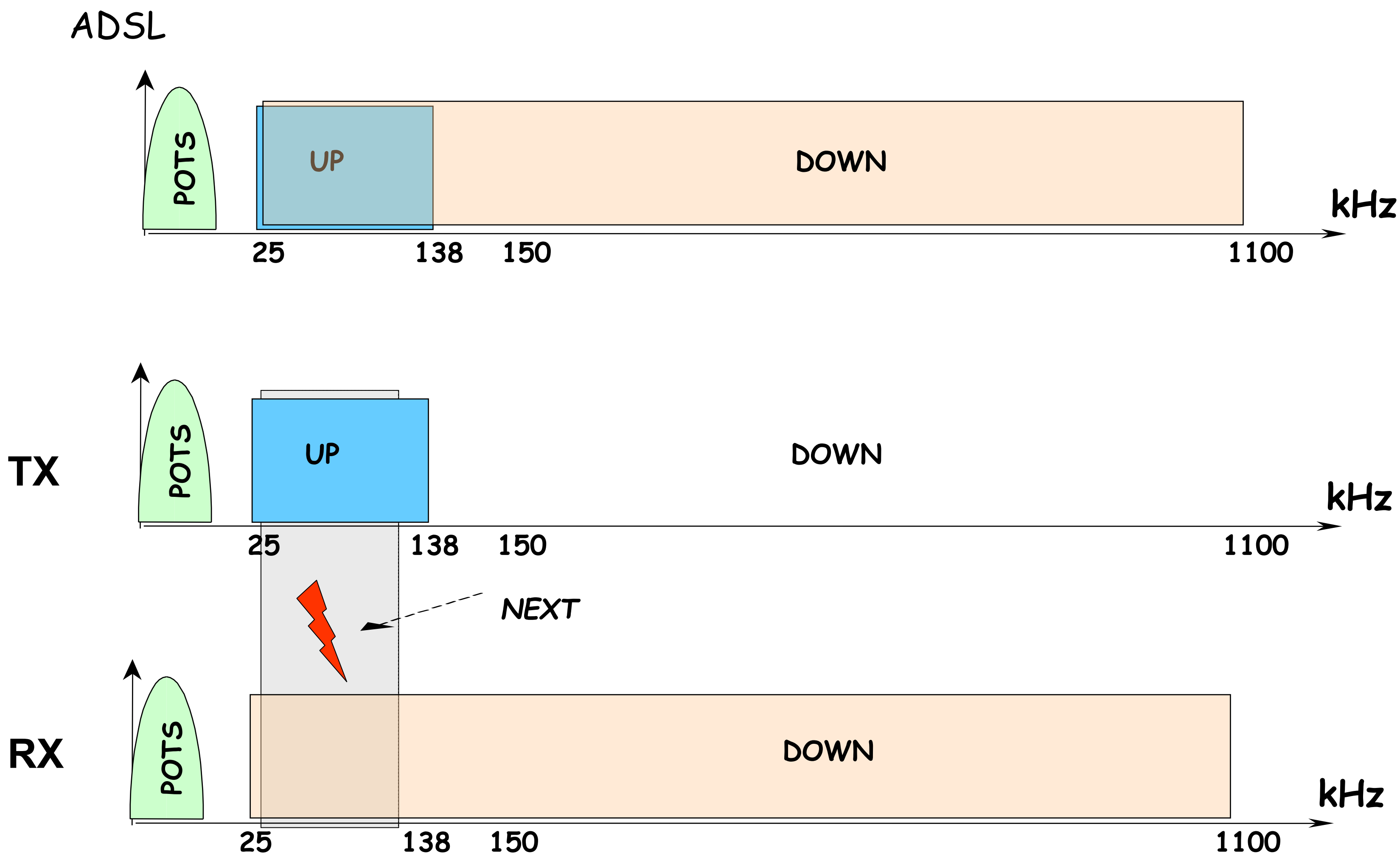
▸ Informazioni collegamento

Tempo di operatività:	0 giorni, 0:09:27
Tipo DSL:	ITU-T G.992.5
Larghezza di banda (upload/download) [kbps/kbps]:	1.022 / 2.042
Dati trasferiti (inviati/ricevuti) [MB/MB]:	1,79 / 21,60
Potenza di output (upload/download) [dBm]:	12,0 / 19,2
Attenuazione linea (upload/download) [dB]:	19,7 / 35,5
Margine SN (upload/download) [dB]:	6,9 / 10,3
Sistema ID fornitore (locale/remoto):	TMMB / ----
Chipset ID fornitore (locale/remoto):	BDCM / BDCM
Perdita di framing (locale/remoto):	0 / 0
Perdita di segnale (locale/remoto):	0 / 0
Perdita di potenza (locale/remoto):	0 / 0
Perdita del collegamento (remoto):	-
Secondi errore (locale/remoto):	0 / 0
Errori FEC (upload/download):	0 / 7.703
Errori CRC (upload/download):	0 / 0
Errori HEC (upload/download):	0 / 0

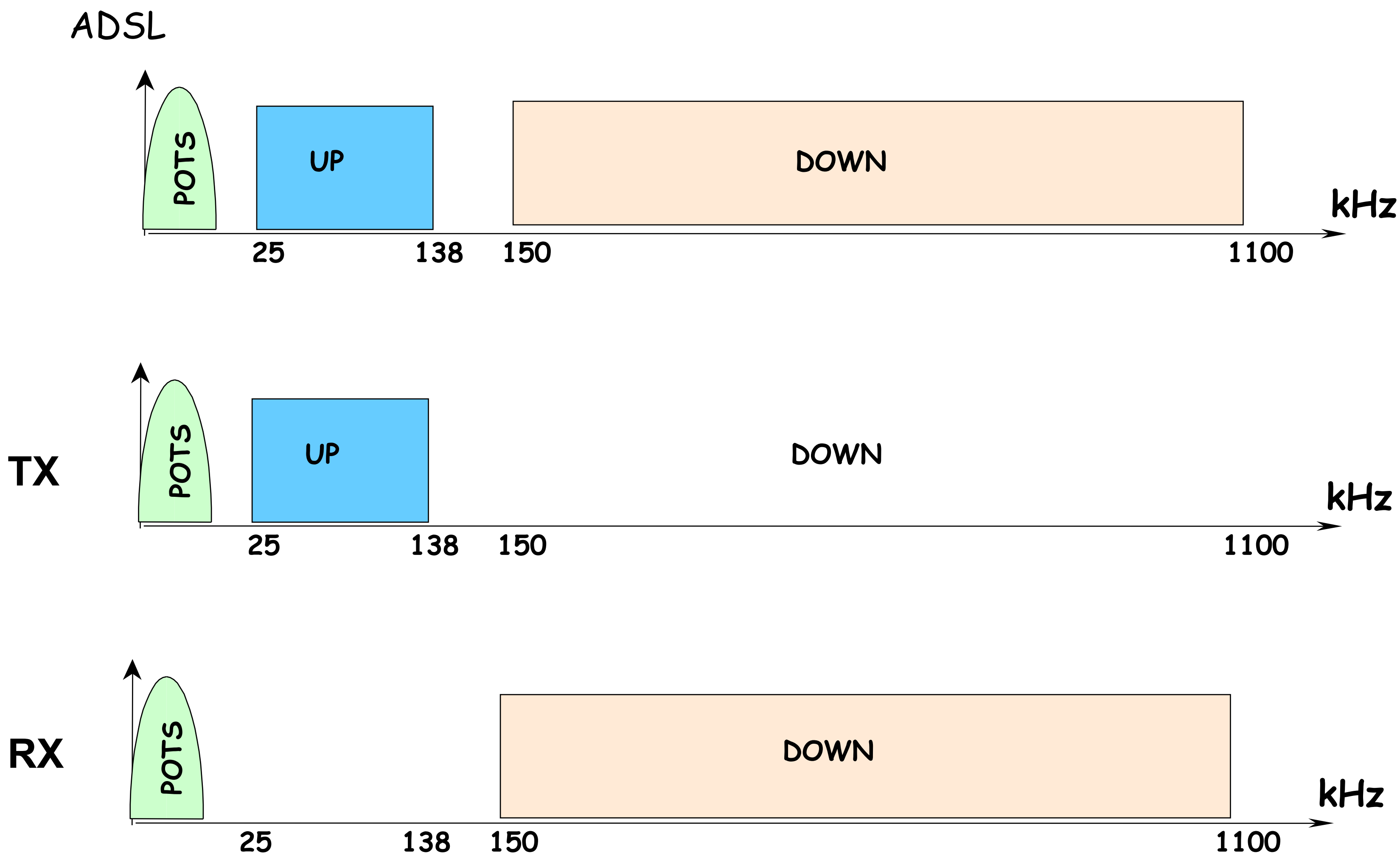
Filtering: splitters

- It is necessary to install appropriate frequency filters at the customers premises to avoid interferences with the voice service
  - either a splitter is installed before connecting the line to phone / DSL modem
  - or DSL signal is "filtered off" at each phone by use of a low pass filter, also known as microfilter.

Echo cancelled



Reduced NEXT or FDD

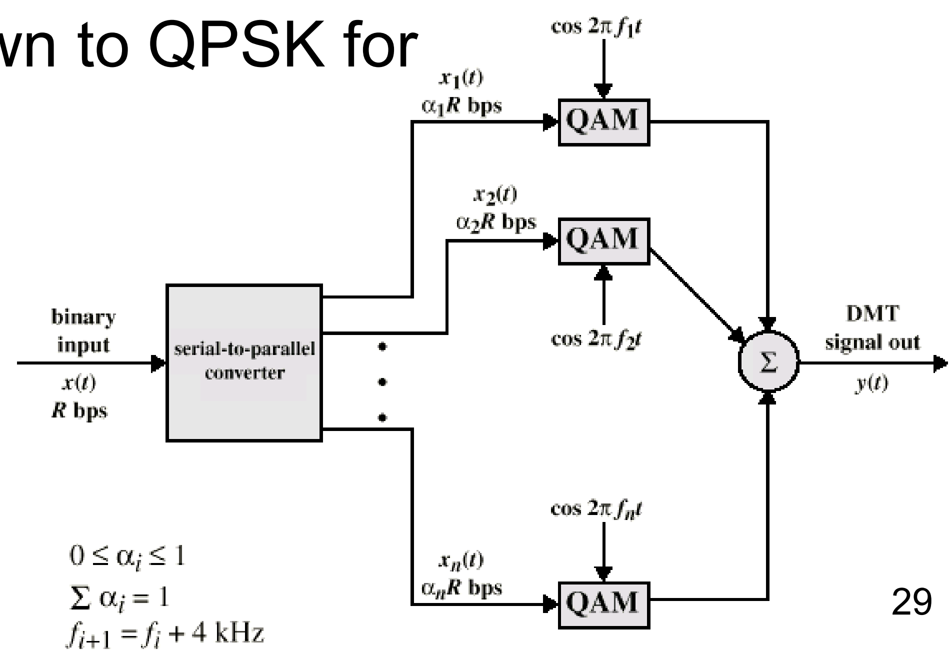


ADSL: Modulations

- Modulation: CAP
  - CAP stands for Carrier-less Amplitude/Phase modulation, and describes a version of QAM in which incoming data modulates a single carrier that is then transmitted down a telephone line.
  - The carrier itself is suppressed before transmission (it contains no information, and can be reconstructed at the receiver), hence the word “carrier-less” (single carrier but suppressed)

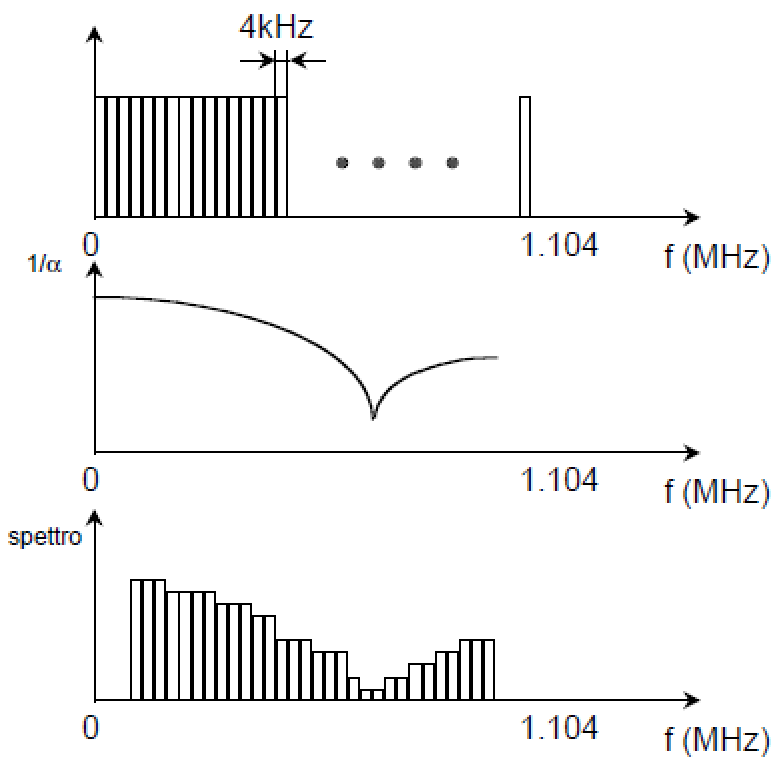
ADSL: Modulations

- Modulation: DMT (Discrete Multi-Tone) (multicarrier)
  - 256 sub-bands of 4,3125 kHz each, so occupying 1.024MHz
  - Each sub-band is QAM64 modulated for clean sub-bands, down to QPSK for noisier lines

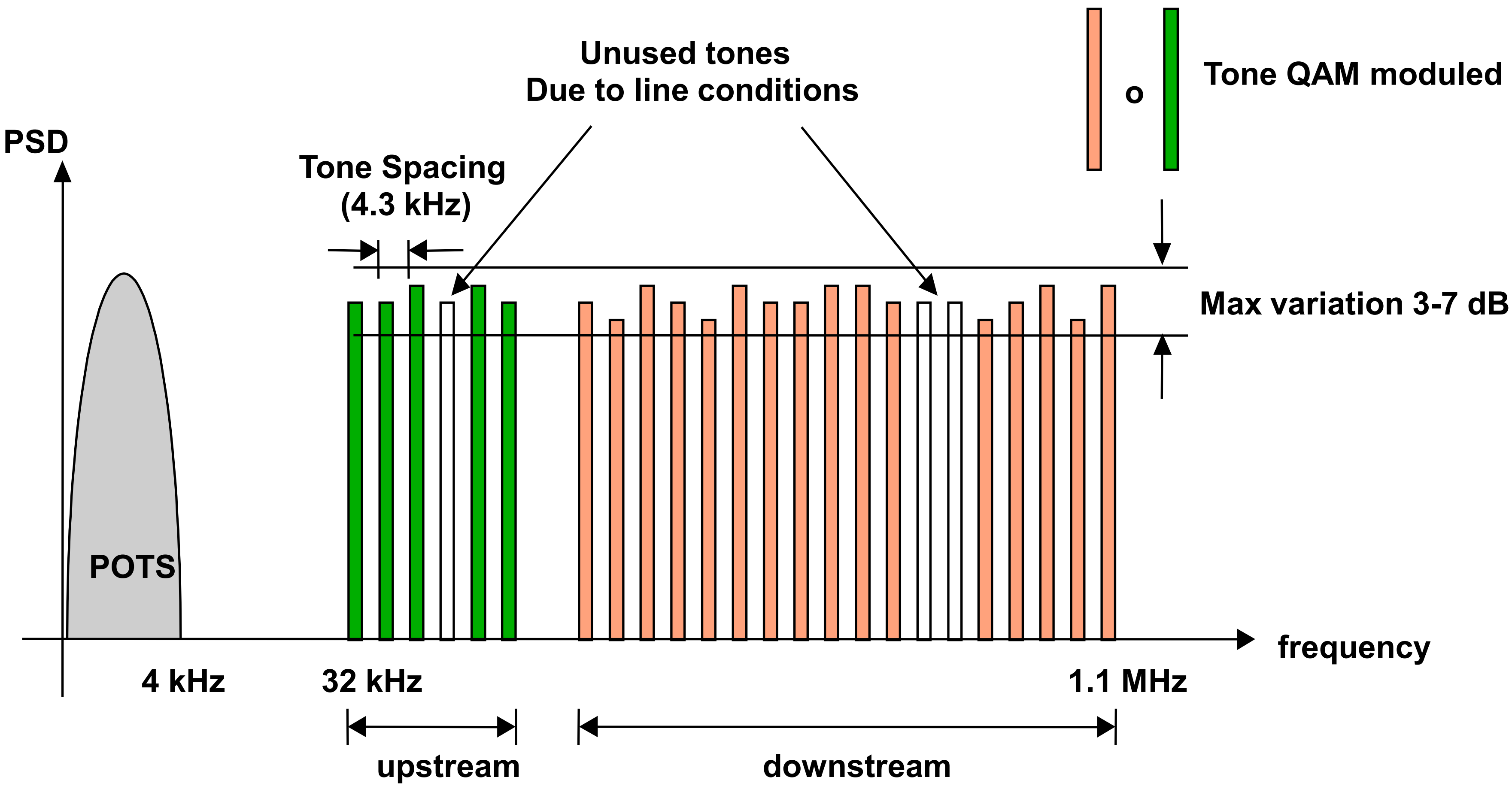


Principle of DMT modulation

- Divide the operational ADSL bandwidth into very small subchannles
- Discrete carriers (or tones) are used in the center of each data subchannel
- These carriers are used to transmit data independently in each subcarrier by means of a specified QAM modulation.



DMT modulation

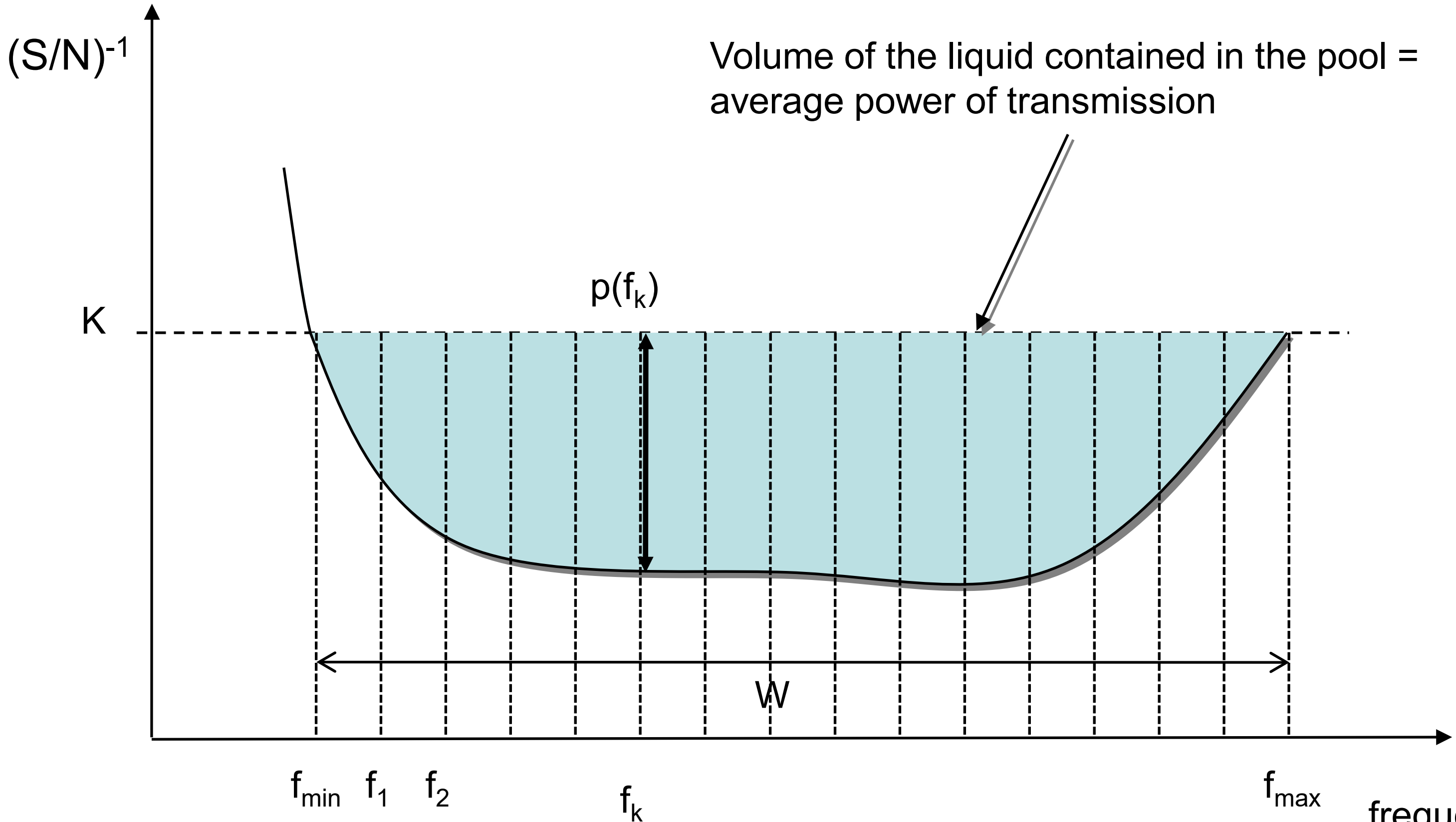


DMT modulation

- Independent subchannels can be manipulated individually with consideration of the line conditions
- If a subchannel is experiencing external interference it may not be used in favor of other subchannles
- DTM can dynamically adapt the data rate to the line conditions
- Theoretical maximum upstream bandwidth:
  - 25 channels X 15 bit/s/Hz/channel X 4 KHz= 1.5 Mbit/s
- Theoretical maximum downstream bandwidth:
  - 249 channels X 15 bit/s/Hz/channel X 4 KHz= 14.9 Mbit/s

Water filling

- The signal power for each subcarrier is determined as the depth of the liquid in a pool
- Knowing the discreate values of $p(f_k)$ for each subcarrier f_k one may deduce the number of bit per simbol to associate to the QAM costellation used in each subchannel



ADSL: Modulation

- CAP and DMT compared for ADSL (see next Table)
  - Adaptive equalizer is required for CAP since noise characteristics vary significantly across the frequency passband.
  - DMT has the speed advantage over CAP
- DSP advances will enable the technologies to converge in cost and function

Comparison of CAP and DMT for ADSL

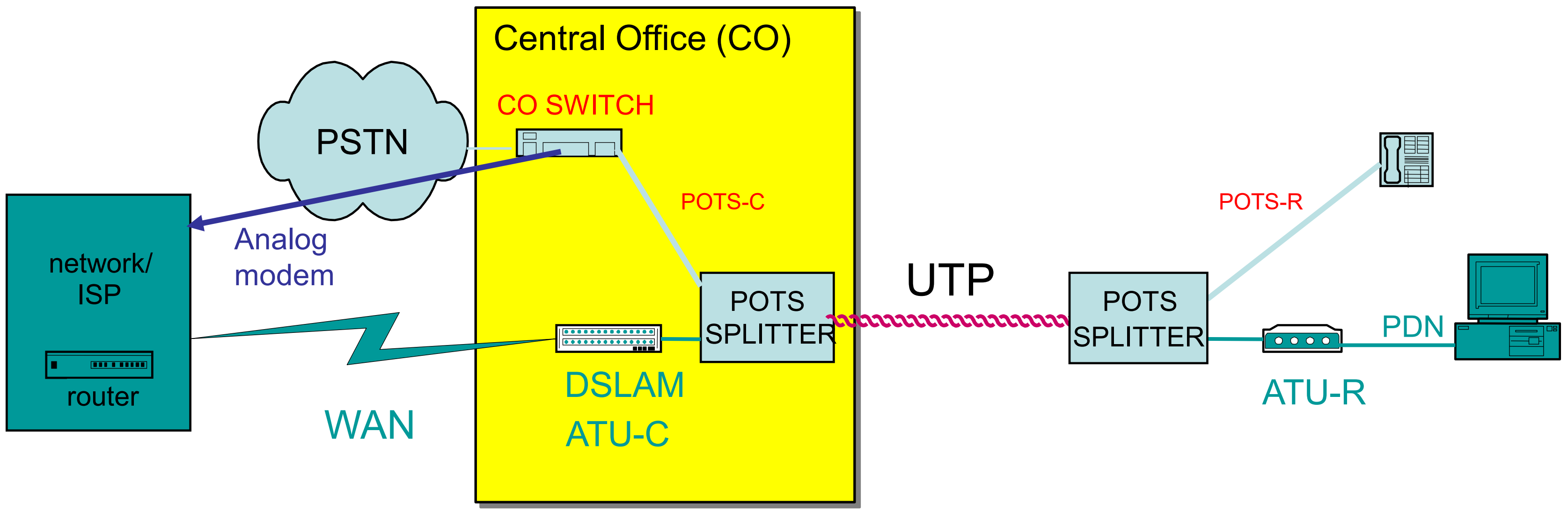
	CAP	DMT
Power consumption	Lower, fewer gates	Higher peak/average, but will likely narrow gap
Forward carriers	1	256
Return carriers	1	32
Increment	320 Kb	32 Kb
Adaptive equalizers	Needed	None
Licensing	Globespan	Many sources
Standardization	In process	ITU and ANSI
Key competitors	Globespan, Paradyne, Westell	Conexant, Cisco, Alcatel, Amati (now Texas Instruments), Westell, Efficient Networks

CAP: Carrierless AM/PM
DMT: Discrete Multi-Tone

ADSL: Architecture

- CAP and DMP are coming together on further architectural elements of an ADSL system
- ADSL Forum provides much information (www.adsl.com)
- Content providers transmit information to the CO over the A9 interface (not shown) and the A4 interface.
- ATU-C: ADSL Transmission Unit – CO
  - Embedded in a line card in the DSLAM
  - One ATU-C per subscriber

ADSL reference model



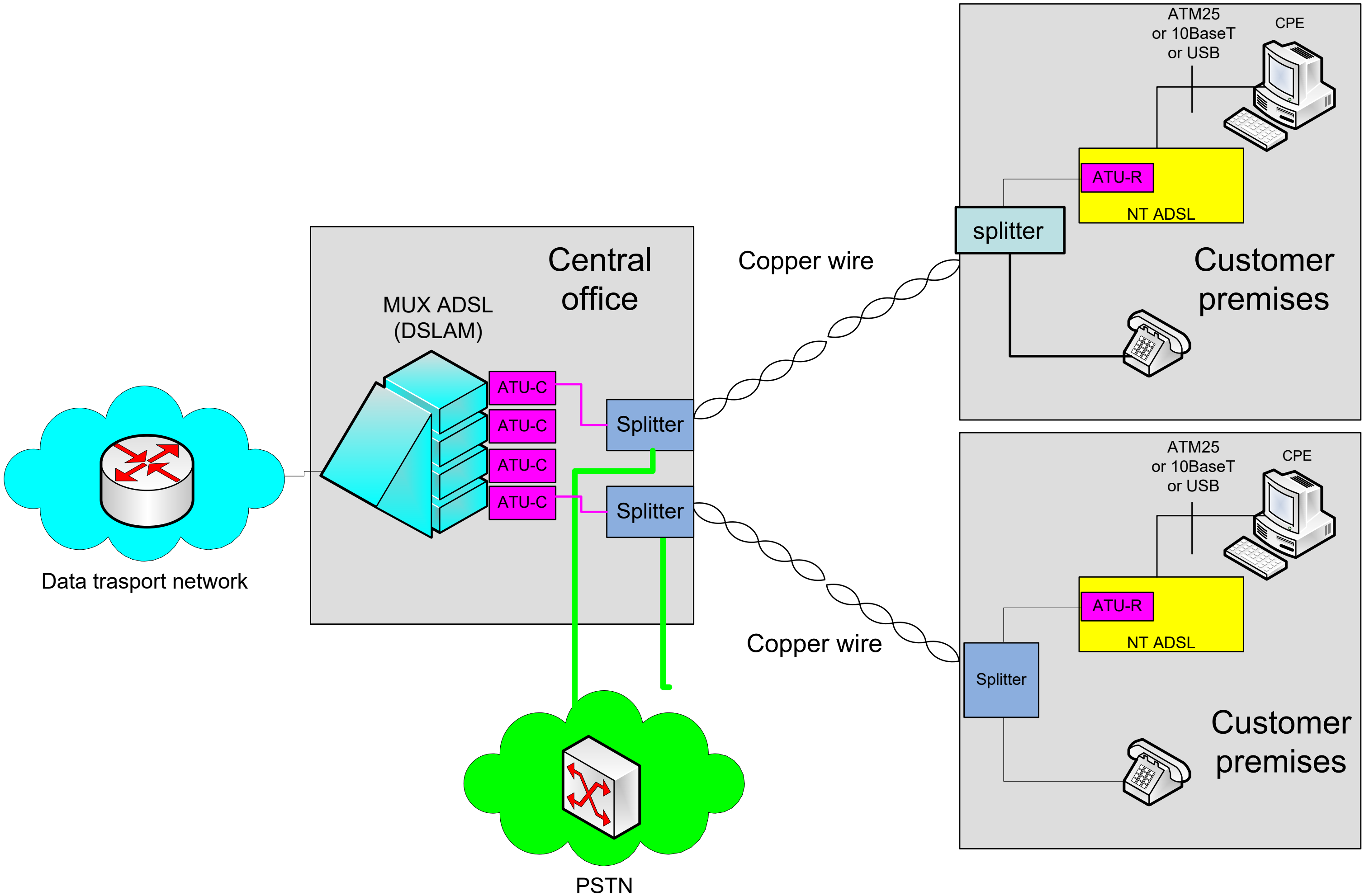
POTS Splitter: separates POTS from DSL signals

ATU-R: ADSL Termination Unit – Remote side

ATU-C: ADSL Termination Unit Central office side

DSLAM: DSL Access Multiplexer

More Detail on an End-to-End Design



ADSL: Principles of Operation

- Two services
  - Transparent access to legacy voice service
  - High-speed digital service
- Voice service
  - POTS splitters used in home shunt the frequencies below 3400Hz to POTS wiring
  - Frequencies above the voice band are for high-speed data service to get to the ATU-R

ADSL: Architecture

- ATU-R: ADSL Transmission Unit – Remote
  - Supports a multidrop or shared-home topology
- ATU-C: ADSL Transmission Unit – Central
  - ATU-C and ATU-R engage in physical-layer negotiations between the home and the CO and they can be considered modems
  - Keep management statistics, such as SNR at the physical layer; packet counts at the network layer, receive software updates; and be remotely manageable by the carrier
- POTS splitter (PS)
  - A low-pass/high-pass filter

ADSL: Architecture

- ATU-C and ATU-R operations
  - Concerned with physical layer
  - Frequency allocation:
    - » Bandwidth on the phone wire is divided into three parts:
      - Legacy analog POTS service: below 3400Hz
      - Upstream digital service: 25-200kHz
      - Downstream digital service: 25/250-1000kHz (Echo cancellation/FDM: frequency division multiplexing)
  - Echo cancellation
    - » Both sides talk at the same time
    - » More bandwidth efficiently than FDM
    - » More complex and expensive
  - Rate adaption

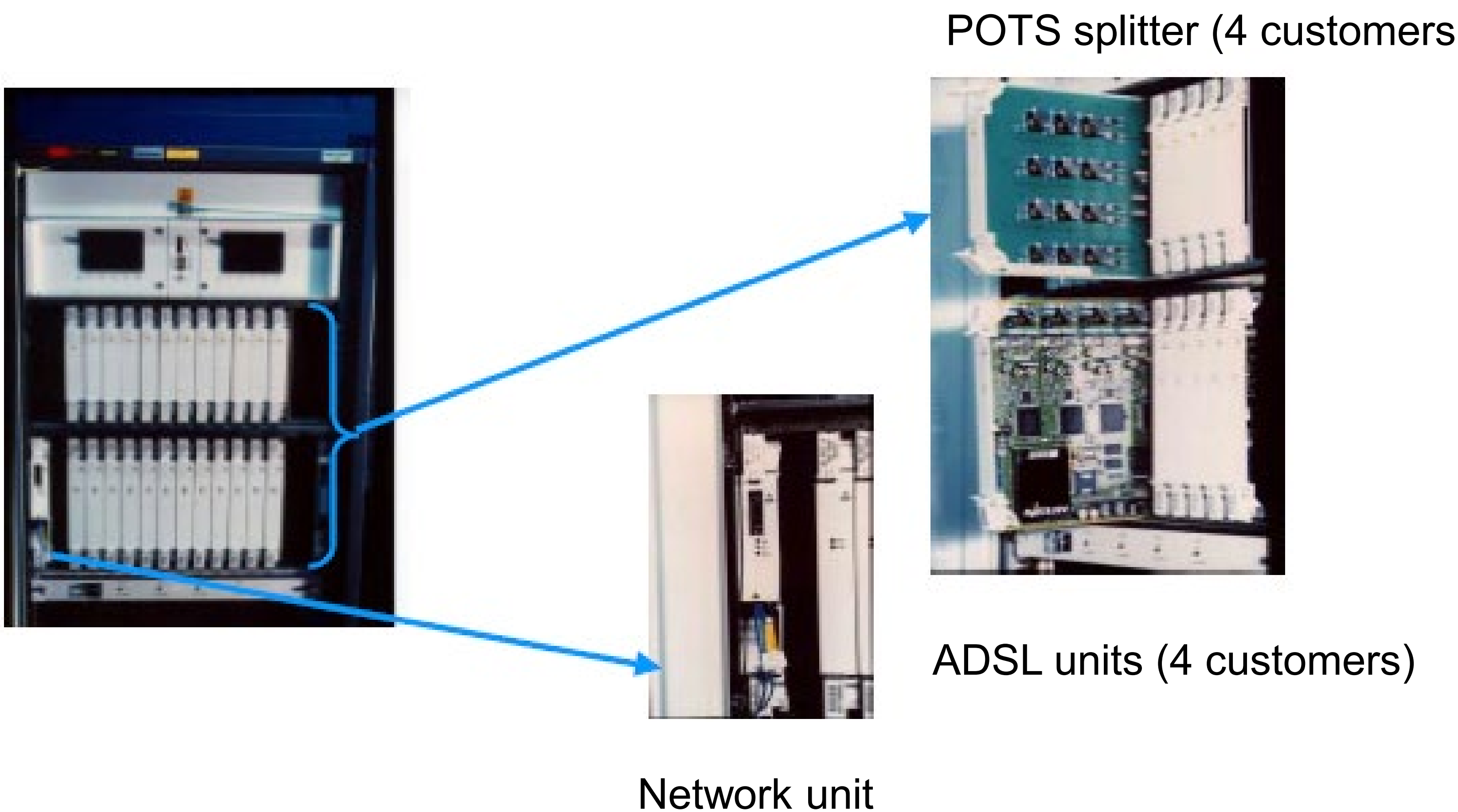
CPE interfaces

- 10baseT
  - 10Mbit/s on a 100m twisted pair
  - widely available on PCs
- ATM25
  - 25Mbit/s on a 100m twisted pair
  - Point-to-point
  - Not very common
  - More expensive
- USB
  - 12Mbit/s till 30m
  - widely available on new genartion PCs
- Wi-Fi

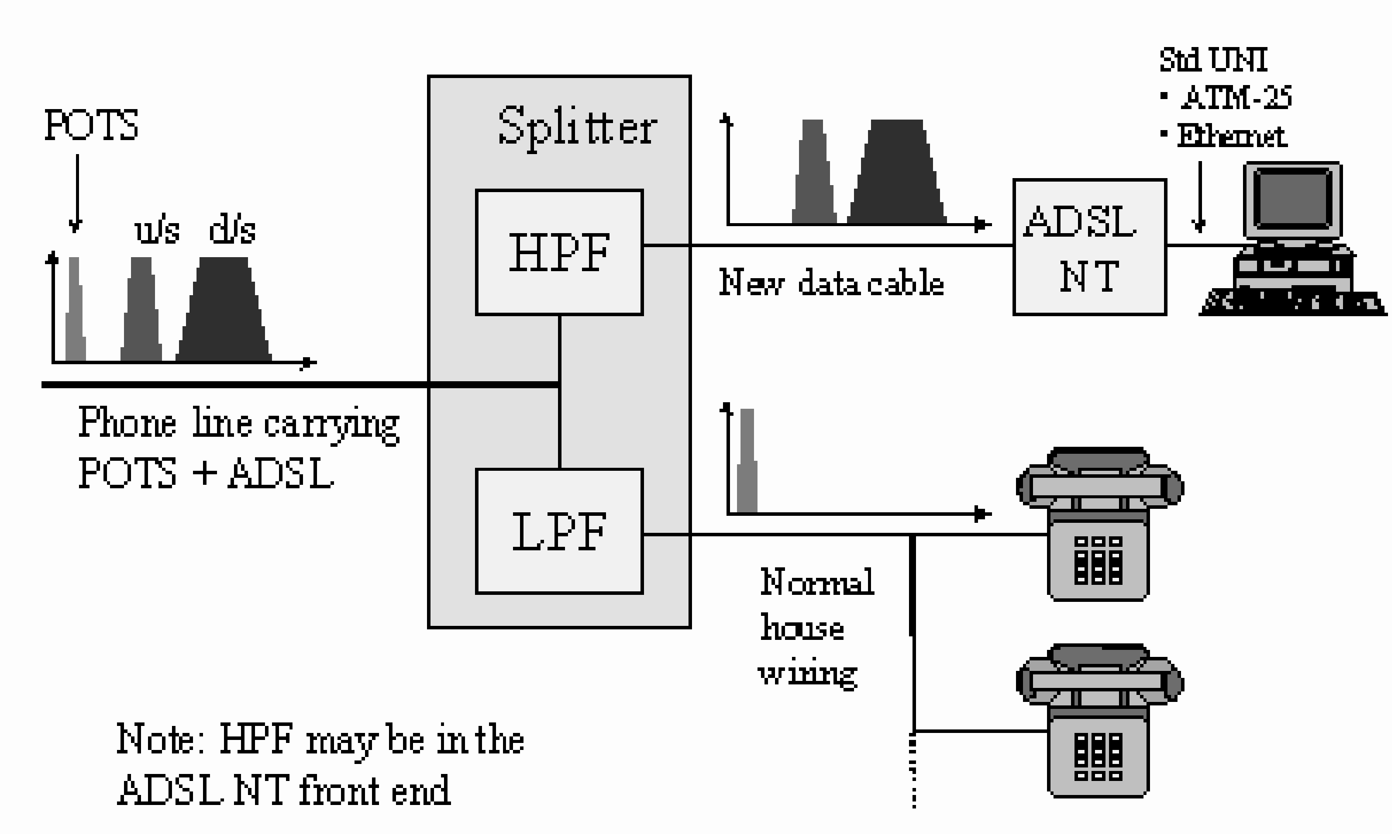
ADSL: Architecture

- DSL Access Multiplexer (DSLAM)
  - Primary functions:
    - » House a set of ATU-C interfaces
    - » Multiplex traffic
    - » Demultiplex traffic
    - » Negotiate line speed
    - » Serve as a central management platform
  - Locations:
    - » CO, adjacent site to CO, remote terminal, customer premises
  - Current DSALMs may include up t a few hundreds

CO elements


POTS splitter (4 customers)
ADSL units (4 customers)
Network unit

In-home configuration



Splitters

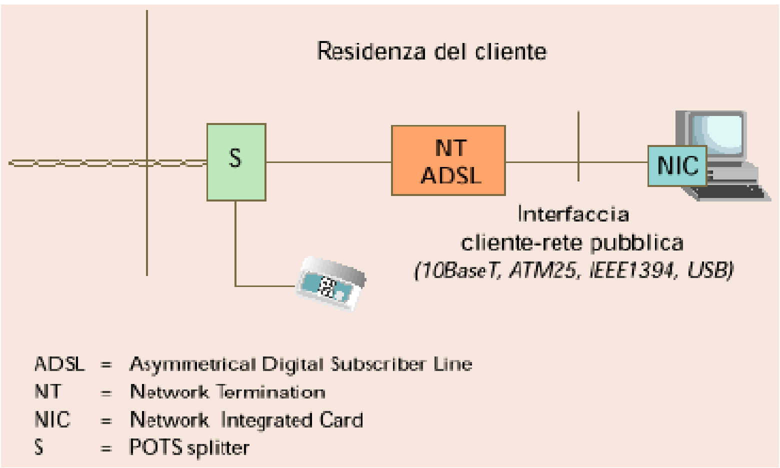
Splitter separates POTS from DSL signals

- Must guarantee lifeline POTS services
- Hence usually passive filter
- Must block impulse noise (e.g. ring) from phone into DSL

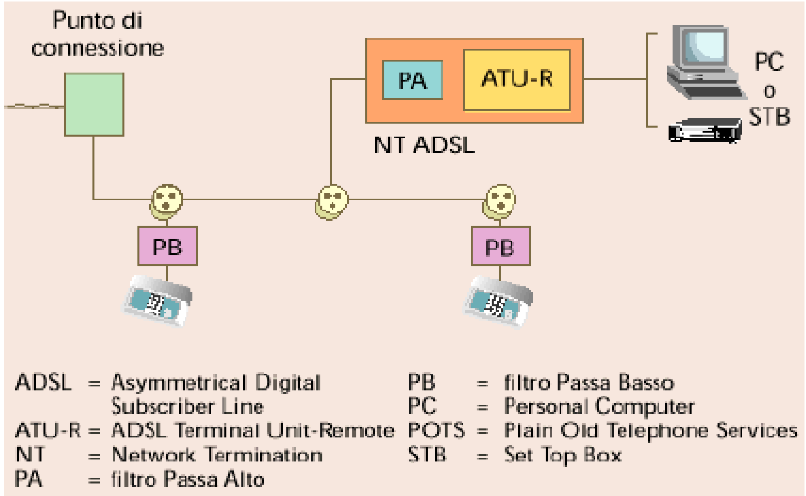
- It is not a simple cascade of a lowpass [0, 25 KHz] filter with a passband [25 KHz, 1,104 kHz] filter but a multiband (or hybrid) filter

Splitter

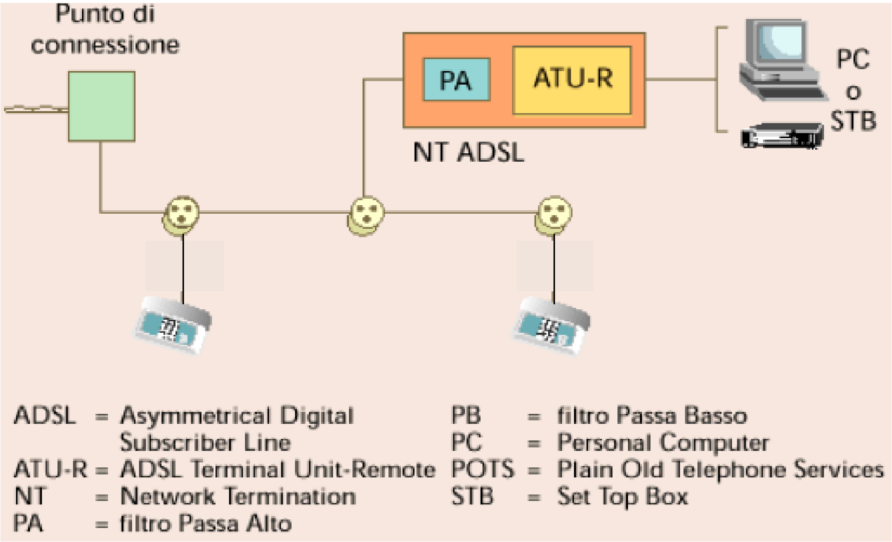
- Splittered



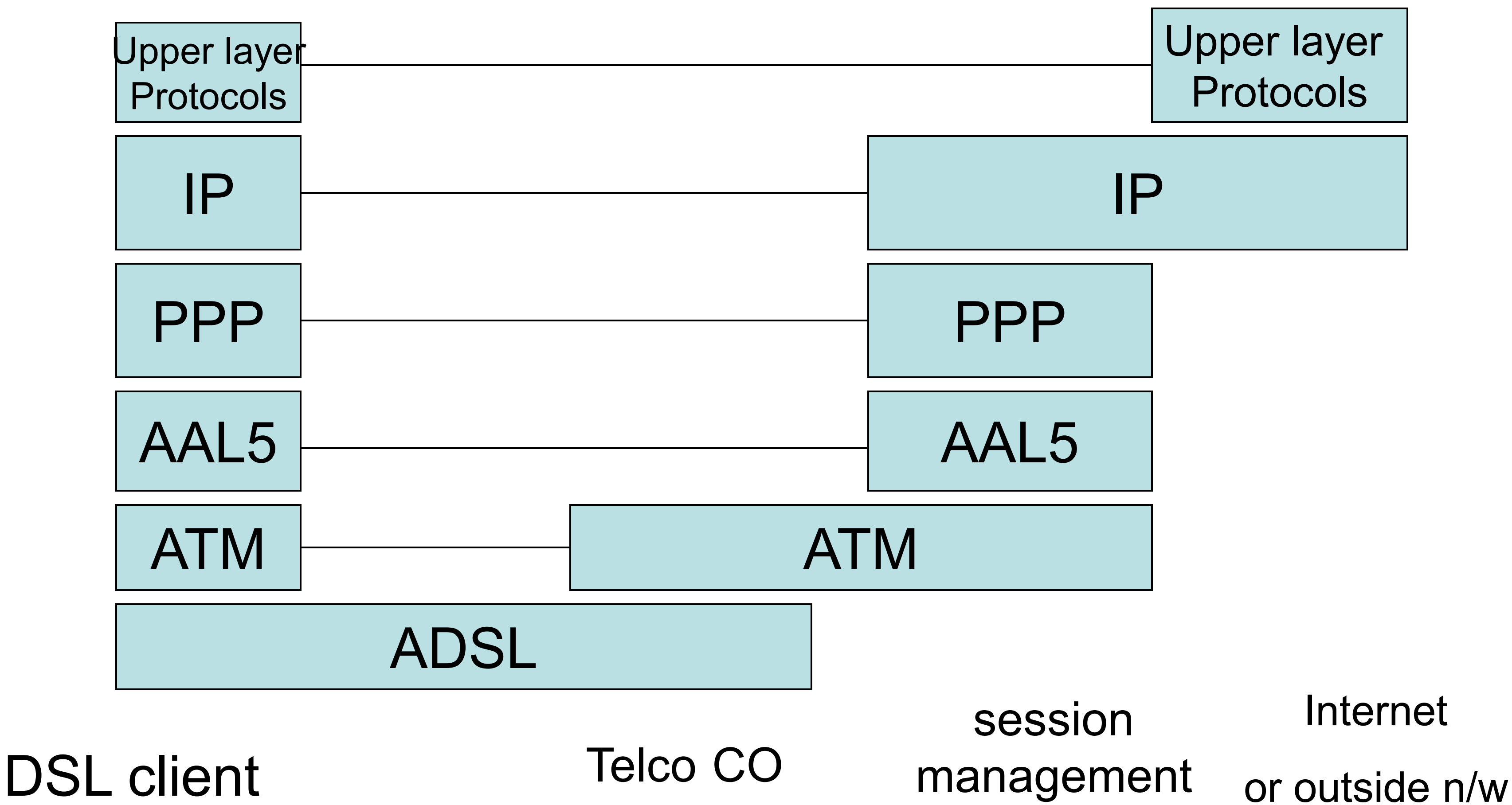
- Distributed splitters



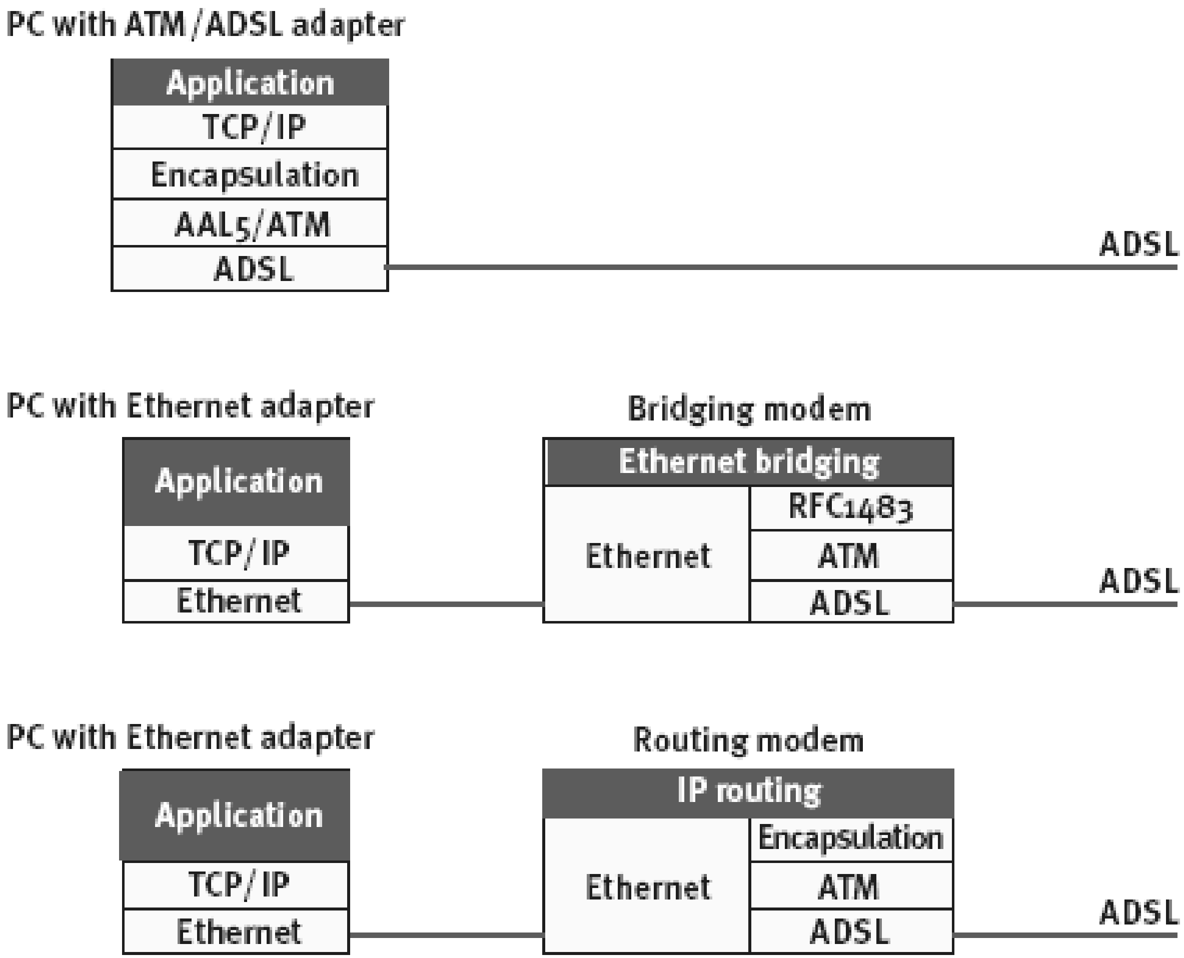
- Splitterless (g.lite)



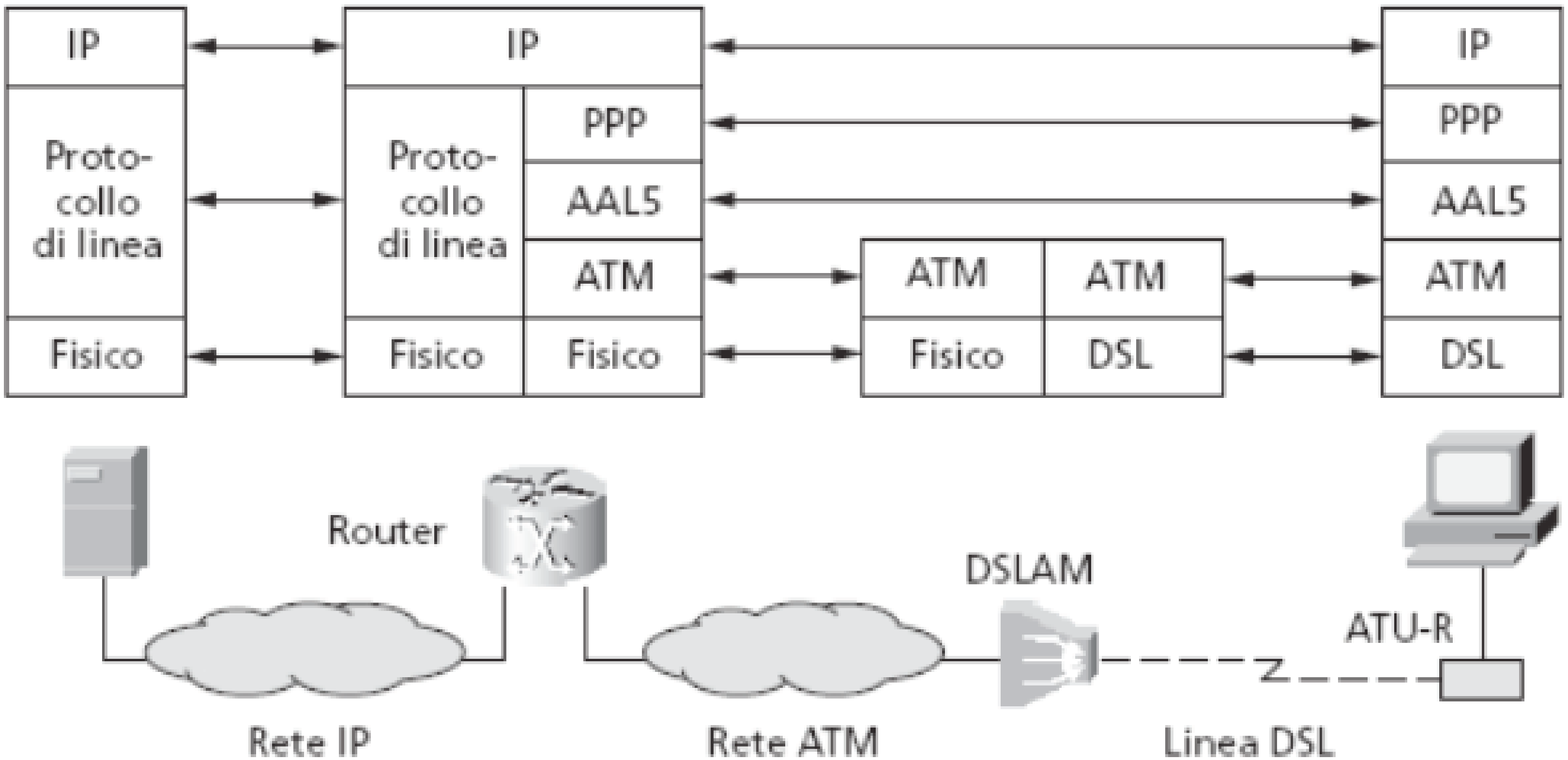
ADSL Protocol Architecture



ADSL Architecture – user side

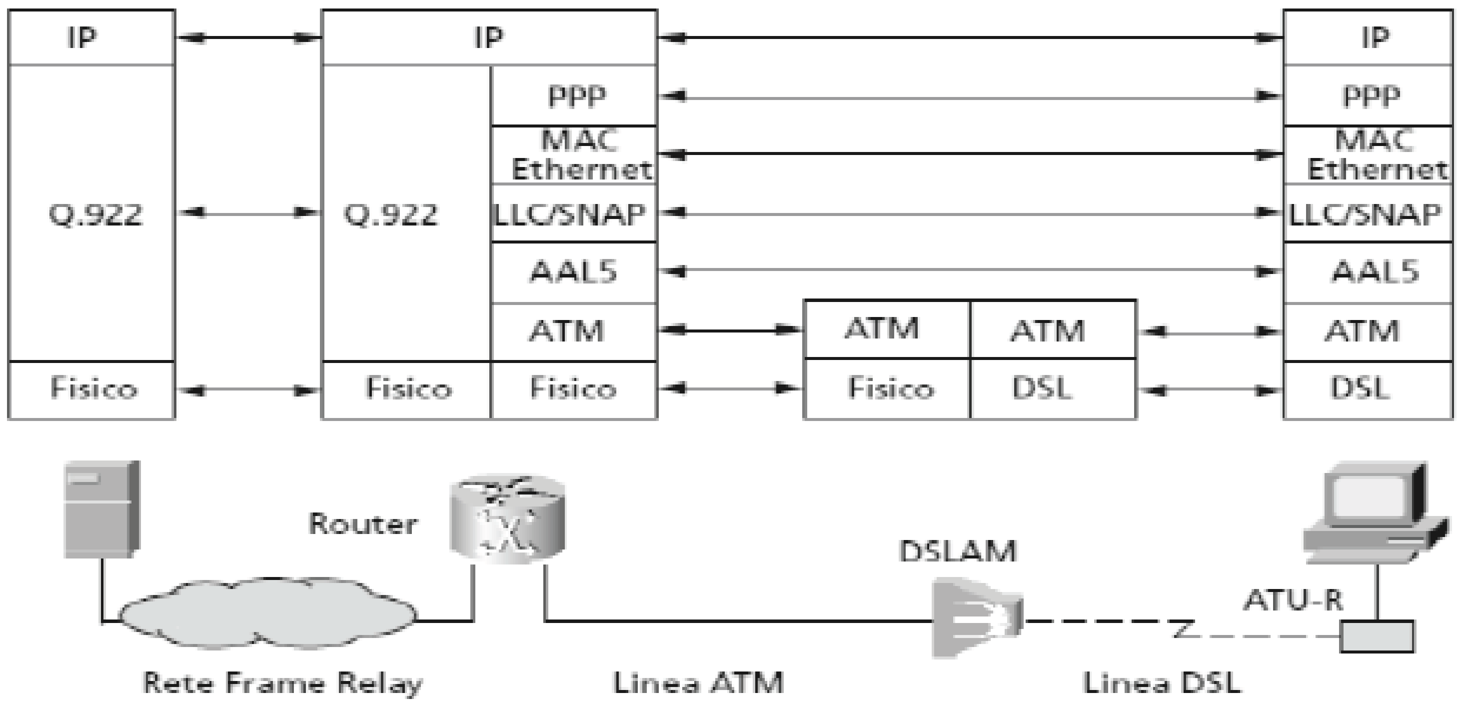


ADSL Architecture – network side



(da A. Pattavina, Reti di Telecomunicazione, 2° ed.)

ADSL Architecture – network side



ADSL: Principles of Operation

- Bit rate negotiation
  - Between ATU-R and ATU-C
  - Four start-up rate options, multiple of 32kbps
  - The entire process is about to take 12~20s (retaining period)
- Autoconfiguration
  - Configuring IP addresses & software filters to ATU-R

ADSL: Principles of Operation

- Benefits and challenges of rate adaption
  - Increases bit rate for customers with good phone wire
  - Covers greater distances for service providers
- Challenges:
  - Technical:
    - » What metrics, algorithms and measurements?
    - » Agreement on different ATU-Rs and ATU-Cs
    - » How to synchronize information?
- Marketing:
  - How to set pricing and bandwidth guarantees?

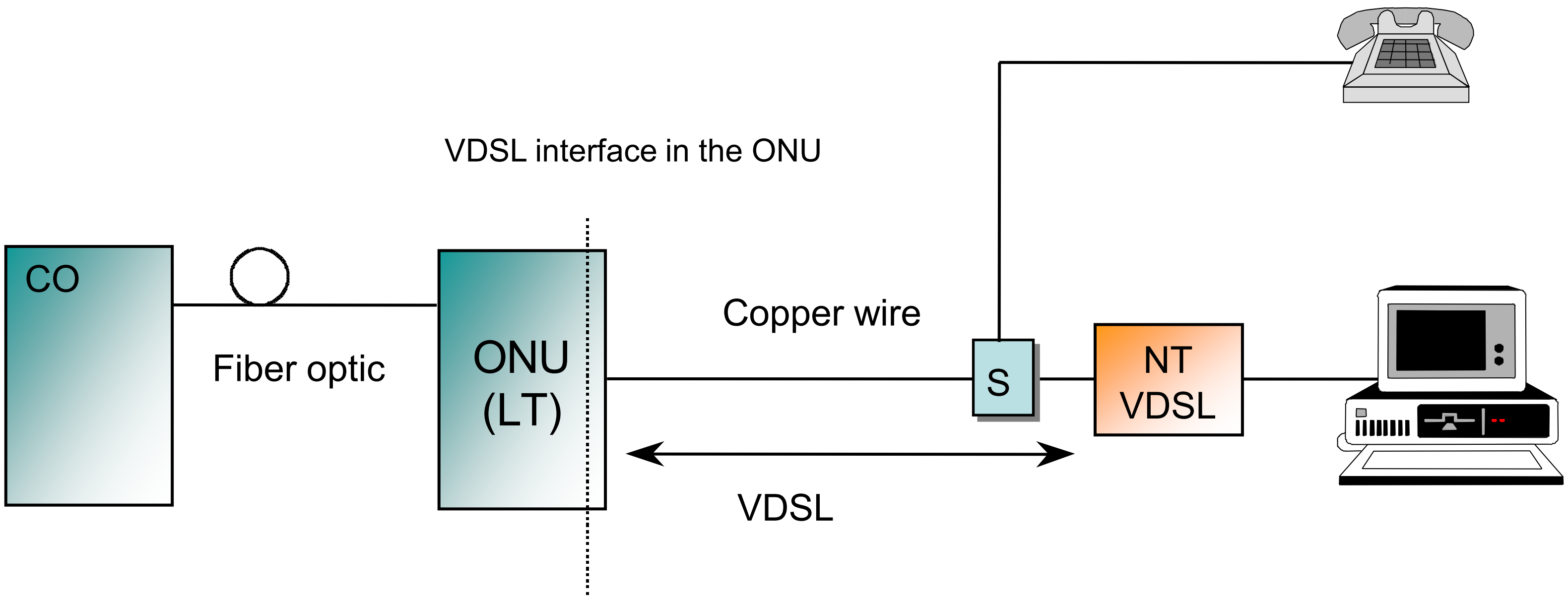
Very high data rate DSL

- VDSL pushes to the limit what can be transmitted over 24-gauge copper pairs.
- Service options:

Upstream	Downstream	Distance
12.96 Mbps	12.96 Mbps	1000 m
2 Mbps	25.92 Mbps	1000 m
25.84 Mbps	25.92 Mbps	300 m
2 Mbps	51.84 Mbps/STS-1	300 m

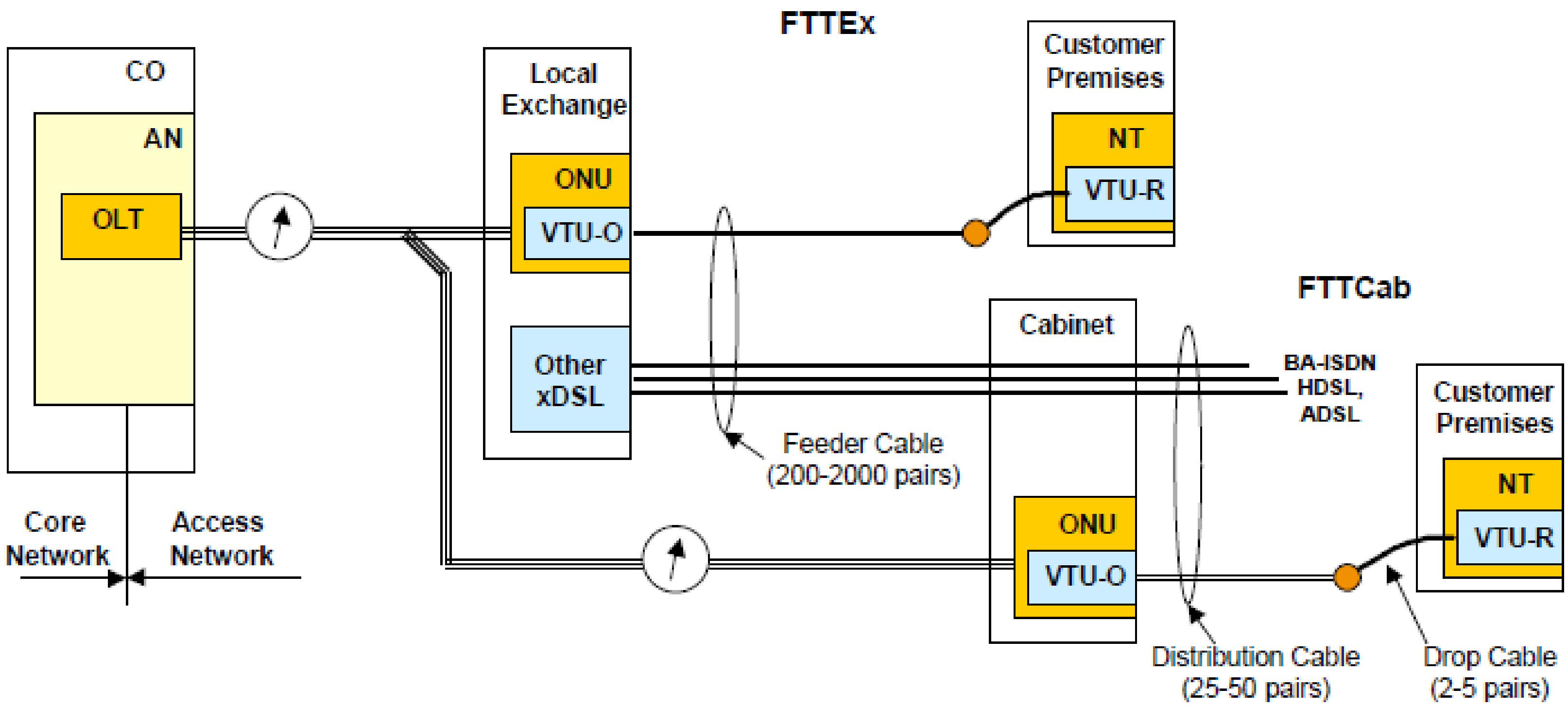
- Key to fastest bit rate possible is to have the shortest possible length of copper wire

VDSL Architecture



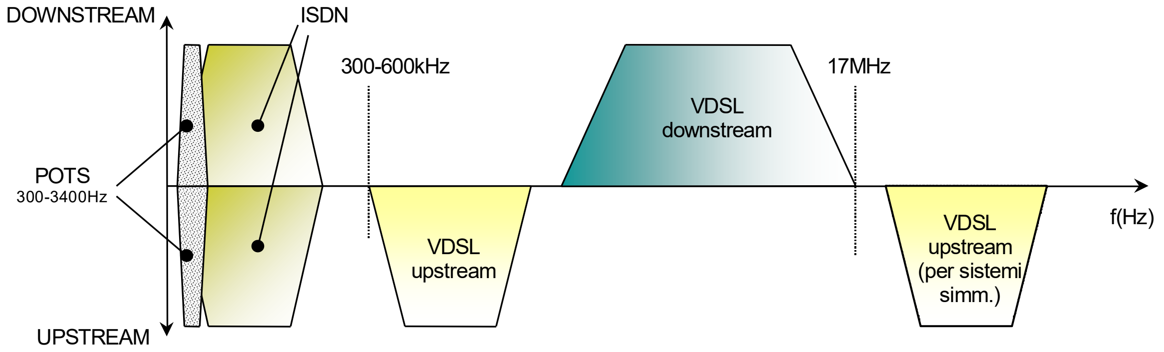
ONU: Optical Network Unit
S: POTS splitter
NT VDSL: Network termination VDSL

Typical configuration

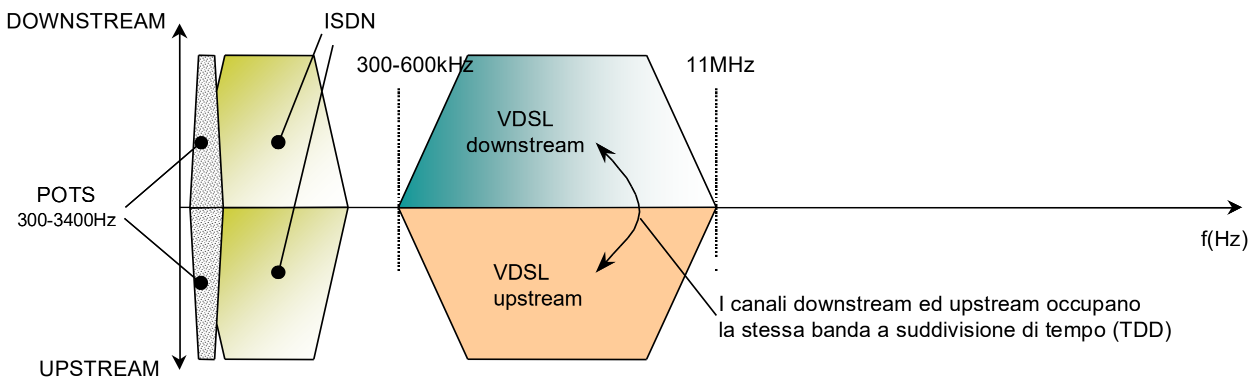


AN - access network
ONU - optical network unit
VTU - VDSL transmission unit

VDSL

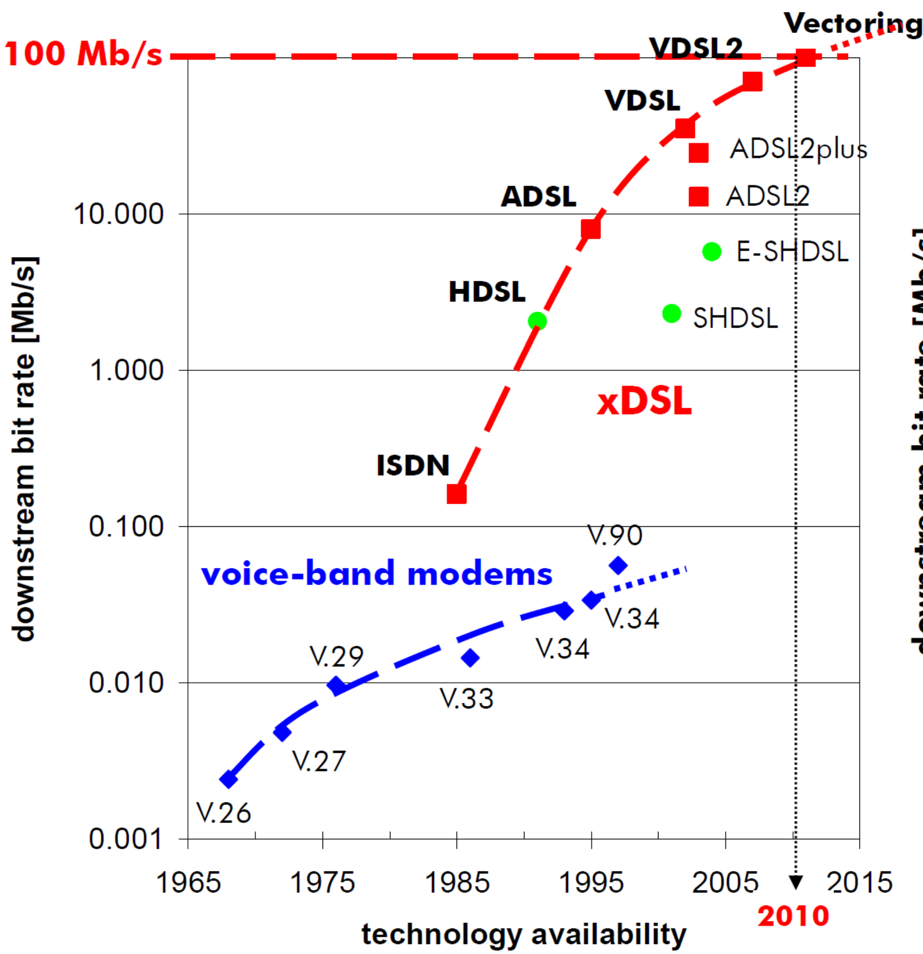


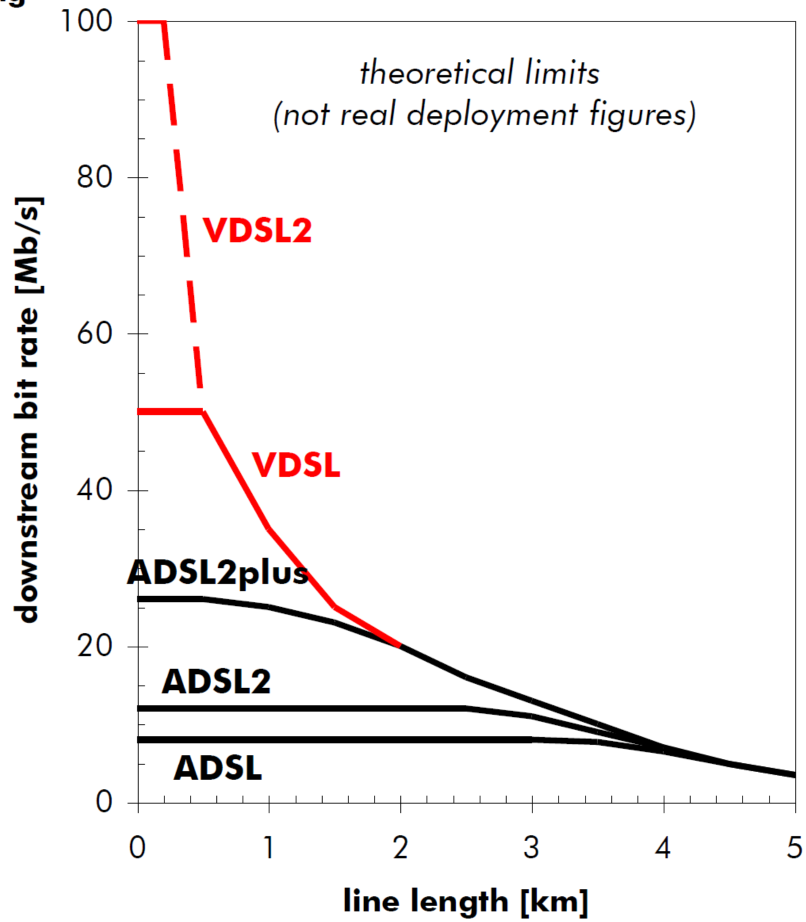
FDD solution



TDD solution

Technology evolution

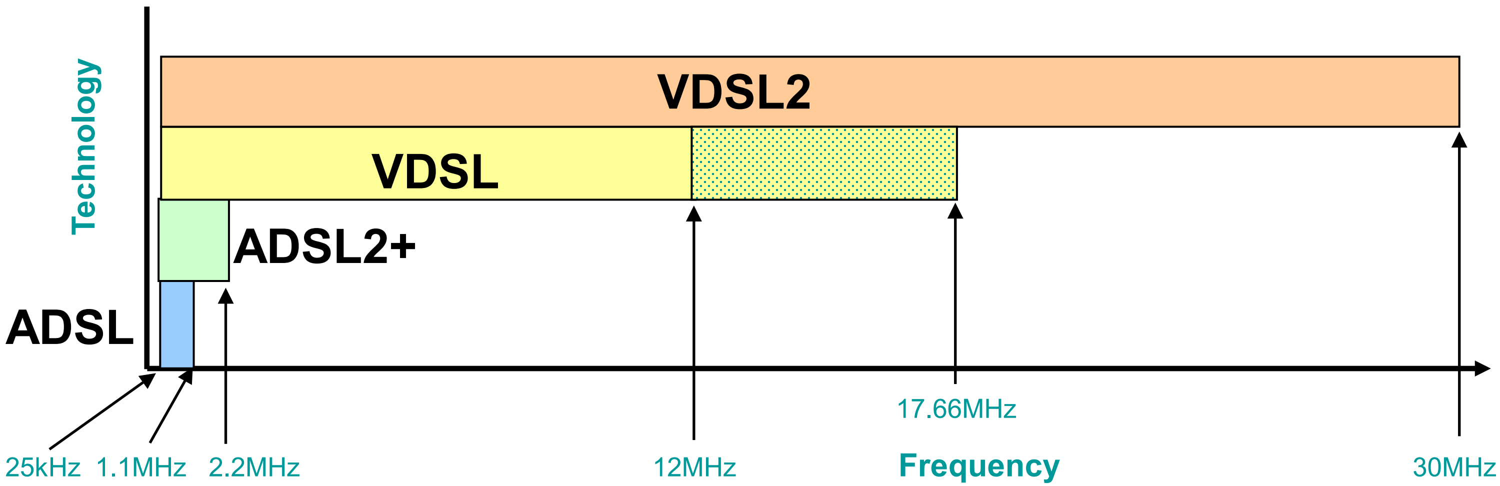




XDSL family

Family	Racc. ITU	Name	Data	Maximum capacity (Mbit/s)
ADSL	G.992.1	G.dmt	1999	7 down 0.8 up
ADSL2	G.992.3	G.dmt.bis	2002	8 down 1 up
ADSL2+	G.992.5	ADSL2plus	2003	24 down 1 up
ADSL-RE	G.992.3	Reach Extended	2003	8 down 1 up
SHDSL	G.991.2	G.SHDSL	2003	5,6 up/down
VDSL	G.993.1	Very-High-data-rate DSL	2004	55 down 15 up
VDSL2-LR	G.993.2	Very-High-data-rate DSL2 Long Reach	2005	55 down 30 up
VDSL-SR	G.993.2	Very-High-data-rate DSL2 Short Reach	2005	100 up/down

ADSL vs VDSL

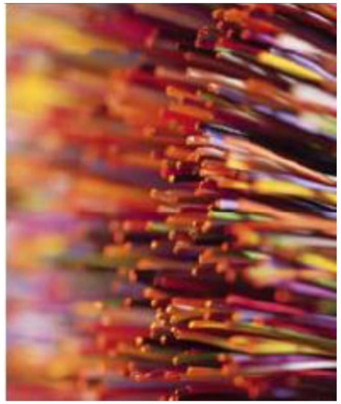


Technology	Freq range	Max Rates	Max # of carriers and Bin spacing
ADSL	25kHz – 1.1MHz	800kbps up 8Mbps down	256 with 4.3125kHz bins
ADSL2+	25kHz – 2.2MHz	1Mbps up 24Mbps down	512 with 4.3125kHz bins Amend. 1 = 29 Mbps down
VDSL(1)	25kHz – 12MHz	15Mbps up 55Mbps down	2782 with 4.3125kHz bins
VDSL2	25khz – 30MHz	100Mbps up 100Mbps down	4096 with 4.3125kHz bins 3478 with 8.625kHz bins

Challenges to xDSL

- Technical:
  - Loop qualification
  - Crosstalk: shared media creates a loss of QoS
  - Bridged taps: a legacy of phone wiring installation practices of Y form, which can be a significant impairment for DSL services for the echo
  - Powering remote terminals
  - Spectral masking
  - Impulse noise
  - ATU-R maintenance

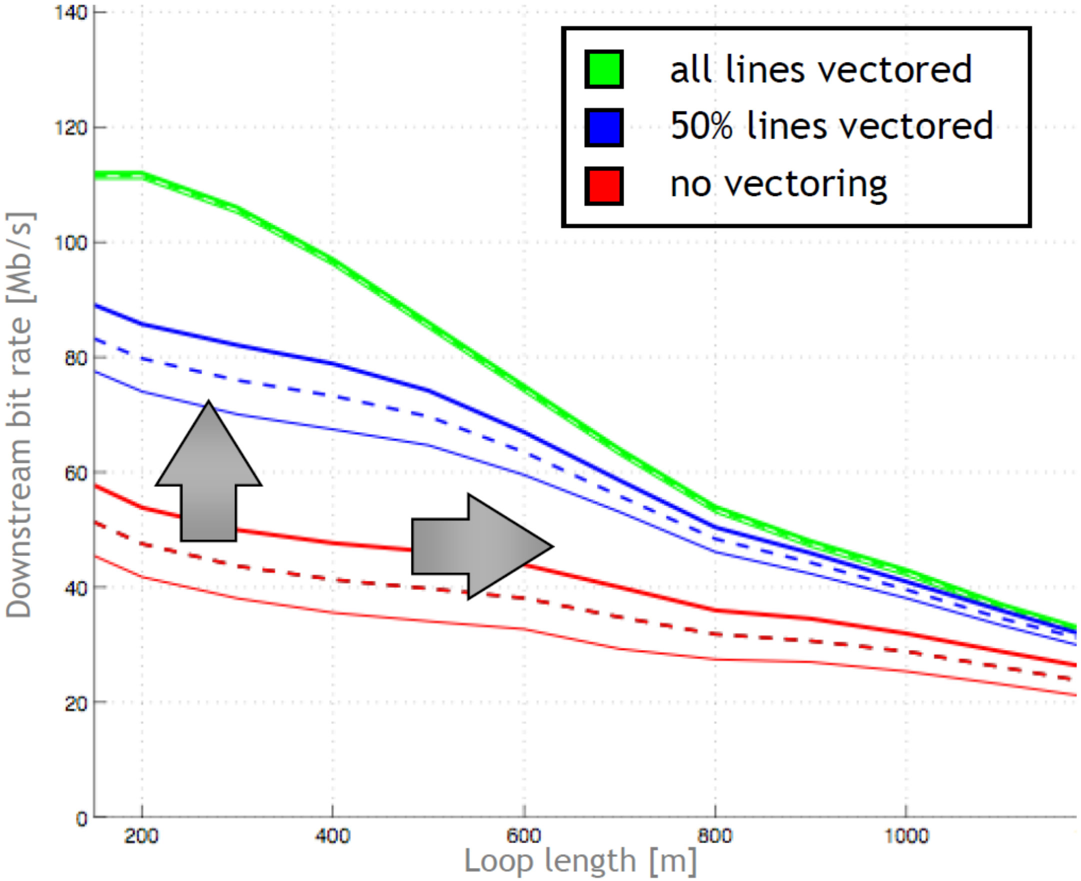
VDSL Vectoring



Crosstalk = dominant disturber for VDSL2

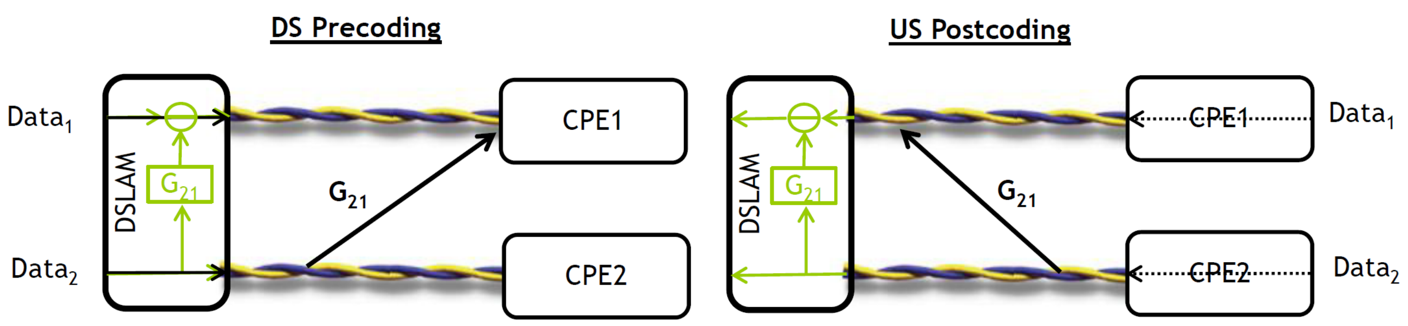
VDSL Vectoring = Noise Cancellation

- measure crosstalk from each line into all other lines in binder
- cancel the noise with an anti-phase signal

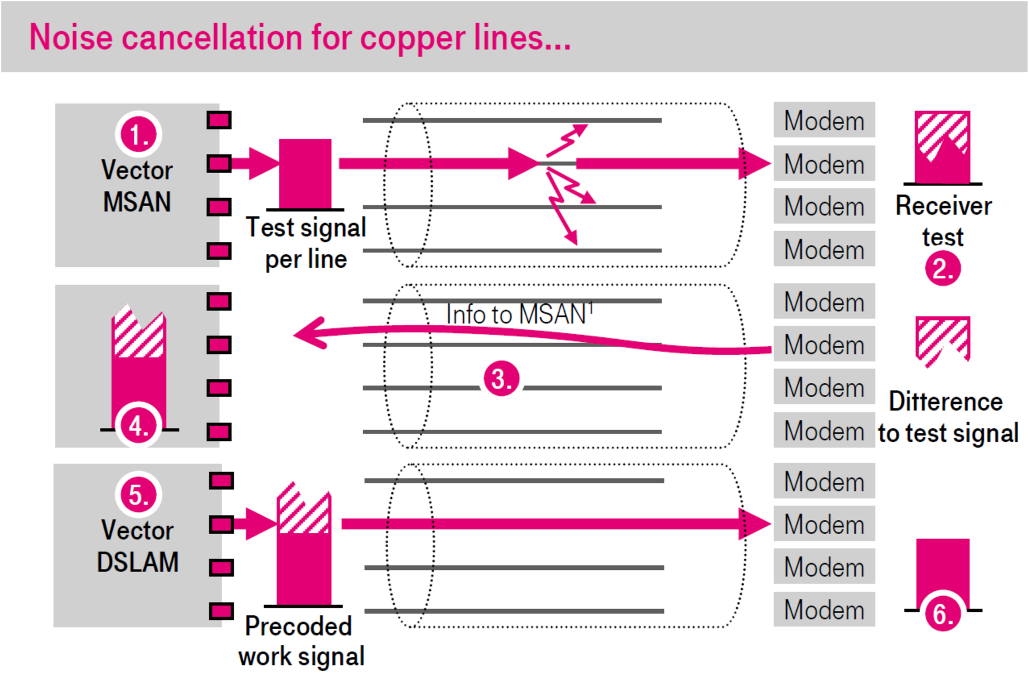


VDSL Vectoring

- *Crosstalk cancelling by injecting an "anti-signal" on each crosstalk-impaired line*
  - Requires full synchronization over the full vectored system
  - All data samples are shared between all the lines
  - Requires calculation of the "anti-signals"
  - Requires a crosstalk estimating mechanism to derive the crosstalk coefficients
  - Mechanism specified in ITU-T G.993.5 (G.vector) standard for DSLAM/CPE interoperability



Vectoring principle



Some References

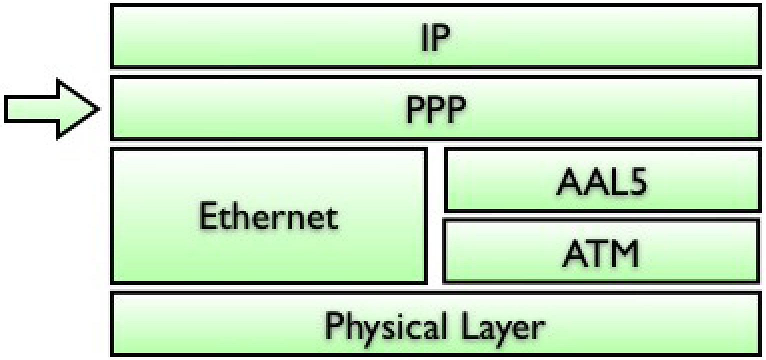
- http://www.cisco.com/univercd/cc/td/doc/cisintwk/ito_doc/adsl.htm
- http://www.adsl.com
- Book: Balaji Kumar, Padmanand Warrier "XDSL Architecture", Publisher: ***McGraw-Hill*** Companies (October 25, 1999)
- BooK: Maurice Gagnaire "Broadband Local Loops for High-Speed Internet Access" (Artech House Telecommunications Library) (2003)
- An Overview of G.993.5 Vectoring https://www.broadband-forum.org/download/MR-257_Issue-2.pdf

Appendix: Point to Point Protocol: summary

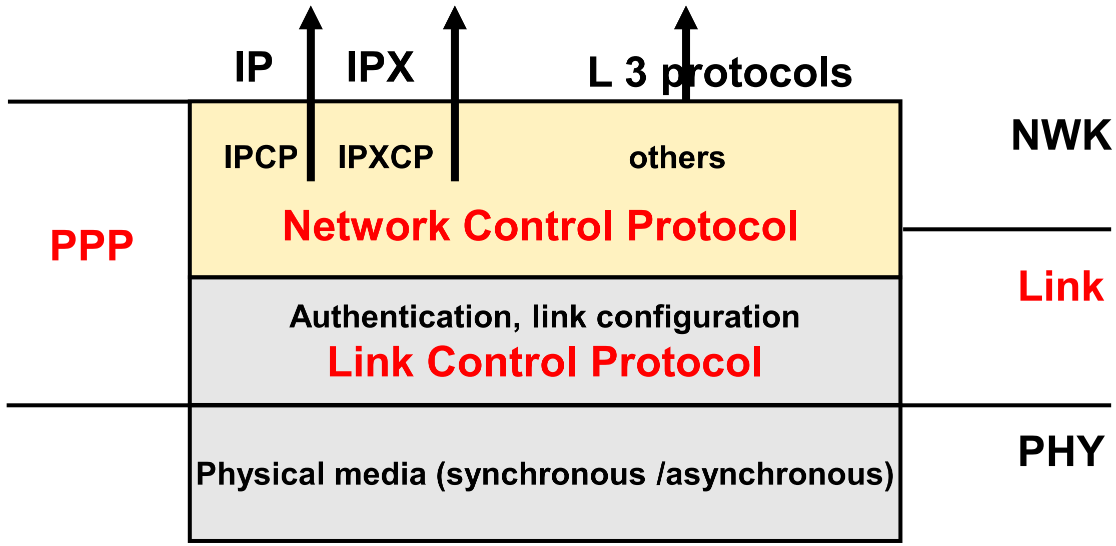
- PPP -designed for simple links to transport packets between two peers
- PPP encapsulation provides for multiplexing of different network-layer protocols simultaneously over the same link
- PPP provides a Link Control Protocol (LCP) which negotiates the establishment and termination of a PPP link.
- LCP also negotiates the options for encapsulation format, authentication and link quality monitoring

PPP

- It is used together with ADSL for its ability to directly connect the user to the Central Office of its ISP and its important functions like: authentication, authorization, automatic configuration of network interfaces and DHCP support.
- In the majority of European countries ADSL is based on the ATM protocol so PPP is encapsulated inside ATM cells (PPPoA).
- Nonetheless ADSL can stand on top of Ethernet and be incapsulated in Ethernet Frames (PPPoE).



PPP: protocol architecture

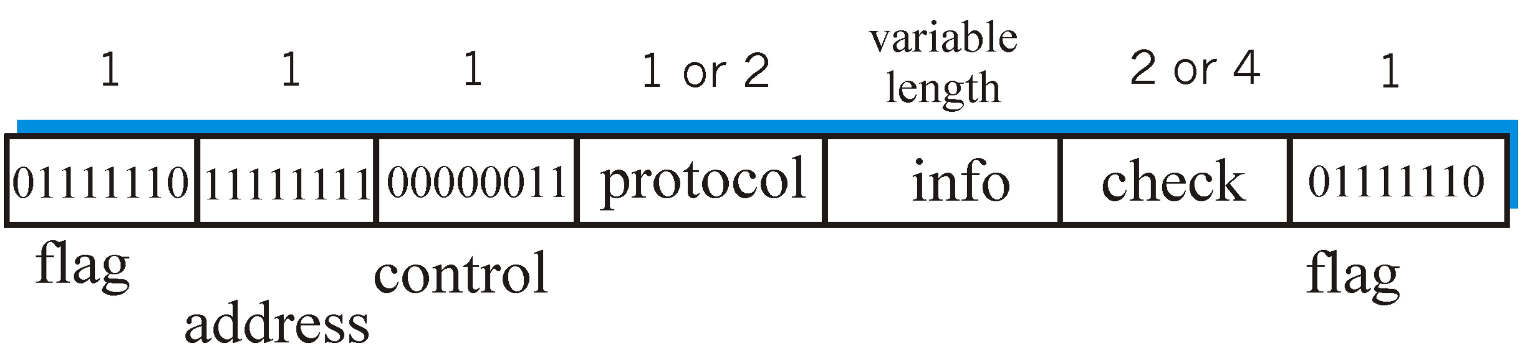


- **LCP**
- Establishment, control and termination of the link
  - Parameters negotiation (kind of authentication, compression, …)
  - Authentication
  - Control and termination of the link

- **NCP**
- Family of protocols used to configure the network layers
  - Configuration of specific parameters of the network layers
  - A different module for each different network protocol

PPP Encapsulation

- The Protocol field identifies the datagram encapsulated in the information fiel.
- Information filed contains the datagram and could be zero or more octets up to a Maximum Receive Unit (MRU)
- The default MRU value is 1500 octets ,though it could vary by negotiation
- The Information field may be padded up to the MRU number of octets



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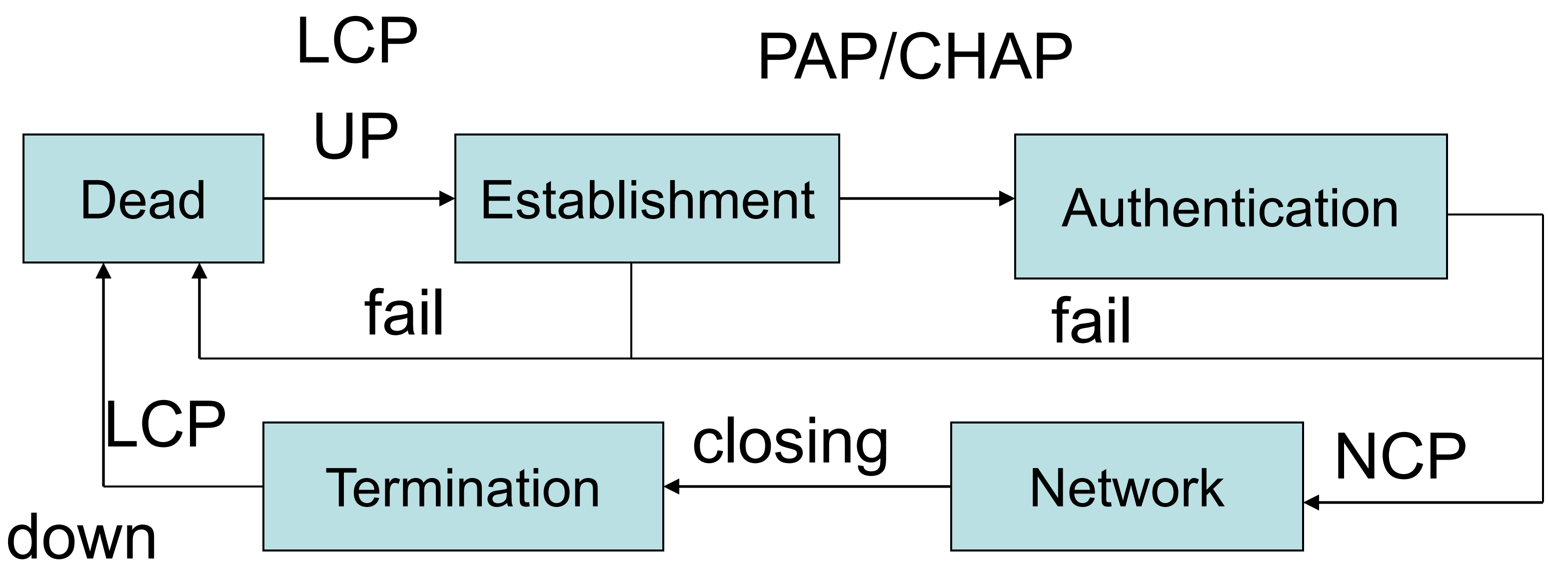
PPP Link Operation.



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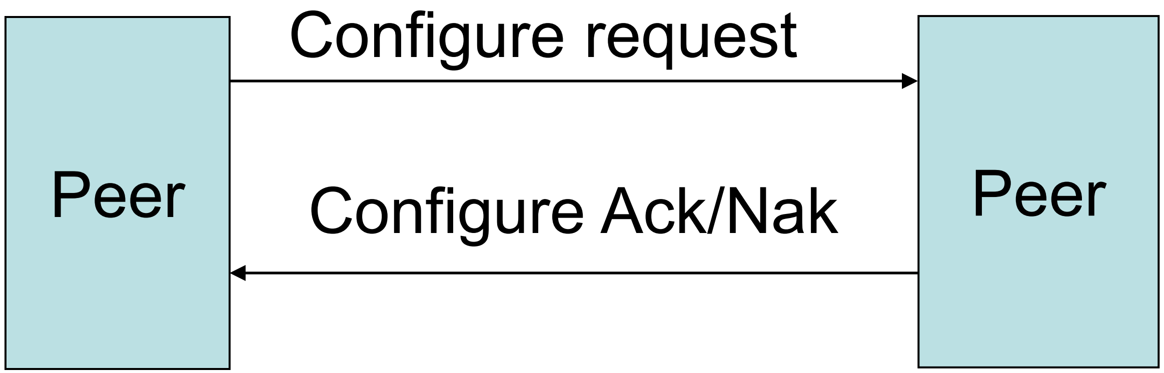
Link Establishment

- Link establishment phase uses the Link control protocol.
  - Link Configuration Options
    - » The Maximum Receive Unit size.
    - » Authentication and protocol to be used for authentication
    - » Protocol Field Compression
    - » Link quality monitoring
    - » Magic number option for detecting looped back links.
    - » Address and Control field compression

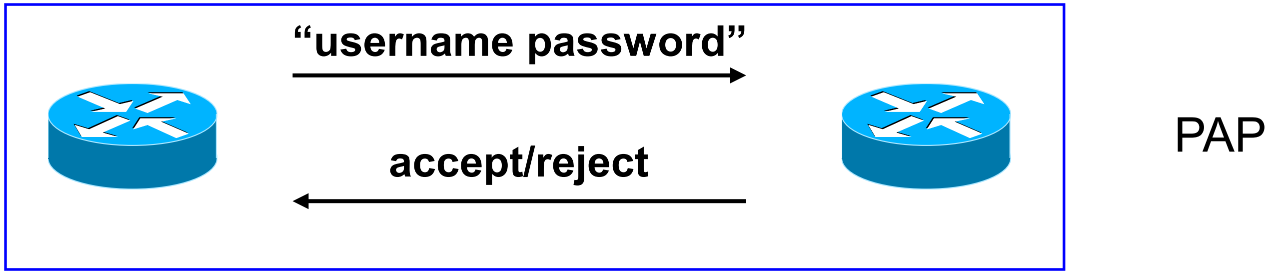
Link Establishment Process

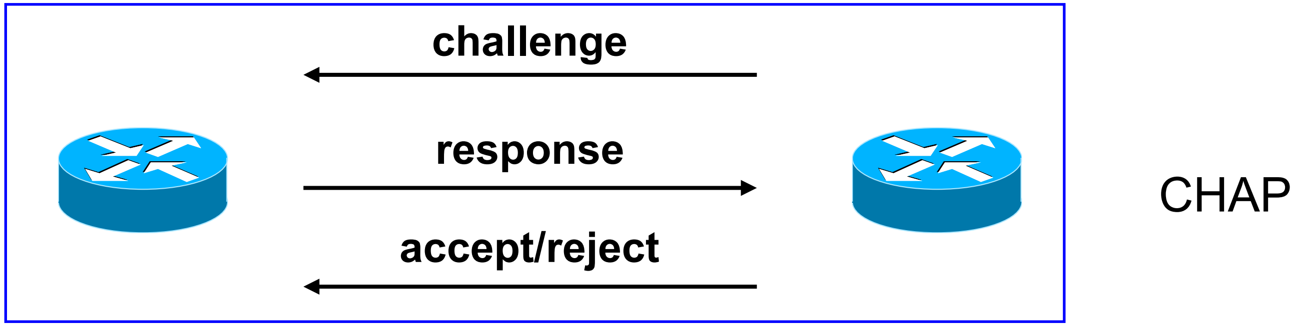


- The configure-request message is sent to request a link establishment and it contains the various options requested.
- This request is responded with a Configure-Ack if the negotiation is accepted.
- A Configure-Nak is sent if the negotiation is not acceptable and it suggests an acceptable negotiation.

Authentication

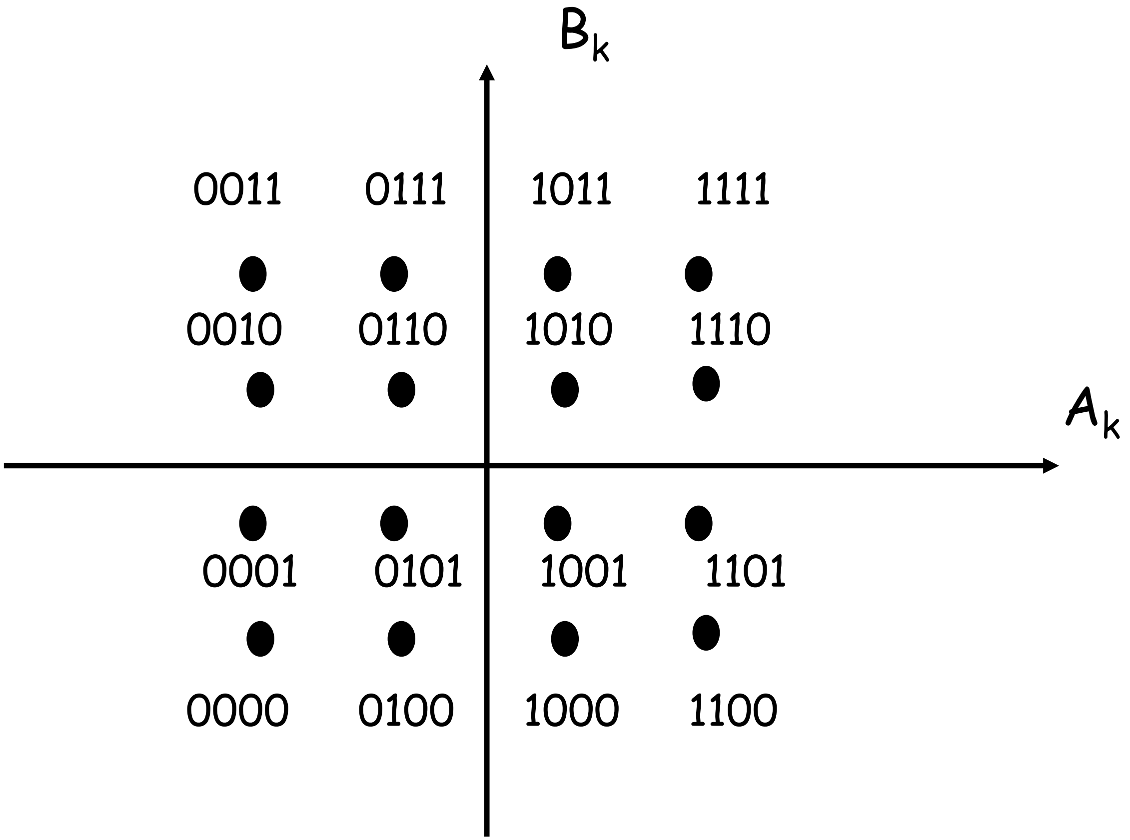
- Authentication Option uses Password Authentication Protocol (PAP) or Challenge Handshake Authentication Protocol (CHAP).
- The protocol used depends on negotiation.
- CHAP uses a one-way hashing algorithm which is known only to the user, to respond to a challenge sent by the authenticator.
- CHAP is more secure than PAP.





QAM constellation

- *16 QAM*



16 constellation symbols in T sec
(4 bit/symbol)

QAM