Computer networks
The physical layer

2025/2026, 1st semester

Dr. Szilveszter Kovacs

E-mail: szilveszter.kovacs@uni-miskolc.hu

www.iit.uni-miskolc.hu/~szkovacs

Institute of Information Technology 107/a.

Phone: +36 46 565-111 / 21-07

Általános INFORMATIKAI Tanszék

The physical media

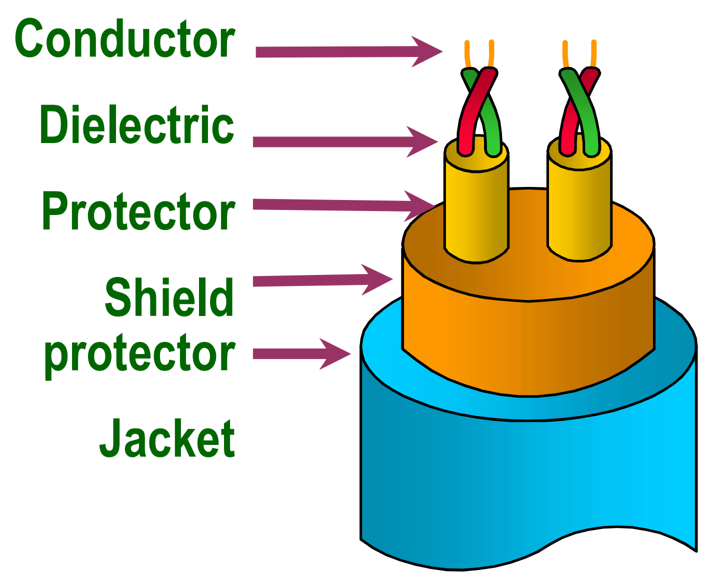
- The transmission media.
- Their goal: to transport the raw bitstream
- Their characteristics:
  - the available data transfer speed
    (based on signal/noise ratio from Shannon's theorem),
    - in practice we treat it separately
      - baseband pulse transmission
      - broadband (modulation) transmission.
  - The maximum distance that can be covered without signal refresh is
  - the interference immunity,
  - reliability (mechanical properties),
  - suitability for broadcast, point-to-point transmission, or both,
  - price, costs.

The transmission medium

- Metallic conductors (electric current) (Copper)
  - Twisted pair
  - Coaxial cable
- Light guides (light waves)
  - Glass, plastic (fiber optic)
- Wireless transmission (electromagnetic waves)
  - microwave,
  - satellite,
  - optical infrared, laser, etc.

Twisted pair

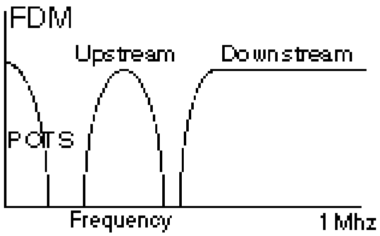
- Primarily for point-to-point connection.
- Telephone wire
  - To a nearby center (2-4 Km), modulated transmission,
  - a few Mbps (e.g. E1: 2.048 Mbps (32*64)),
  - medium immunity and reliability,
  - cheap solution.
  - Twisting: untwisted conductors are “loop antennas”; twisted is more balanced.



Twisted pair

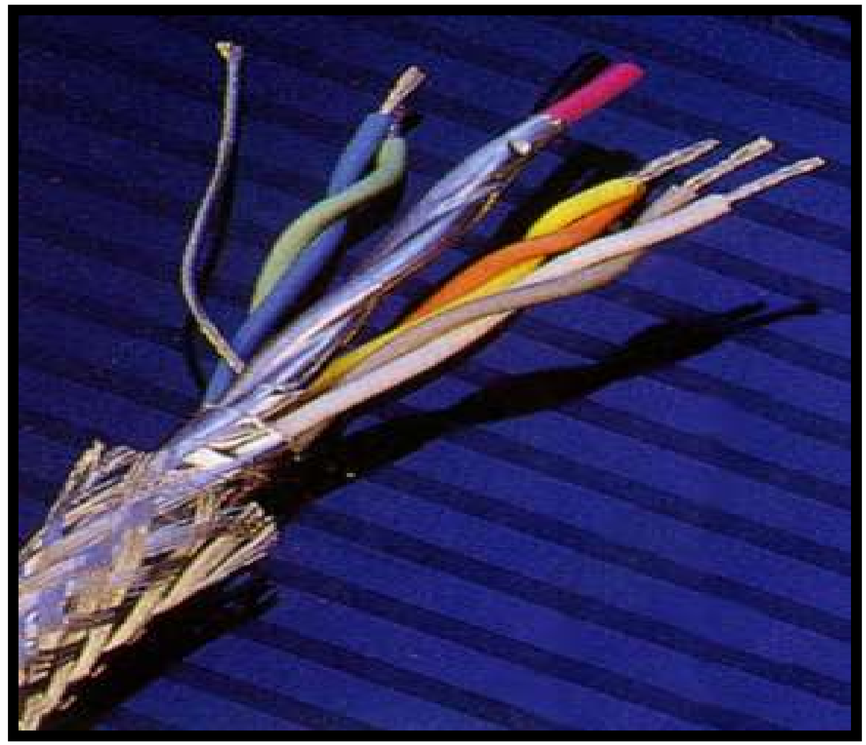
- **xDSL (Digital Subscriber Line)**
- **High Data-Rate Digital Subscriber Line (HDSL)**
  - **On two pairs of wires T1/E1 approx. 3.6 km away .**
- **Single-Line Digital Subscriber Line (SDSL)**
  - **On a single pair T1/E1 approx. 3 km away .**
- **Very high bit-rate Digital Subscriber Line (VDSL)**
  - **VDSL2 300Mbps 300-400m**
- **Asymmetric Digital Subscriber Line (ADSL)**
  - **Asymmetric (** downstream and one duplex channel **):**
    1.5 - 2.0 Mbps downstream and one 16 kbps duplex channel, or
    6.1 Mbps downstream and 64 kbps duplex, nowadays
    8 Mbps downstream and 640 kbps duplex.
    ADSL2+ 24 Mbps downstream

Sebesség	Vezeték vastagság	Távolság
1.5 or 2 Mbps	0.5 mm	5.5 km
1.5 or 2 Mbps	0.4 mm	4.6 km
6.1 Mbps	0.5 mm	3.7 km
6.1 Mbps	0.4 mm	2.7 km



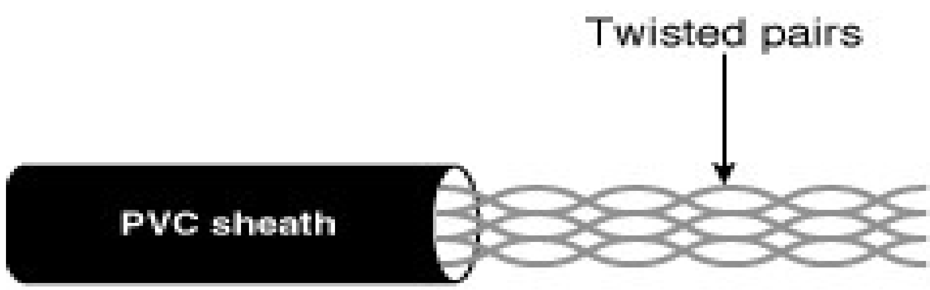
STP

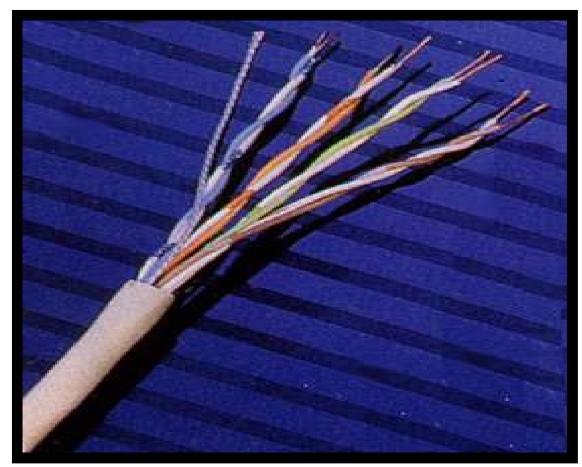
- **STP (Shielded TP) shielded twisted pair**
  - **Shielding (reduces interference, crosstalk)**
    - **good interference immunity,**
    - **good reliability**
  - **4 wires (transmit/receive)**
  - **Slightly more expensive**
  - **Thicker bundles**
  - **1Gbps max. 25m (1000BaseCX)**



UTP

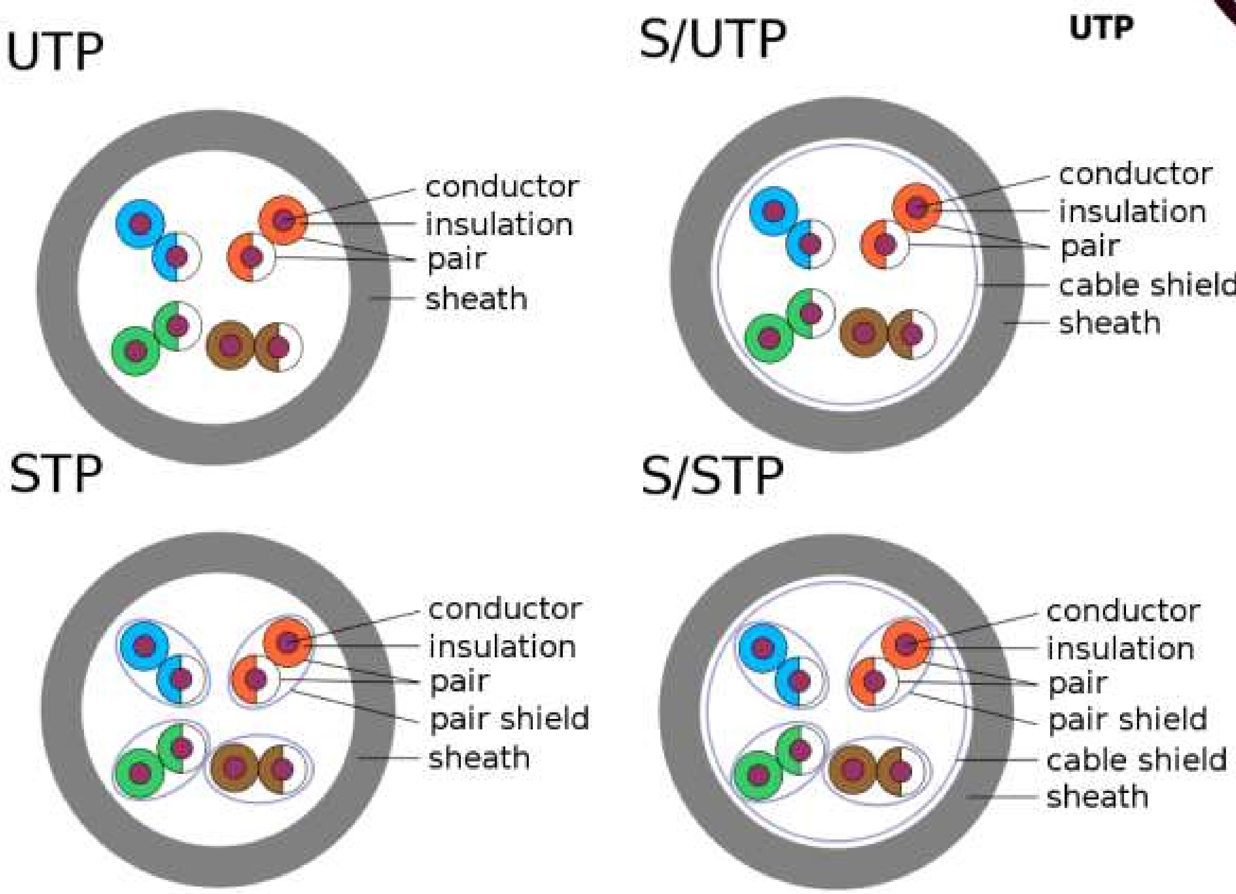
- UTP (Unshielded Twisted Pair)
  - Medium immunity and reliability
  - Slightly cheaper, easy to install
  - For typical 10/100(/1000)BaseT Ethernet cabling
    - 4 wires, transmit and receive branches,
    - max 100 m, baseband pulse transmission





STP-UTP

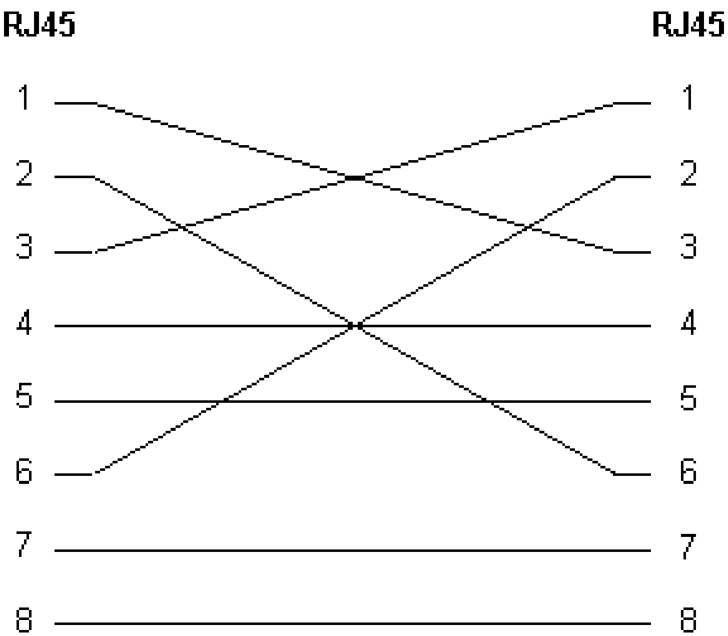
UTP
STP



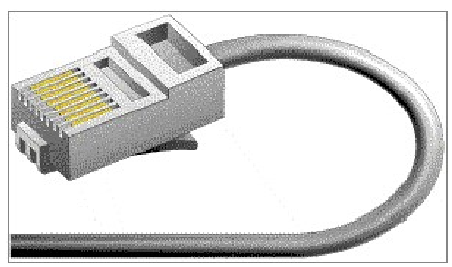
UTP
conductor
insulation
pair
sheath
S/UTP
conductor
insulation
pair
cable shield
sheath
STP
conductor
insulation
pair
pair shield
sheath
S/STP
conductor
insulation
pair
pair shield
cable shield
sheath

UTP

- **RJ45 pinouts for 100 BaseT**



10BaseT Crossover

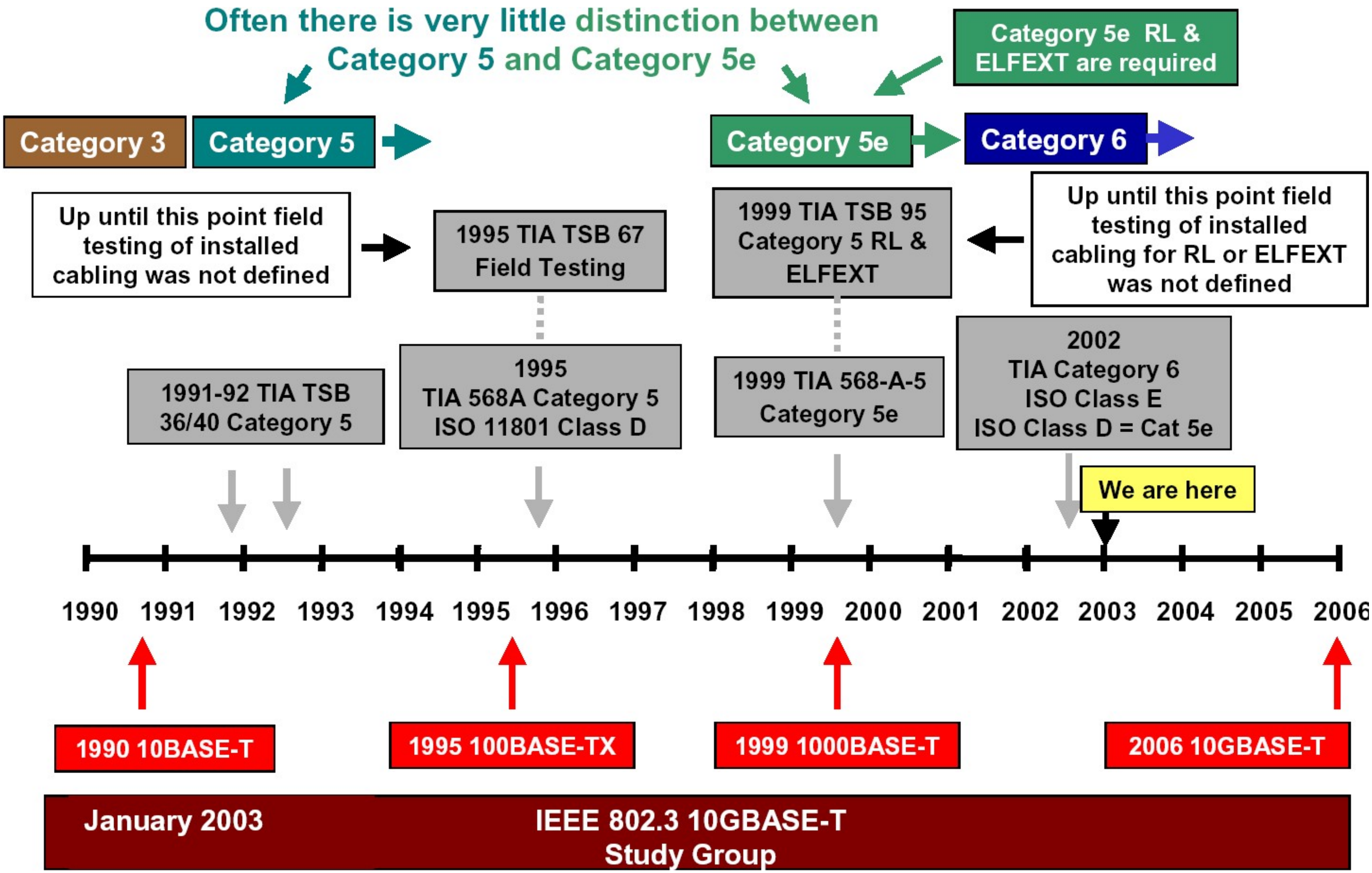


RJ45 Pin	Function	Colour
1	Transmit	White/Orange
2	Transmit	Orange/White
3	Receive	White/Green
4		Blue/White
5		White/Blue
6	Receive	Green/White
7		White/Brown
8		Brown/White

UTP categories

- **Category 1: voice transmission, 2 Mbps**
- **Category 2: data transmission, 4Mbps**
- **Category 3: data transmission, 10BaseT (10Mbps), 4Mbps IBM Token Ring, 16 MHz , (100BaseT4) TIA/EIA 568-A standard**
- **Category 4: data transmission, 10BaseT , 16Mbps IBM Token Ring, 20 MHz , (100BaseT4)**
- **Category 5: the most common today.**
  100BaseTX, (1000BaseT)
  (3-4 twists/inch)
  ANSI/TIA/EIA-568-B.1 and 568-B.2 standards

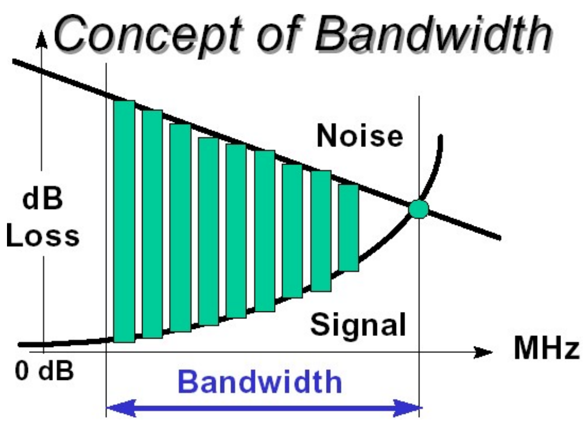
UTP categories



UTP categories

- **Category 1-5: attenuations, crosstalk**

	Attenuation (dB per 100 m)			Near-end Crosstalk (dB)		
Frequency (MHz)	**Category 3 UTP**	**Category 5 UTP**	**150 Ω STP**	**Category 3 UTP**	**Category 5 UTP**	**150 Ω STP**
1	2.6	2.0	1.1	41	62	58
4	5.6	4.1	2.2	32	53	58
16	13.1	8.2	4.4	23	44	50.4
25	—	10.4	6.2	—	42	47.5
100	—	22.0	12.3	—	32	38.5
300	—	—	21.4	—	—	31.3



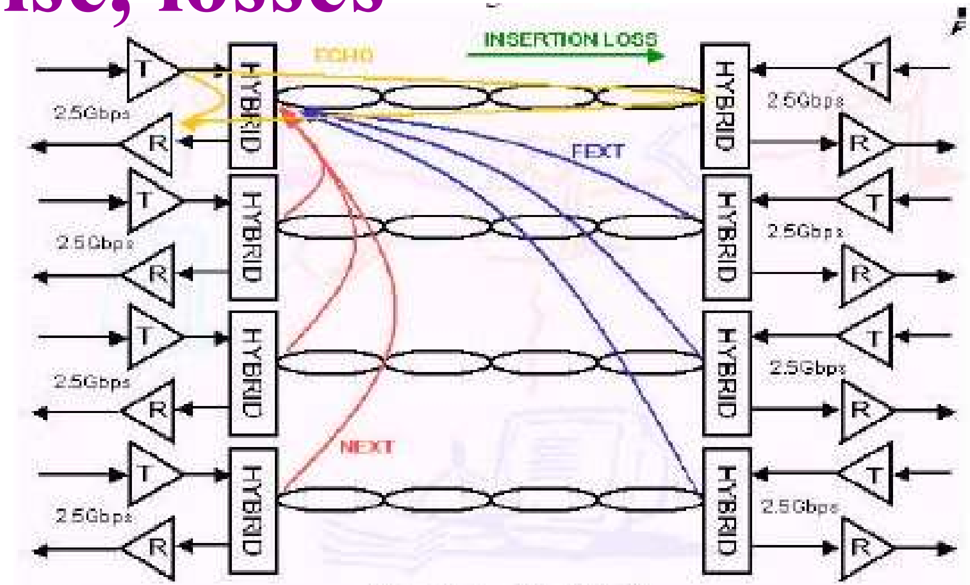
Shannon: MaxSpeed = $H \cdot \log_2 (1+S/N)$
Cat5 : max. 600Mbps in the worst case approx.
Cat5 - 1000BaseT?
→ 4-pair dual duplex and
5-level Pulse Amplitude Modulation

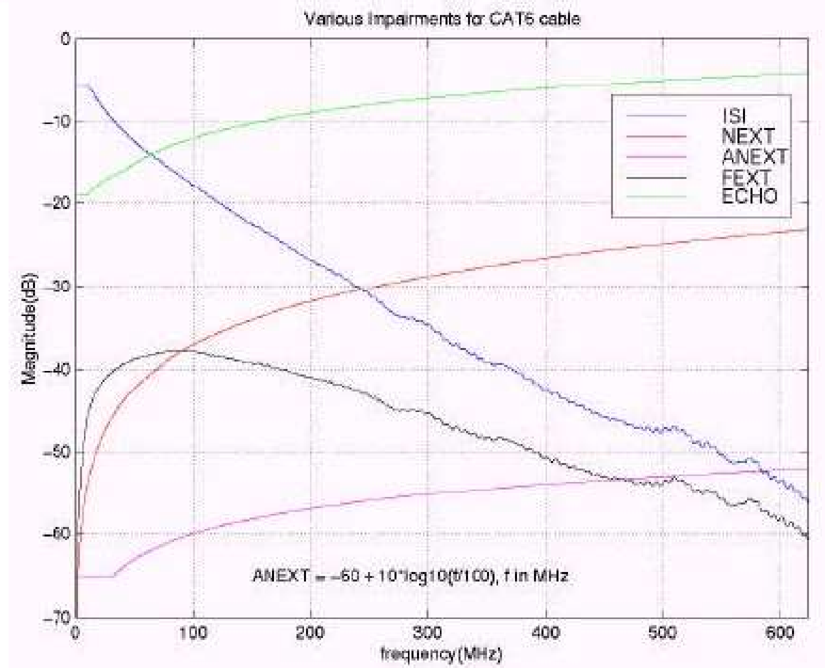
UTP noise, losses

- **Insertions loss (attenuation)**
- **Return loss (echo)**

Crosstalk :

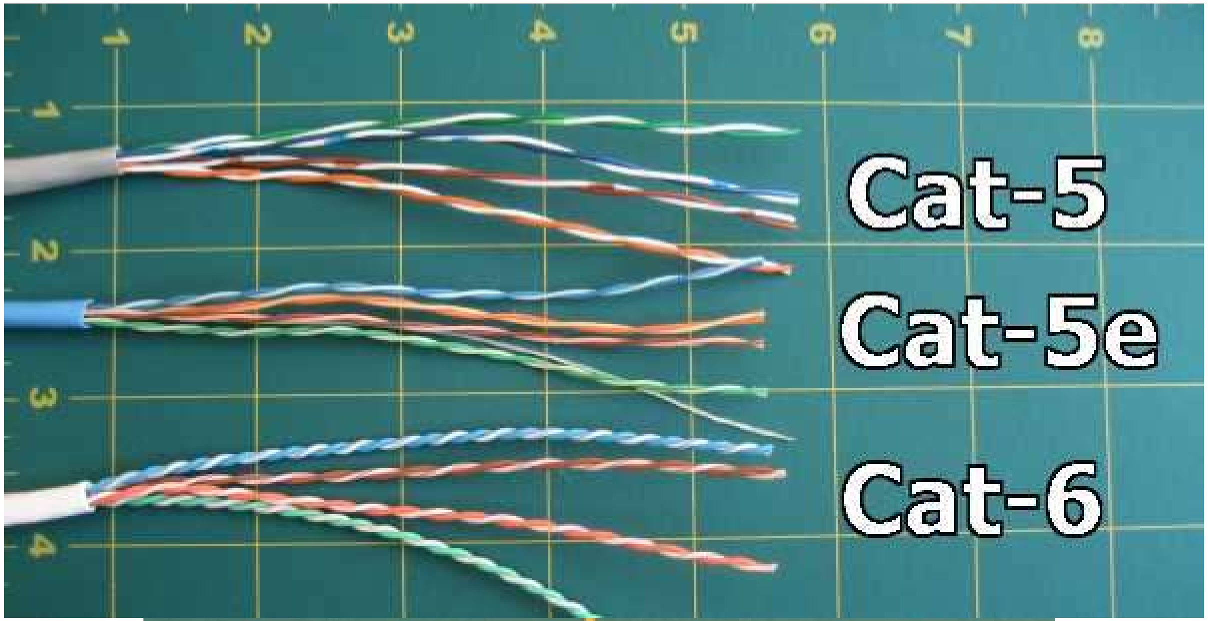
- **Caused by the interactions of different wire-pairs inside the same cable :**
  - **Near-end crosstalk (NEXT)**
  - **Far -end crosstalk (FEXT)**
- **C aused by other unrelated cables :**
  - **Alien cross talk (ANEXT)**

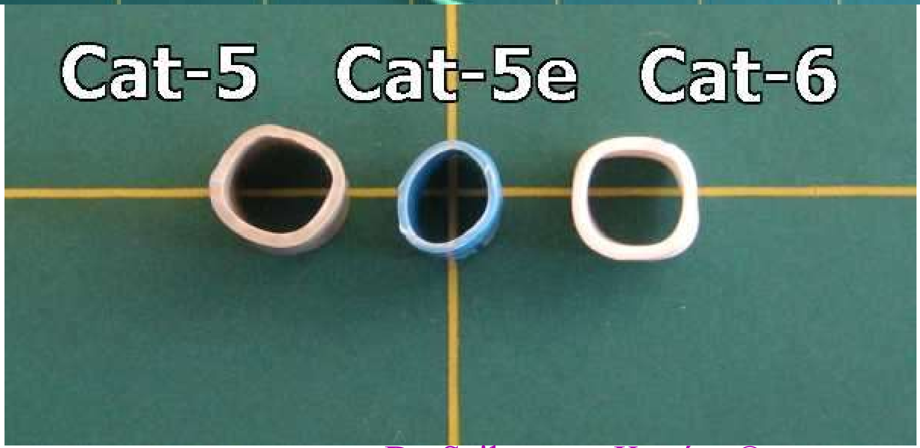




UTP categories

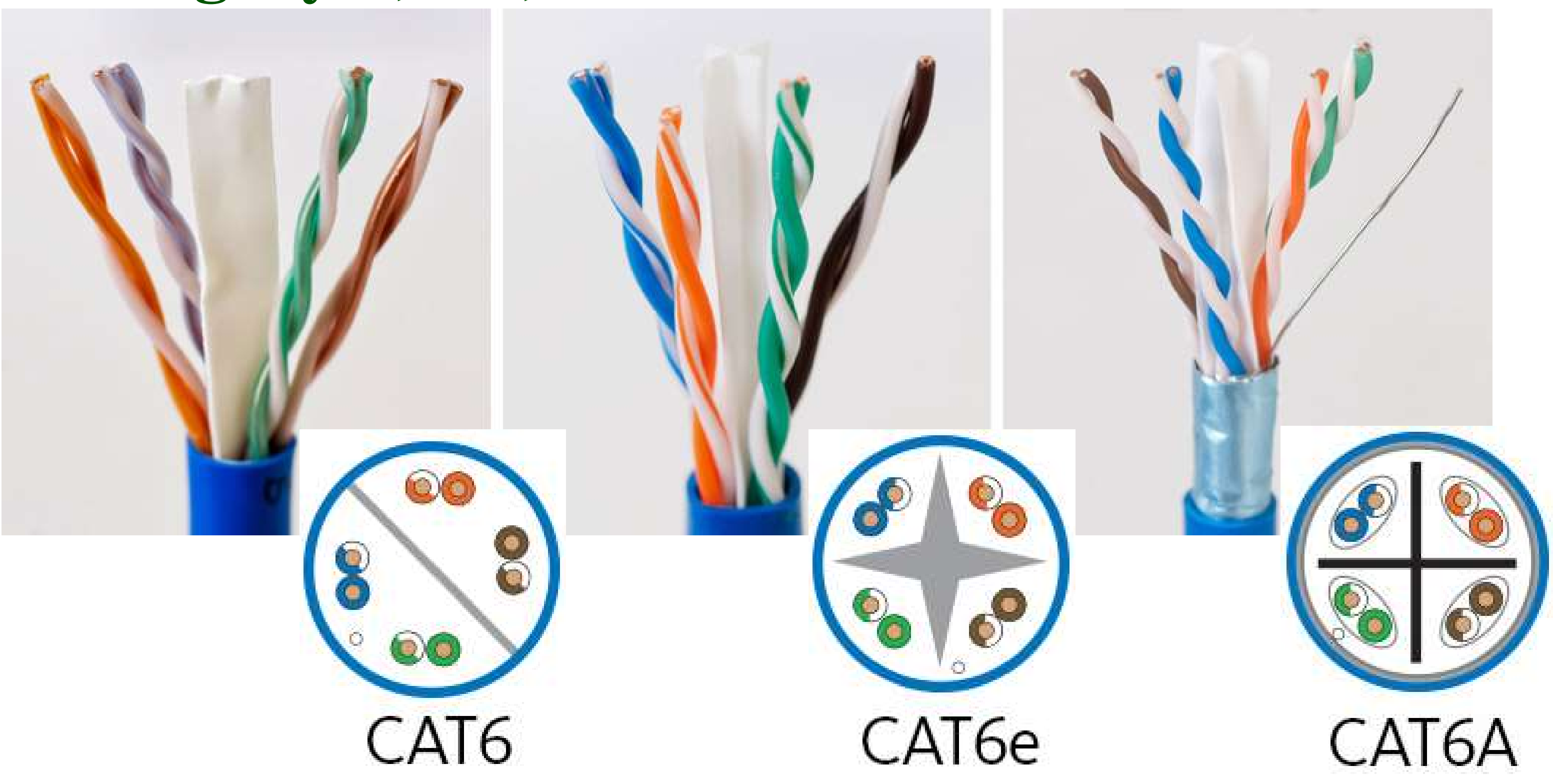
- **Categories 5, 5e, 6,**





UTP categories

- **Category 6, 6e , 6A**



10GBASE-T 802.3an-2006 (64B65B PAM-16 128-DSQ)

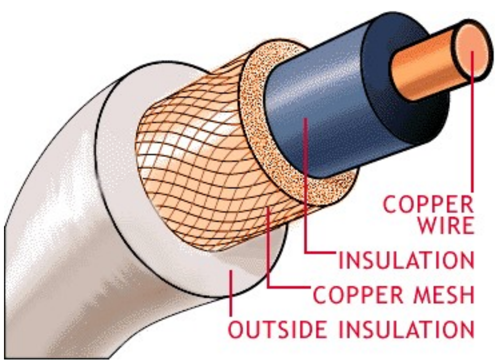
100m Cat 6A, 55m Cat 5e , Cat 6

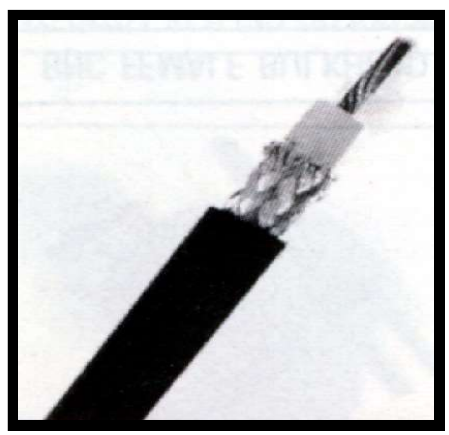
2.5GBASE-T , 5GBASE-T IEEE 802.3bz-2016 , NBASE-T, MGBASE-T

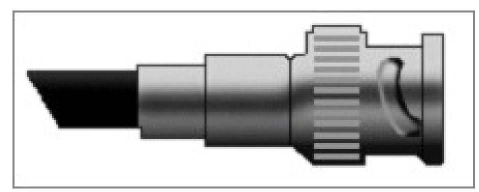
100m Cat 5e, Cat 6

Coaxial cable

- Suitable for both point-to-point and broadcast
- Typical LAN application
  Ethernet - broadcast
  - 10Base5 Thick Ethernet ("Vampire" connector)
  - 10Base2 thin Ethernet
- Structure
  - copper core, insulating dielectric, braided outer conductor, plastic sheath







Coaxial cables

- **Typical wave impedances:**
  - **50 : data and radio cable**
  - **75 : TV coaxial cable**
  - **93 : ARCNET cable (Novell)**
- **For baseband transmission: 10 Mbps (Ethernet):**
  - **500 m: thick coax ,**
  - **187 m: thin coax .**
- **Modulated: about 150 Mbps , up to 100Km distance**
  - **Cable television uses modulated**
    - **broadcasting (about 6 MHz channels, the amplifiers are unidirectional) (DVB-C modulation standard 8 MHz)**
    - **Computer connection**
      - **A separate return path is being built. Special modem, transmits and receives on a separate frequency**
      - **Data Over Cable Service Interface Specification (DOCSIS)**
      - **DOCSIS 1.0 (1997) Down: 40 Mbit/s Up: 10 Mbit/s**
      - **DOCSIS 3.1 Full Duplex (2017) Down: 10 Gbit/s Up: 10 Gbit/s**

Coaxial cable

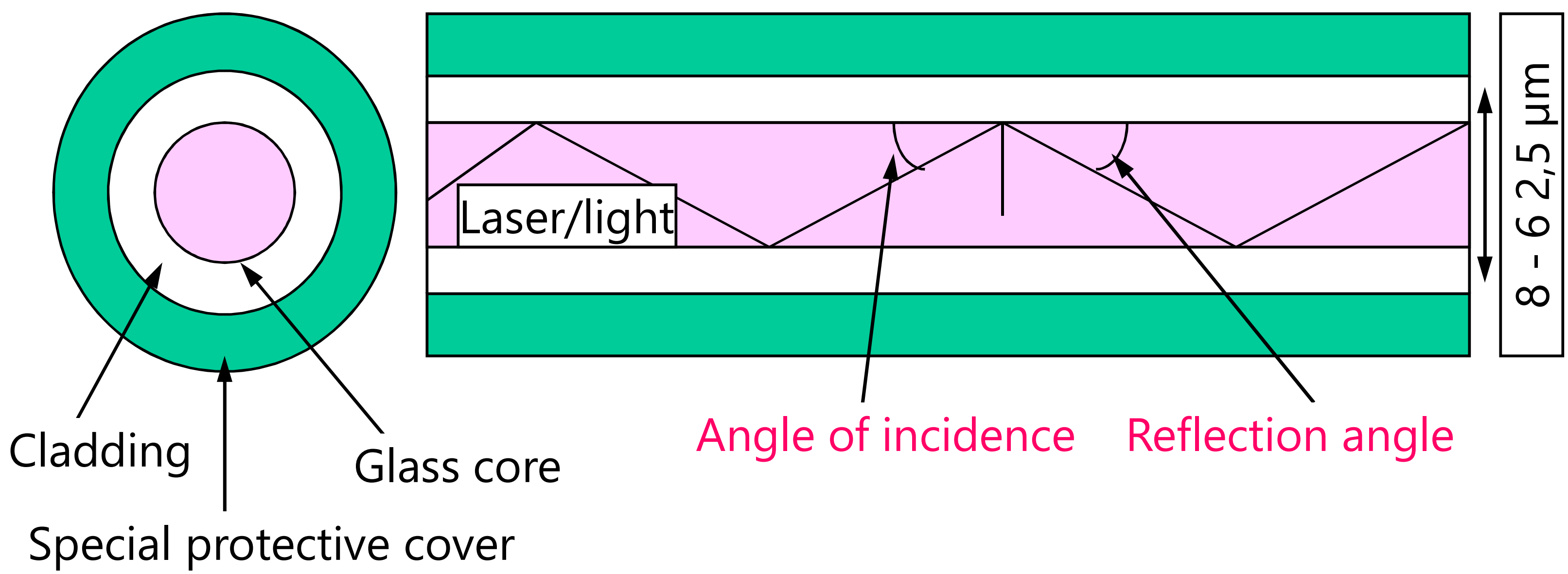
- **Coaxial cable (grounded at 1 point) has good interference protection and good reliability.**
- **Moderately expensive**
  - **(thin Ethernet is cheaper than UTP).**
- **Creating a broadcast channel (bus) on coaxial cable:**
  - **A single power line, terminated at the ends with a wave impedance.**
  - **High impedance connections (transceiver), voltage monitoring, current generator drive.**
  - **T-plug or push-on, “vampire” connection (can be connected/disconnected during operation)**

Optical cable

- Thin glass fiber (silicate), “guides” light waves
- Excellent interference immunity, good reliability.
- Currently approx. max. 400 Gbps 80km distance (DWDM)
- Typically for point-to-point connections.
- High costs (connections, extensions, transmitters/receivers).
  - Connectors: SMA: screw; ST bayonet; MIC: FDDI dual, SC plug

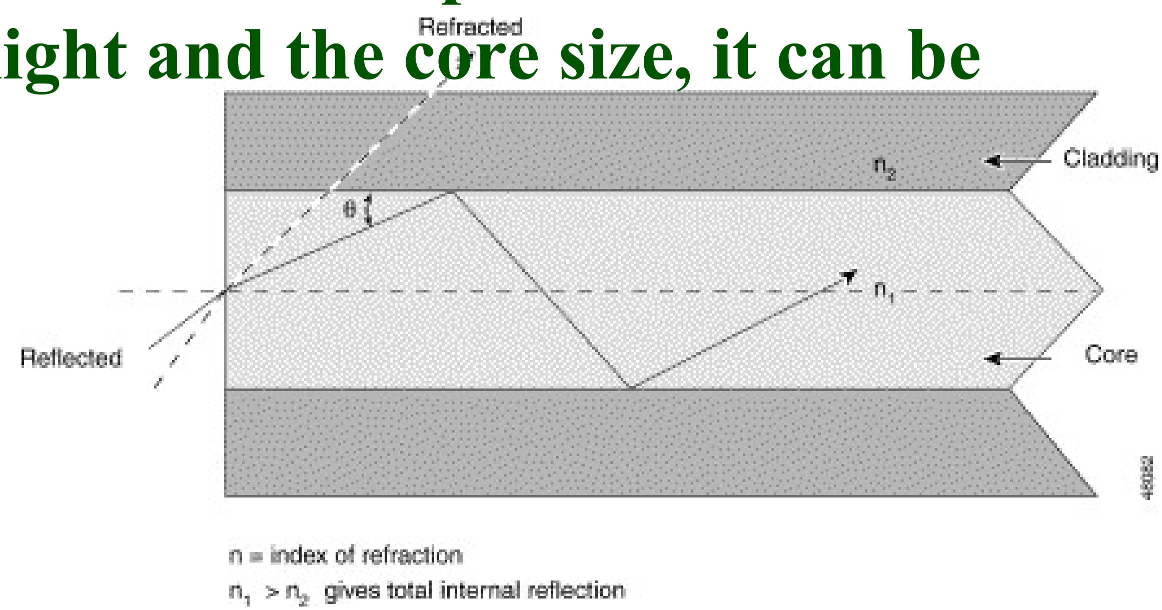
The optical cable

- **Core (higher refractive index), core diameter: 9-50-62.5 μ m**
- **lower refractive index outside (clad) (typical diameter: 125 μm).**



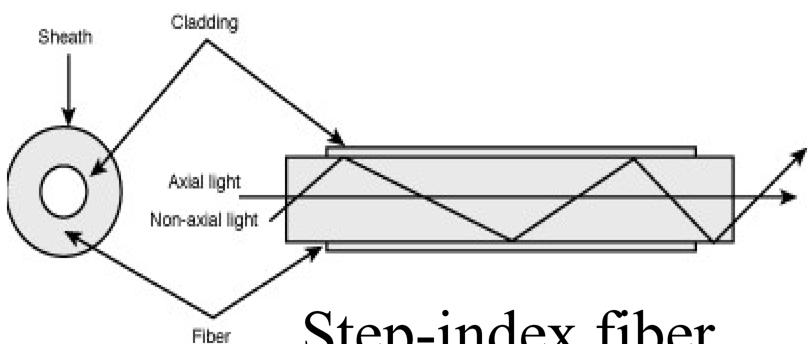
Light cables

- **Light is reflected below the "critical angle", above it: absorbed**
- **Visible light frequency: nearly 10^8 MHz: potentially huge bandwidth!**
- **Depending on the relationship between the wavelength of light and the core size, it can be**
  - **Multimode, or**
  - **Single-mode.**

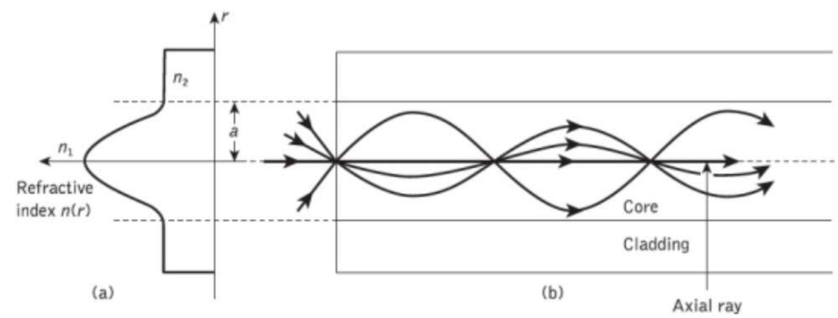


Multimode fiber

- **Core diameter > light wavelength**
  - **Light travels by reflecting at the boundaries,**
  - **Light can travel with different path lengths, it does not arrive at the same time (modal dispersion).**
  - **Typically, the transmitter is an LED (Light Emitting Diode), visible red (wavelength: 850 nm), the receiver is a photodiode/transistor.**
  - **Bridgeable < 10Km, opt. Ethernet 2 Km, FDDI**
  - **Data transfer rate: approximately < 10 Gbps**

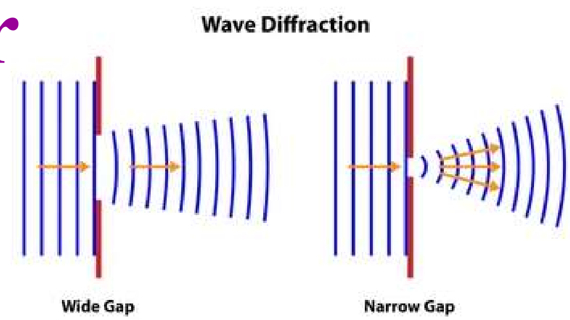


Step-index fiber

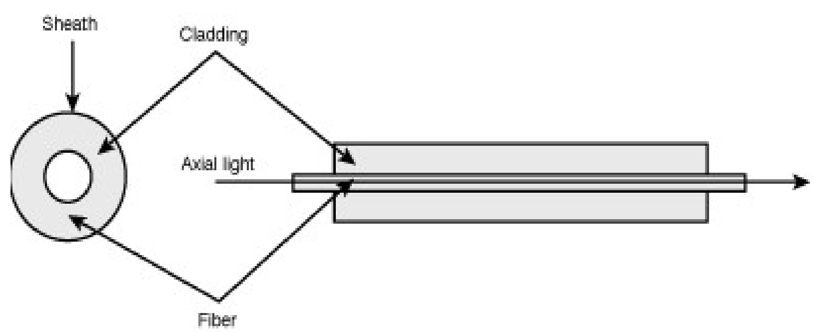


Graded-index fiber

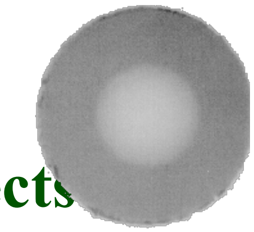
Single-mode fiber

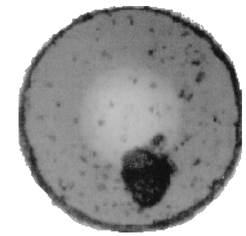


- **Core diameter ≅ light wavelength**
  - **Diffraction: light “bends” with the fiber.**
  - **The transmitter is a semiconductor laser, infrared 1300nm (1310nm, 1550nm) wavelength, core diameter 9 μm**
  - **lower attenuation, greater distance covered, approx. 100 Km.**
  - **Fast, data transfer speed < 10Gbps (depending on the device, it can be higher).**

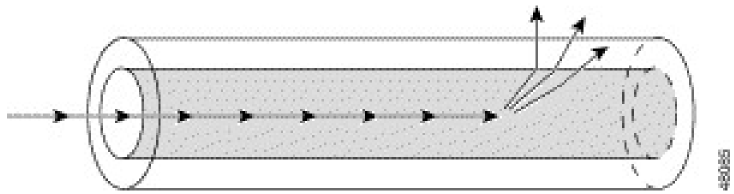


Optical losses

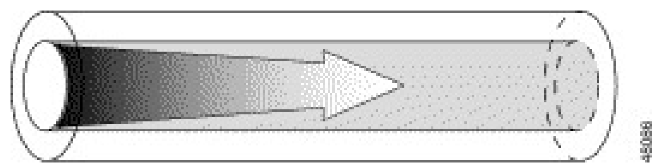




- **Rayleigh scattering: on atomic glass defects**



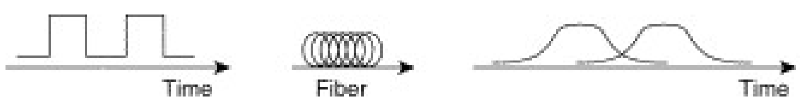
- **Absorption: absorption**

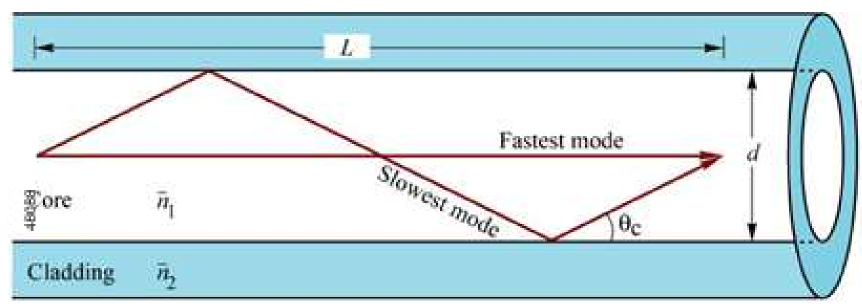


TIA/EIA-568A max. damping	Wavelength	Max Attenuation (dB/Km)
Multi-Mode	850	3.75
Multi-Mode	1300	1.5
Single - Mode	1300	0.5

Extension (cold/warm): 0.3 – 1 dB
Connector : 0.5 – 2 dB

- **Modal Dispersion: dispersion** path length difference



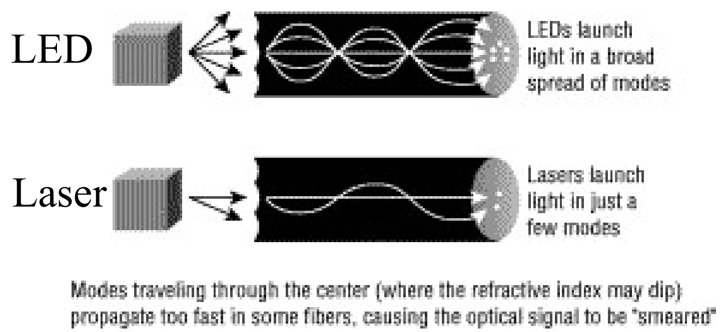


Step-index Fiber

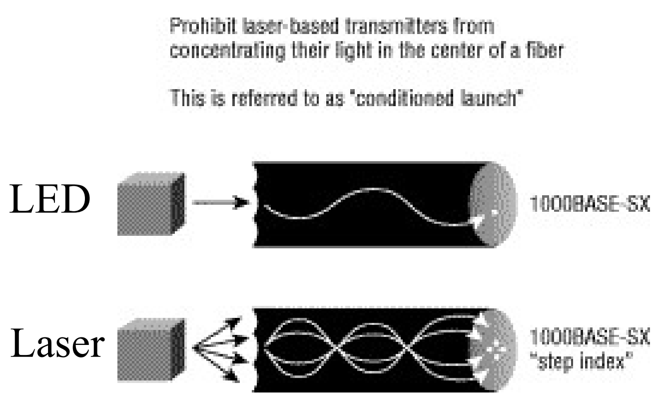
- **Chromatic Dispersion:** components of different frequencies propagate at different speeds

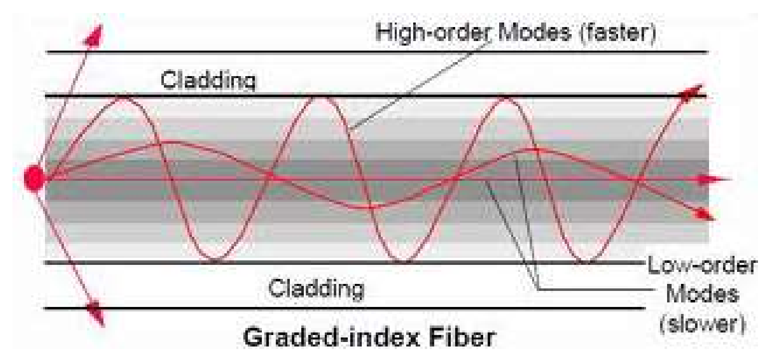
Optical losses

- **Dispersion due to path length difference**

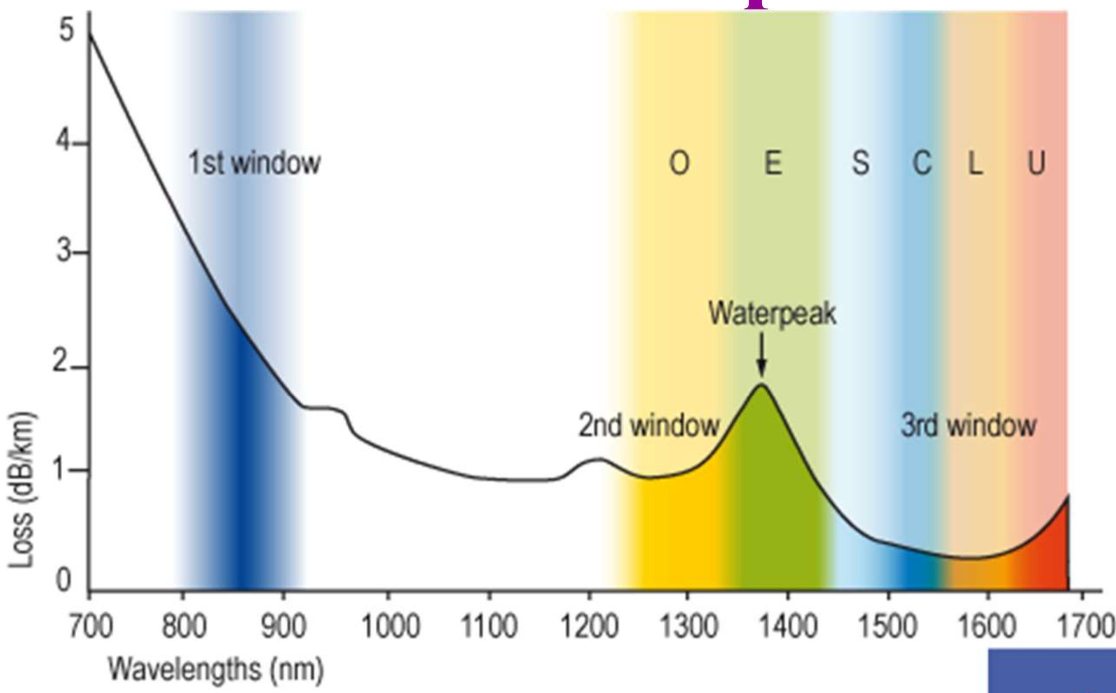


- **"Conditioner" installation, "Graded-index" fiber**



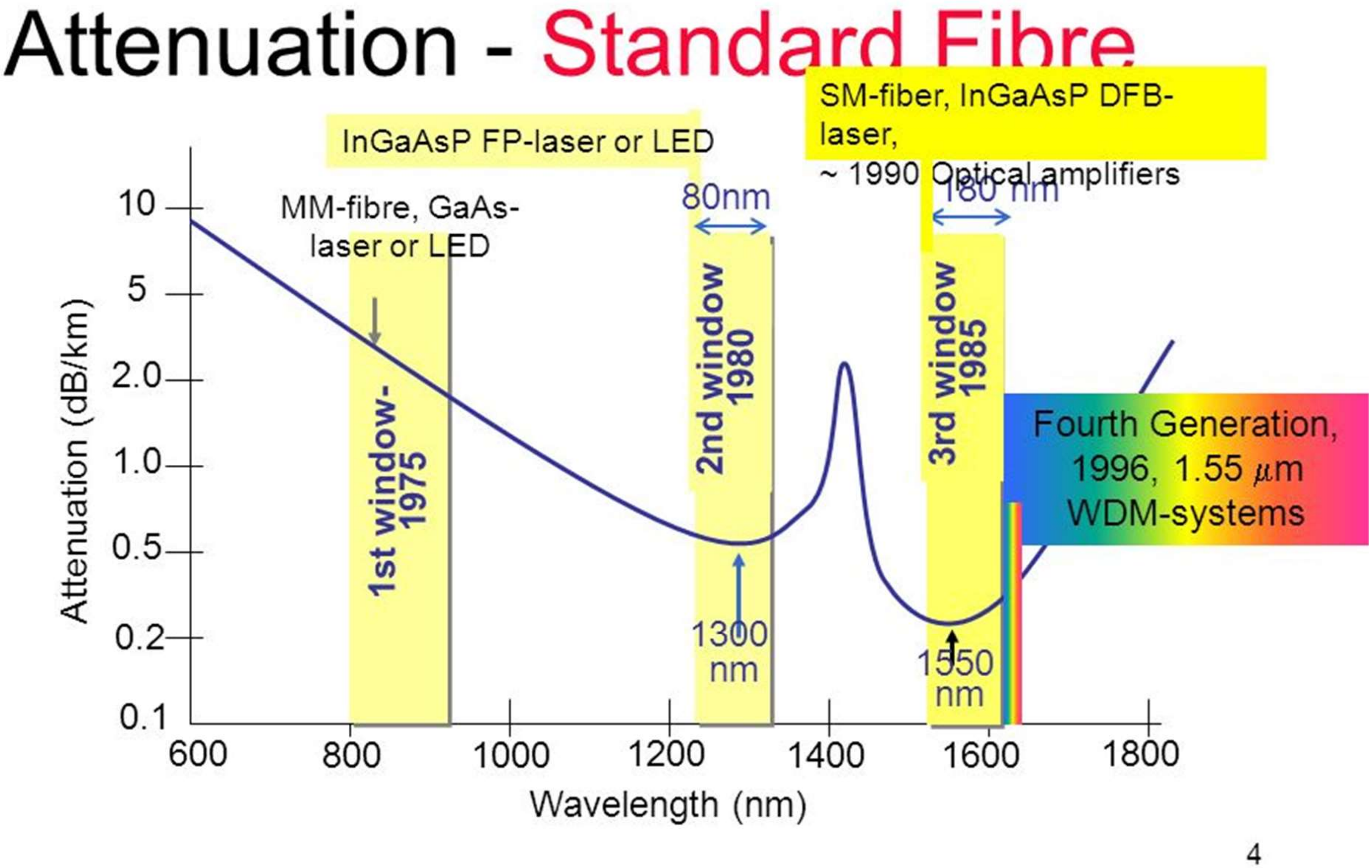


Optical losses

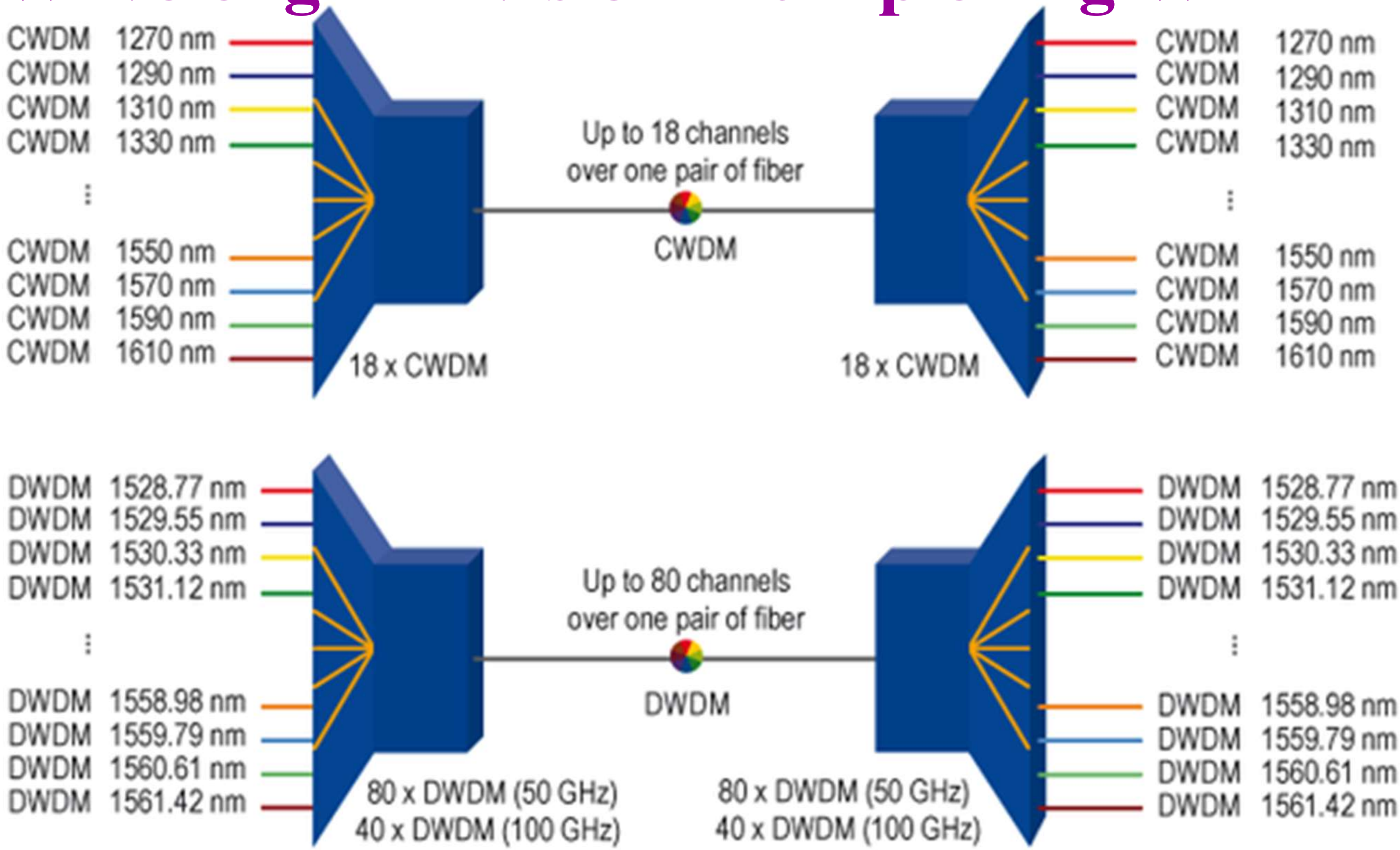


	Optical band	Wavelengths
O	(Original)-Band	1260 nm – 1360 nm
E	(Extended)-Band	1360 nm – 1460 nm
S	(Short)-Band	1460 nm – 1530 nm
C	(Conventional)-Band	1530 nm – 1565 nm
L	(Long)-Band	1565 nm – 1625 nm
U	(Ultralong)-Band	1625 nm – 1675 nm

Optical losses

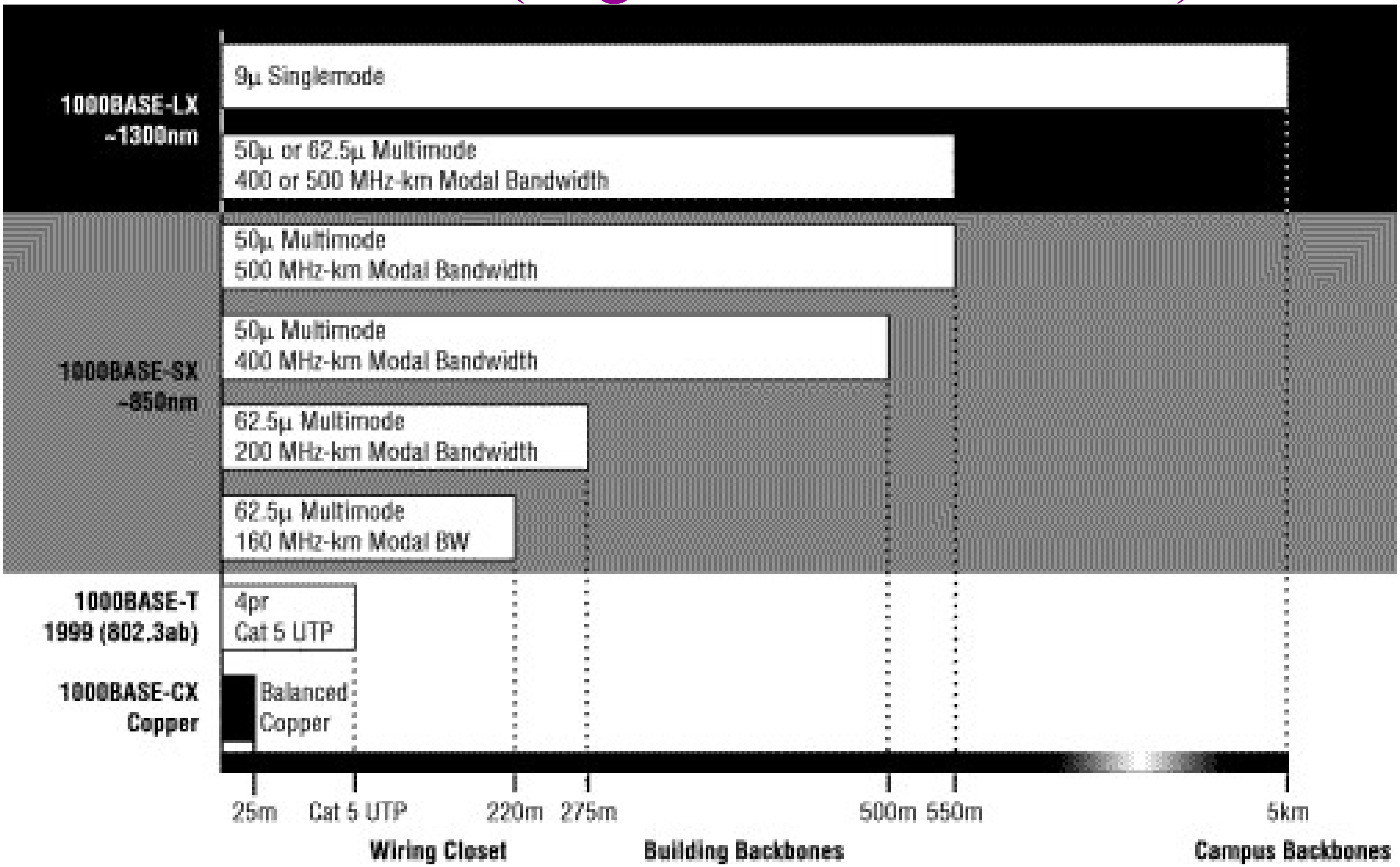


Wavelength Division Multiplexing WDM



- **CWDM: 20nm**
- **DWDM: 0.8nm – 100GHz / 0.4nm – 50GHz**

Distances (Gigabit Ethernet LAN)



10GBASE Ethernet (802.3ae 802.3an)

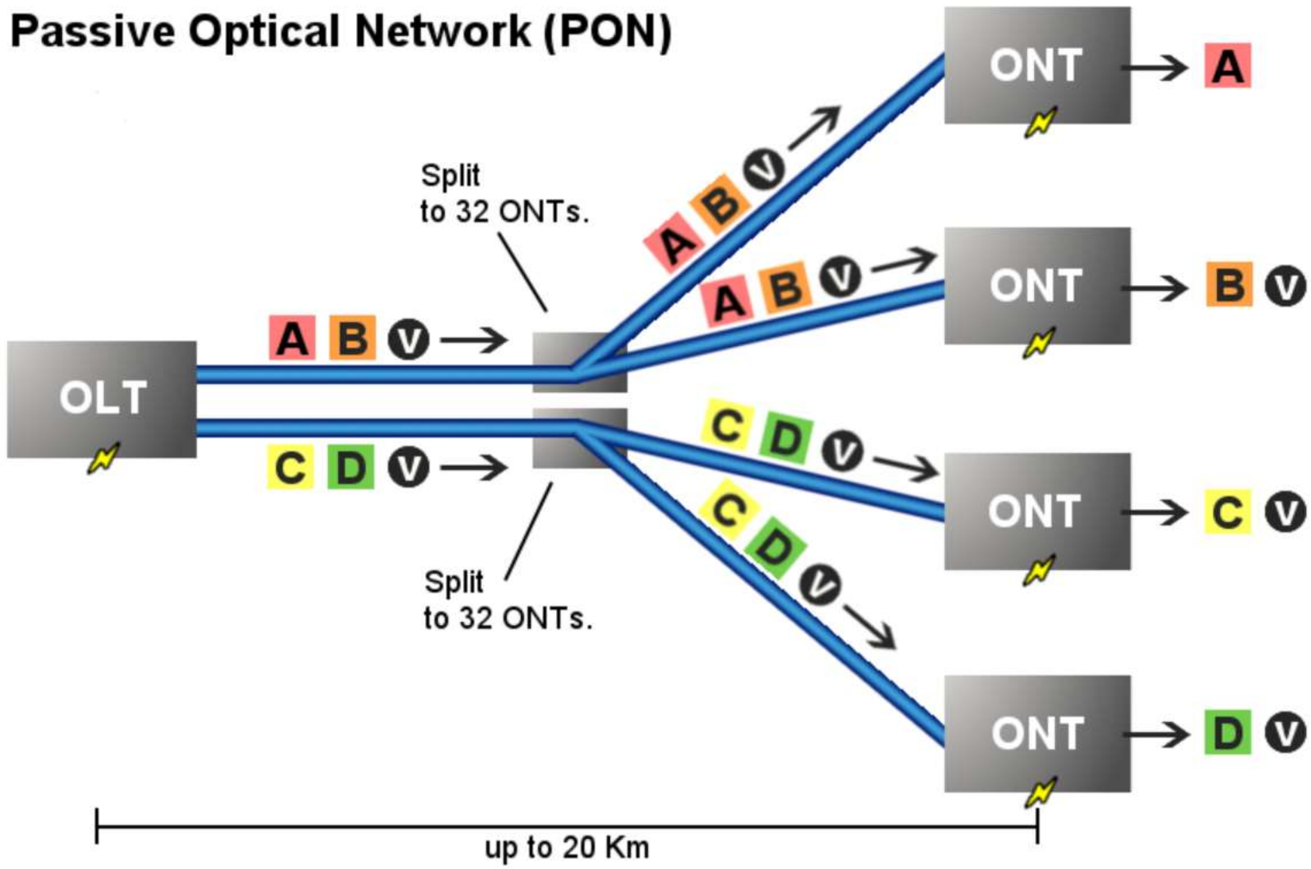
10GBASE-LX4	1310 nm	62.5μm MMF	500 MHz/km	2 - 300 m
10GBASE-LX4	1310 nm	50μm MMF	400 MHz/km	2 - 240 m
10GBASE-LX4	1310 nm	50μm MMF	500 MHz/km	2 - 300 m
10GBASE-LX4	1310 nm	10μm MMF	N/A	2 - 10 km
10GBASE-S	850 nm	62.5μm MMF	160 MHz/km	2 - 26 m
10GBASE-S	850 nm	62.5μm MMF	200 MHz/km	2 - 33 m
10GBASE-S	850 nm	50μm MMF	400 MHz/km	2 - 66 m
10GBASE-S	850 nm	50μm MMF	500 MHz/km	2 - 82 m
10GBASE-S	850 nm	50μm MMF	2000 MHz/km	2 - 300 m
10GBASE-L	1310 nm	10μm SMF	N/A	2 - 10 km
10GBASE-E	1550 nm	10μm SMF	N/A	2 - 30 km

10GBASE-SR SFP+ transceiver

10GBASE-T 802.3an-2006 (64B65B PAM-16 128-DSQ)
100m Cat 6A, 55m Cat 5e , Cat 6

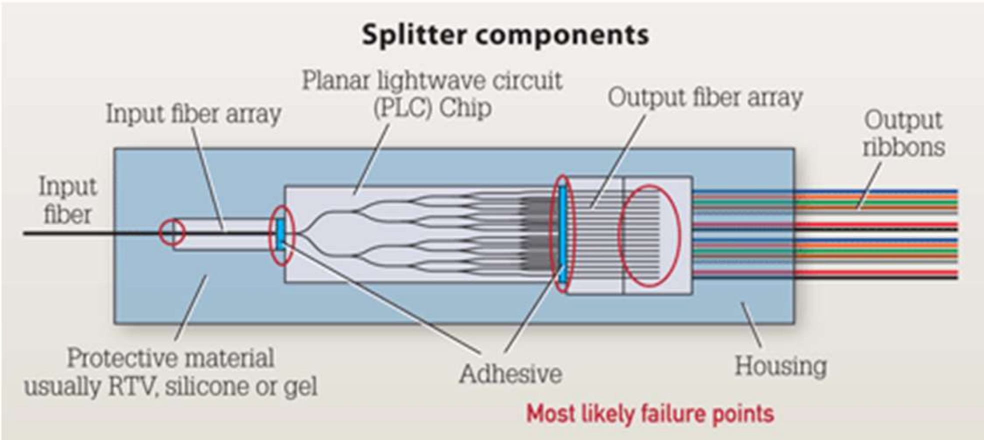
2.5GBASE-T , **5GBASE-T IEEE 802.3bz-2016** , NBASE-T, MGBASE-T
100m Cat 5e, Cat 6

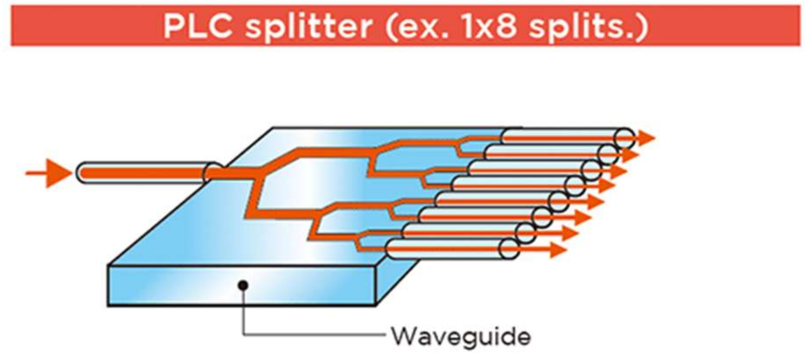
Passive Optical Network (PON)

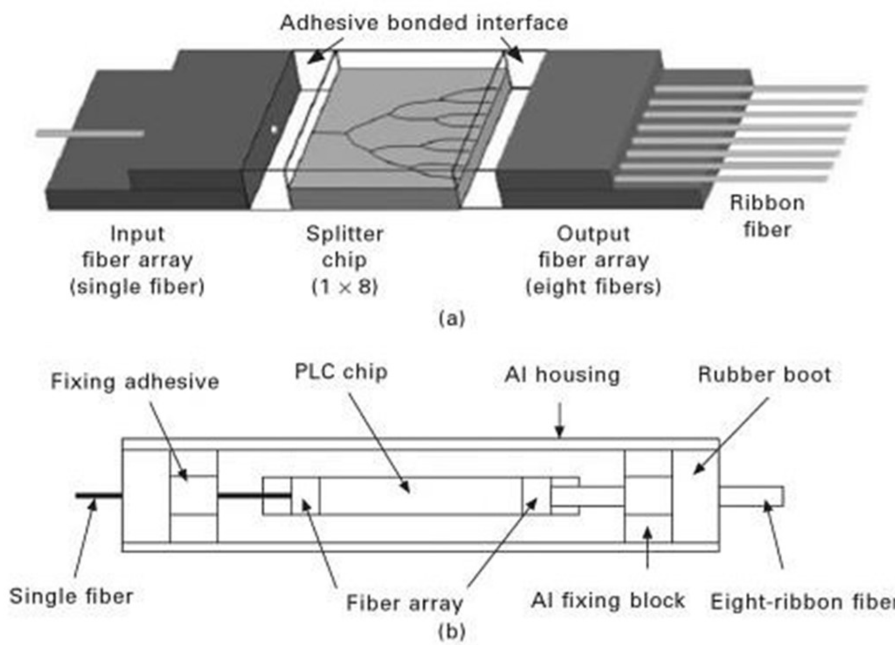


Optical Line Terminal (OLT) - service provider
Optical Network Terminals (Units) (ONTs) – end users
Downstream: broadcast, single mode, 1490 nm
Upstream : TDMA, single mode, 1310 nm
1550 nm is reserved for optional overlay services, e.g. RF (analog) video

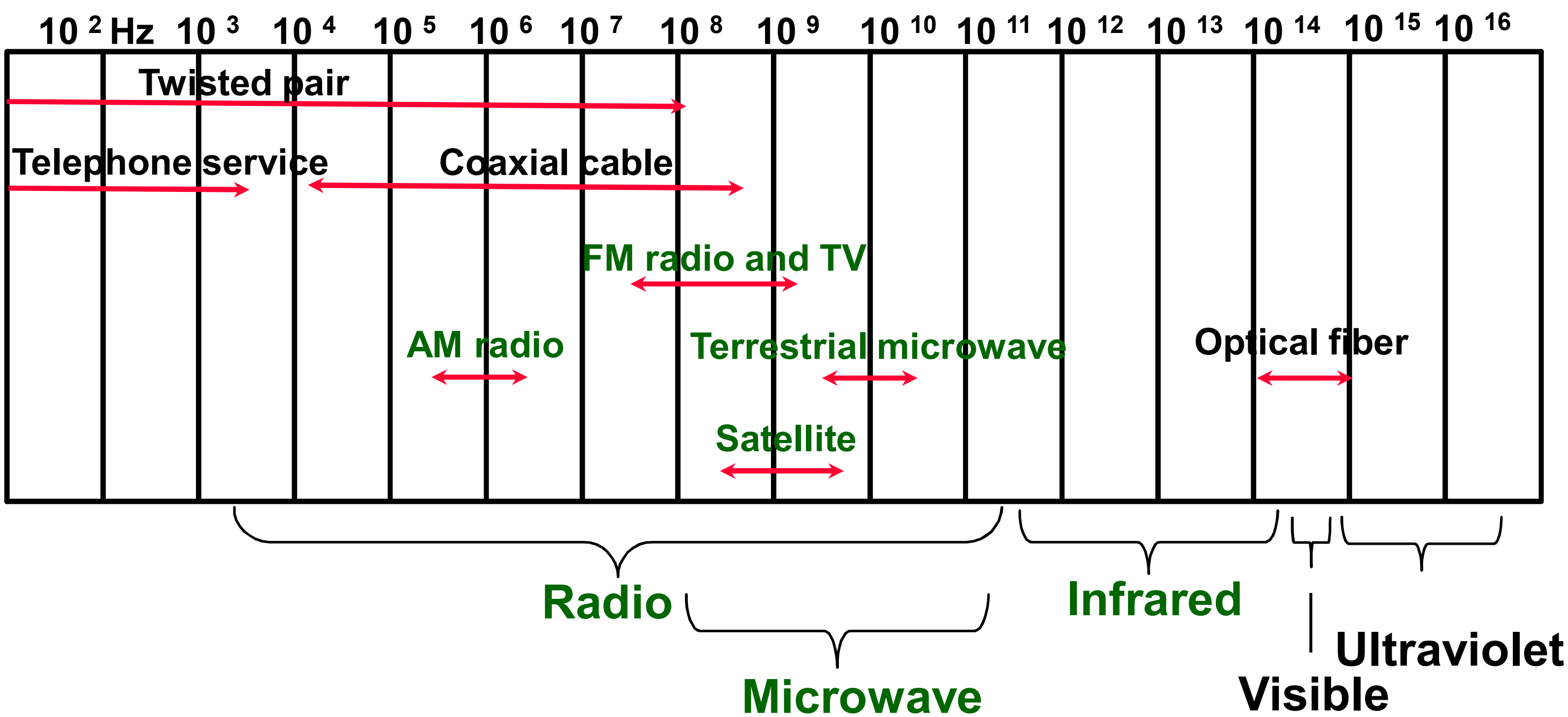
Passive Optical Network (PON)







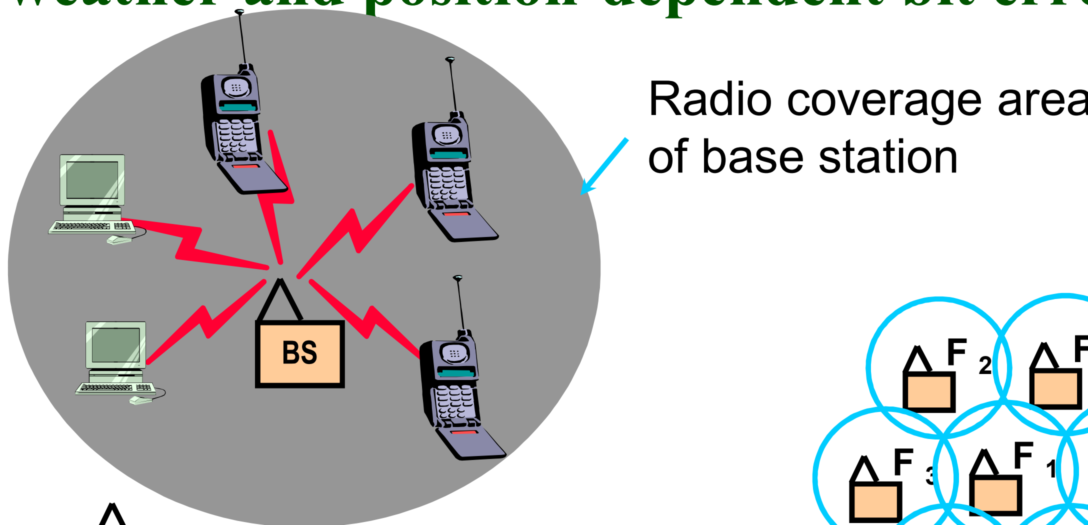
Wireless transmission

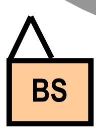


- Propagation of electromagnetic waves "in the air" (no need to establish a separate physical connection)
- You can even cover very long distances with it.

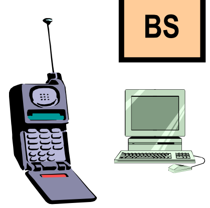
Terrestrial radio (VHF)

- **Short-range, low-speed mobile connection between the base station and the terminals.**
- **Satisfactory availability, weather and position-dependent bit error rate.**

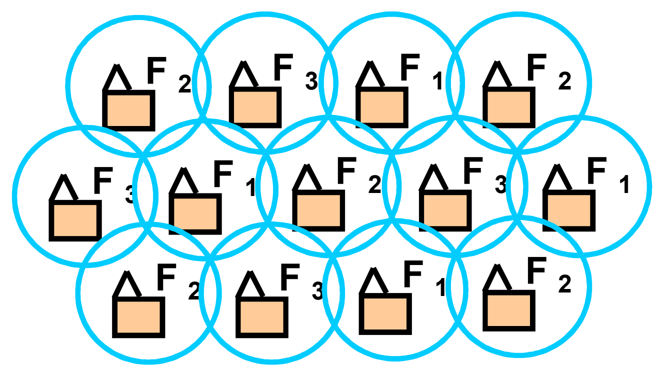




= Base station



= User computer/terminal



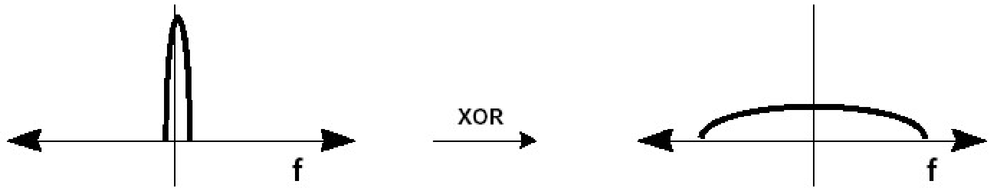
F_1, F_2, F_3 = Frequencies used in cell

Terrestrial radio (WLAN)

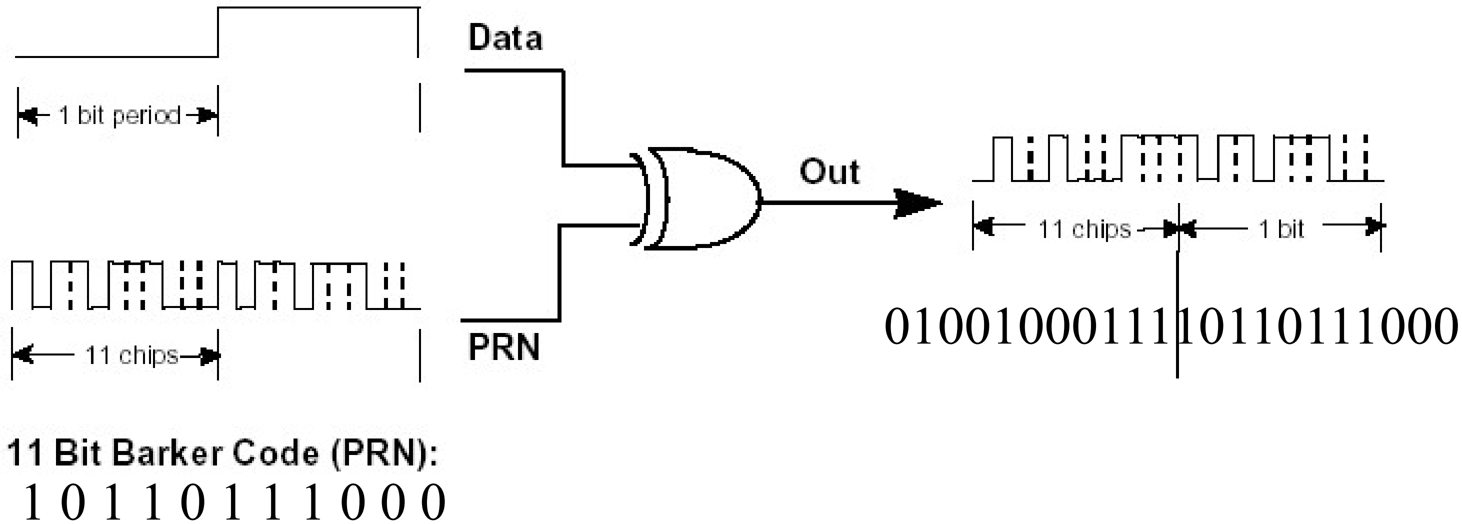
- Wireless LAN (WLAN) - e.g. IEEE 802.11b
- Speed: 1, 2, 5.5, 11 Mbps (IEEE 802.11b)
- Frequency 2400-2483.5 MHz
- Power: 100mW
- Range 1Mbps (typical):
  460m in open area, 300m for handheld, 90m in office
- Range 11Mbps (typical):
  120m in open area, 90m handheld, 30m office
- Spread spectrum radio channel
  - Direct Sequence Spread Spectrum (DSSS), or
  - Frequency Hopped Spread Spectrum (FHSS)
- No need for frequency license

Terrestrial radio (WLAN)

- **Spread spectrum radio channel**
  - **Higher bandwidth: reduced transmitter power, unchanged signal power**



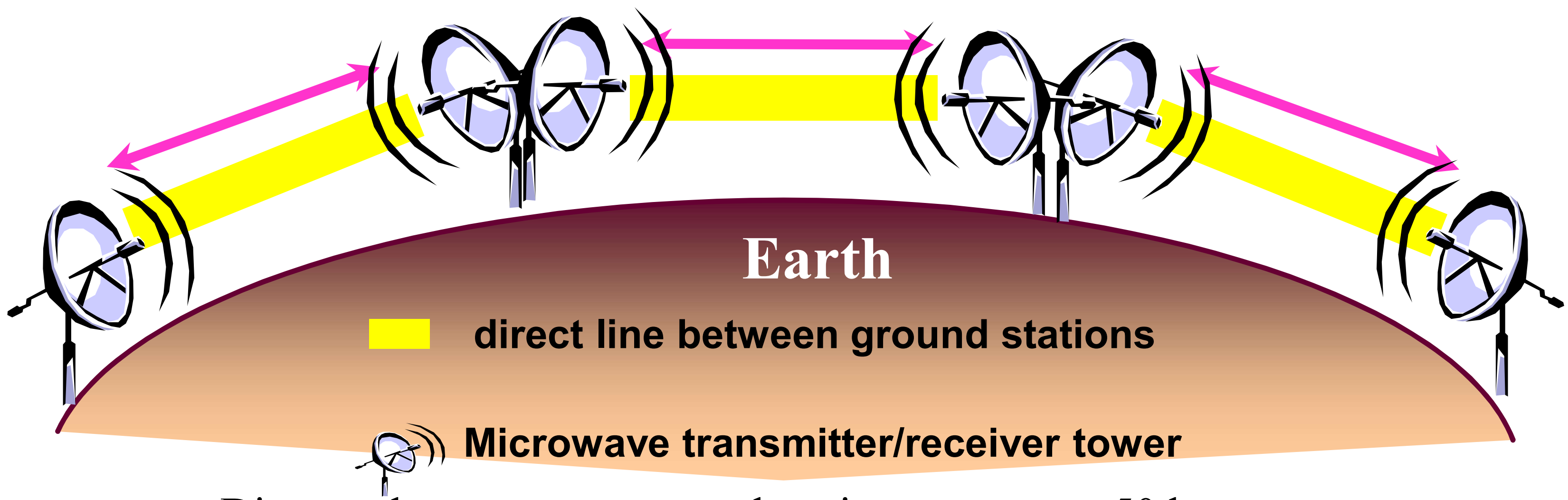
- **Direct Sequence Spread Spectrum (DSSS)**



  - **Demodulation with a correlator (removal of the Barker code)**
- **Frequency Hopped Spread Spectrum (FHSS)**
  - **Rapid change of transmitter frequencies according to some predefined function (followed by the receiver)**

Terrestrial microwave

- **Bridging medium or long distances (instead of expensive cables),**
- **between stable stations where there is “microwave line of sight.” High speed, weather dependent.**



Distance between two ground stations approx. ≈ 50 km

Telecommunications satellites

- Microwave transmission (also for long-distance computer networks) between ground stations and satellites.
- high speed (although weather dependent: rain absorbs it), high propagation delay is a problem.
- Transponder: they monitor a certain spectrum, amplify it and retransmit it (in a different spectrum, with different polarization, to avoid interference). International agreements for frequency bands. Geostationary satellites at an altitude of about 36,000 km:
  - They can also cause a delay of 250-300 msec.
  - Three satellites can " cover " the entire earth .

Satellite frequencies

- **Optimal is 1 - 10 GHz.**
  - Below it are atmospheric noises, noises from electrical devices;
  - There is strong atmospheric attenuation above it.
- **C-band 4/6 GHz**
  - "uplink" 5.925 - 6.425 GHz
  - "downlink" 3.7 - 4.2 GHz
- **KU band 12/14 GHz (requires higher transponder sensitivity)**
  - uplink 14 - 14.5 GHz
  - downlink 11.7 - 12.2 GHz

Laser optical

- **Short-distance, stable installation (e.g. between buildings),**
- **high bandwidth,**
- **weather dependent.**

Factors for choosing the medium

- **Bandwidth and data transfer speed:** choose the one that suits your needs
- **Distance:** consider the distance you can cover. You also need to consider the delay!
- **Quality:** difficulties are tolerable or not? (interference immunity, reliability, e.g. availability in bad weather)
- **Suitability for Broadcasting**
- **Cost:** the medium and the tools have different costs

Let's compare

	Terestrial radio	Laser	Microwave	Satellite
Transfer speed	16 Kbps	100 Mbps	100 Mbps	500MHz more 500Mbps
Max distance	10-50 Km	1-2 Km	100 Km	continent
Delay	3 μs/km	-	3 μs/km	250-300 msec
Noise tolerance	Weather dependent			
Robustness	average	good	good	kiváló
Broadcast	possible	point-point	point-point	suitable
Cost	Expensive devices			

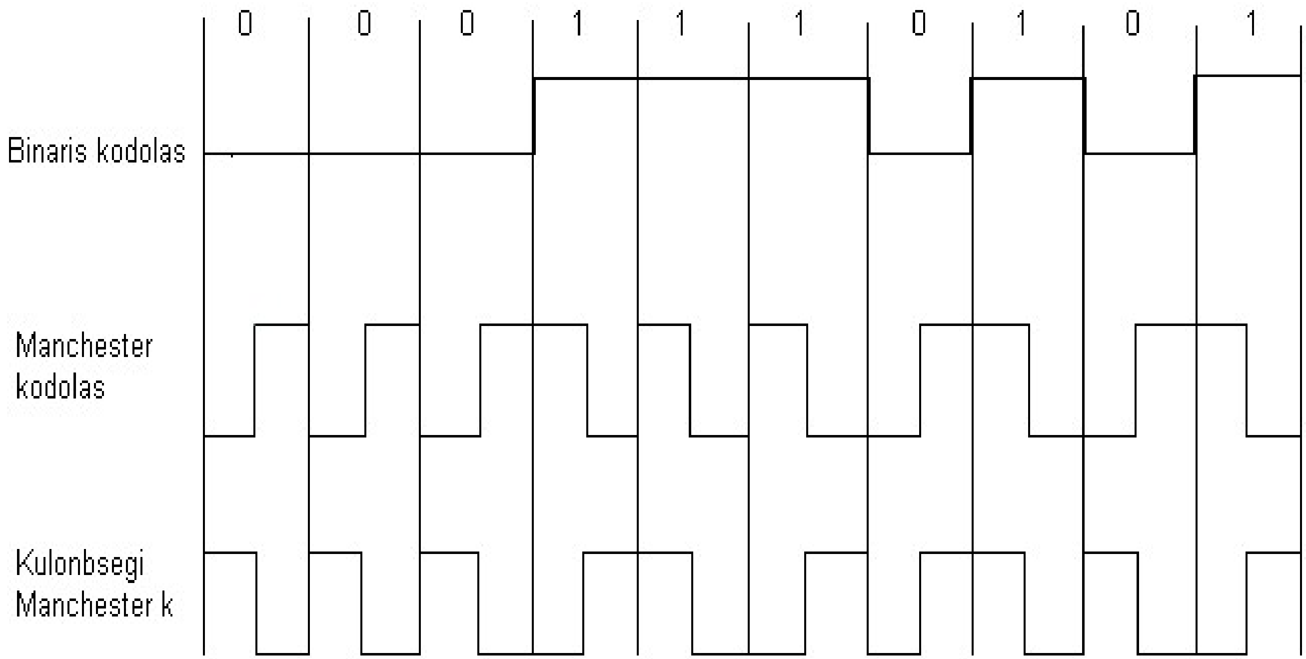
Codec

- **Transmission modes can be**
  - **Baseband transmission**
  - **Broadband transmission**
    (telephony: modulation –
    transmission of digital signals over an analog channel)
- **Simple binary code (baseband)**
  - **for binary values the signal levels (voltage or current):**
    e.g. 1: 1V; 0: 0V
  - **Problem synchronization :**
    e.g. in case of all 0s no change in signal
  - **Manchester encoding can help with this, for example.**

Manchester encoding

- **Manchester encoding**
  - **Each bit period is divided into 2 parts,**
  - **there is always a transition in the middle of the bit time (bit synchronous):**
    - **1: high-low,**
    - **0: low-to-high transition.**
  - **Disadvantage: double bandwidth requirement (pulses half as wide).**
- **Differential Manchester encoding** (variant)
  - **1: missing transition at the beginning of the bit time,**
  - **0: transition present at the beginning of the bit time and the**
  - **There is always a transition here in the middle of the bit, but**
  - **insensitive to signal polarity.**

Example of three different codecs

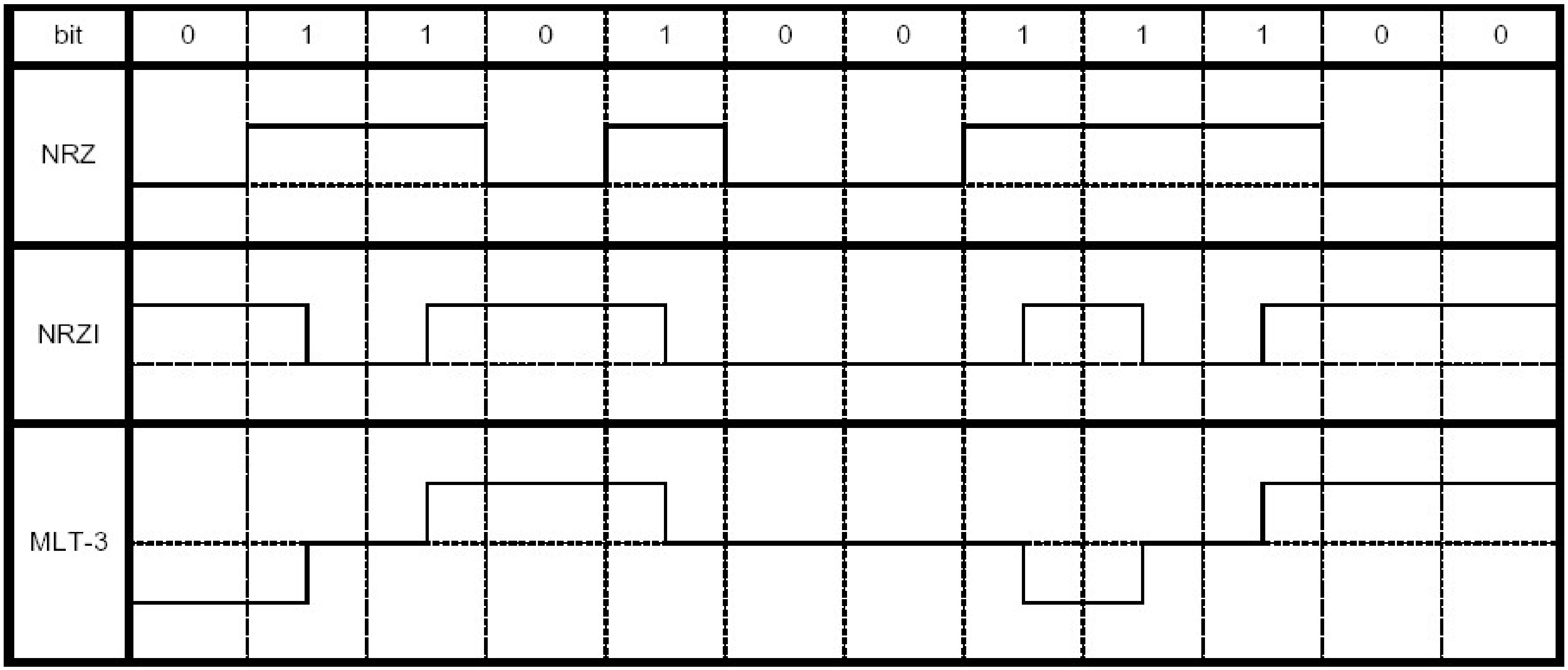


In the middle of the bit time:
1: ↓; 0: ↑

1: missing at the beginning of the bit time,
0: existing at the beginning of bit time,
and always in the middle!

MLT-3 Encoding

- **Non - Return** to **Zero**, **NRZ- Invertive (**switches at 1), **Multi - L**evel **T**ransition **3**



- **In case of all "1" e.g.: 1111=+1.0,-1.0 → 1/4 frequency decrease**
- **In case of all "0" → no transmission** (there may be a bit synchronization error)
- **The max. frequency decreases, but bit sync cannot be extracted from it**

4B/5B Encoding

Data Input (4 bits)	Code Group (5 bits)	NRZI pattern	Interpretation
0000	11110		Data 0
0001	01001		Data 1
0010	10100		Data 2
0011	10101		Data 3
0100	01010		Data 4
0101	01011		Data 5
0110	01110		Data 6
0111	01111		Data 7
1000	10010		Data 8
1001	10011		Data 9
1010	10110		Data A
1011	10111		Data B
1100	11010		Data C
1101	11011		Data D
1110	11100		Data E
1111	11101		Data F
	11111		Idle
	11000		Start of stream delimiter, part 1
	10001		Start of stream delimiter, part 2
	01101		End of stream delimiter, part 1
	00111		End of stream delimiter, part 2
	00100		Transmit error
	other		invalid codes

- **Control codes**
- **Error detection**
- **25% loss (4+1)**
- **Synchronization**
- **4B/5B + MLT-3 → 100BaseT**

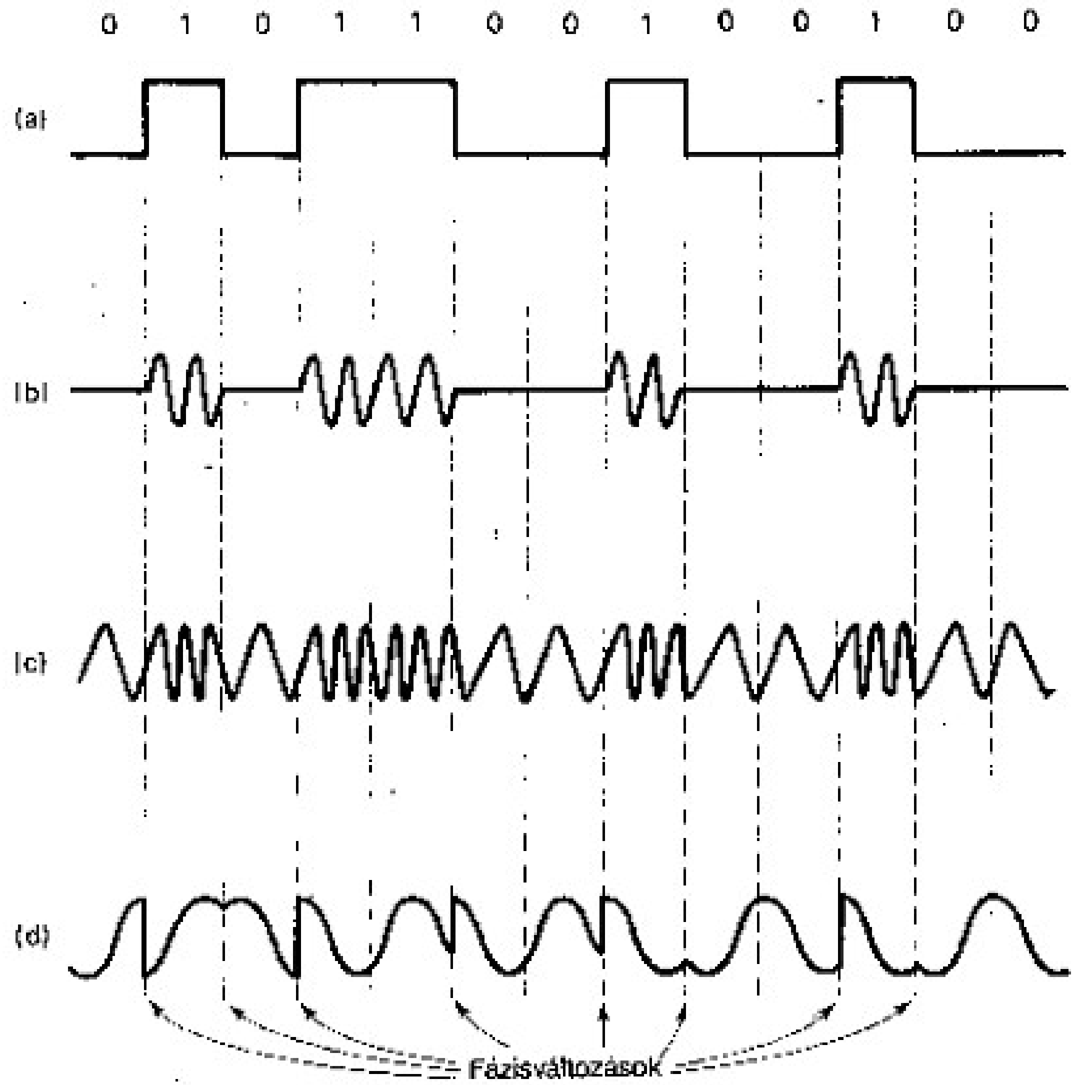
Signal modulation

- **This is what is needed, for example, for digital signal transmission over an analog telephone system**
  - **The telephone system: public switched network → a worldwide (analog) switched line network**
- **The problem is the transmission of digital signals over an analog switched line. A modem (modulator-demodulator) is required. Its function:**
  - **establishing and ending a connection (like a telephone)**
    - **dialing,**
    - **in-band signaling DTMF signals** (2 sinuses at the same time out of 7)
  - **conversion of the digital bit stream into a modulated carrier signal (back and forth).**

Converting a digital bitstream into a modulated carrier signal

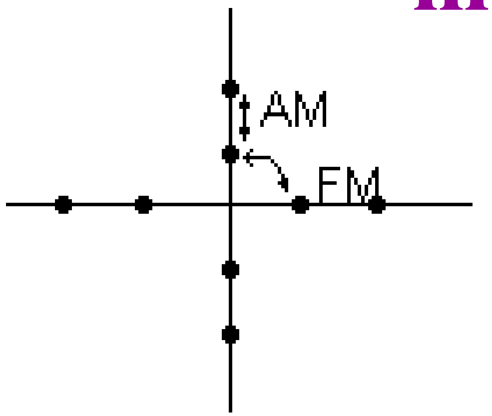
- **Modulation methods (sine carrier wave)**
  - **amplitude modulation: the amplitude of the carrier signal is changed;**
  - **frequency modulation: the frequency of the carrier signal is changed;**
  - **phase modulation: the phase of the carrier signal is changed;**
  - **and a combination of these (combined).**

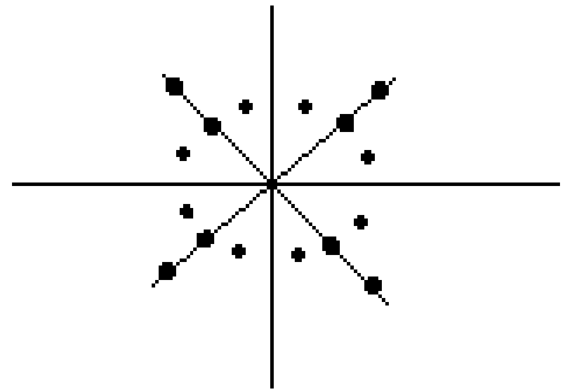
Modulation methods



a) egy bináris jel; b) amplitúdómoduláció; c) frekvenciamoduláció;
d) fázismoduláció

Combined amplitude and phase modulation





- **0, 90, 180 and 270 degrees per phase (4 pcs),**
- **two amplitude levels →**
- **8 possible signals**
  3 bits/baud modulation.

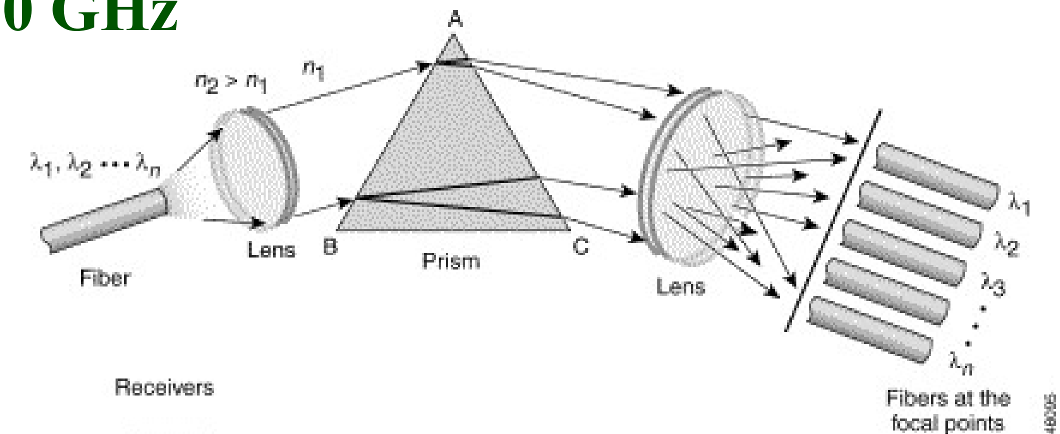
- **30 degree phase shifts,**
  of which 8 have one and
  4 have two amplitude levels:
- **There can be 16 signal combinations with 4 bit/baud modulation.**
- Quadrature Amplitude Modulation **(QAM)**
  It provides 9600 bps on a 2400 baud line.

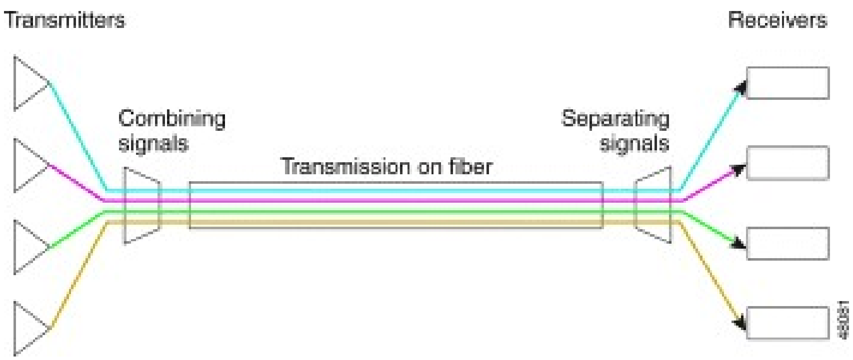
Modems

- **Shannon limit on telephone line:**
  Bandwidth: 2,400 Hz – 2,800 Hz , S/N 24 d B - 30 dB ⇒ ≈ 24,000 bps
- **1950 : manufacturer specific, mainly FSK (300 bps - 600 bps) and vestigial sideband (1200 bps - 2400 bps).**
- **1964 : The first CCITT Modem Recommendation ,**
  V.21 (1964), 200 bps FSK modem (now 300 bps) V.34/V.8 interface
- **1968 : 4 Phase (2X2 QAM)**
- **1984 : 4X4 QAM , V.22bis**
- **1984 : technological breakthrough V.32**
  echo cancellation and trellis coding
  V.32bis 14,400 bps.
- **1989/90 : V.34 – 19,200 bps , 24,000 bps then 28,800 bps.**
- **1996 : V.34 – 33,600 bps.**
- **Nowadays 56,600 bps (but it is asymmetric)**
- **But telephone bandwidth limits are typically not due to the subscriber loop, but to the bandpass filters of the switching machines**
  → much higher bandwidth is available on the subscriber loop (xDSL)

Optical modulation

- **Wavelength Division Multiplexing (WDM)**
- **> 64 channels 25-50 GHz**





SONET/SDH :
Synchronous Optical Network/Synchronous Digital Hierarchy

STS-1 :
Synchronous Transport Signal level 1

SONET	SDH	Data Rates
STS-1		51.840 Mbps
STS-3	STM-1	155.520 Mbps
STS-12	STM-4	622.080 Mbps
STS-48	STM-16	2,488.320 Mbps
STS-192	STM-48	9,953.280 Mbps

The RS-232-C interface

- Interface between a computer and a terminal or modem.
- Standard names:
  - Computer or terminal: Data Terminal Equipment: DTE
  - Modem or Data Circuit-Terminating Equipment: DCE
- Physical layer protocol:
  - mechanical
  - electrical
  - functional
  - proceedings

  definition of interfaces.

The RS-232-C interface

- **RS-232-C is the third, improved version of RS-232**
  - **Created**
    by : Electronic Industries Association → EIA RS-232-C
  - **CCITT version: V.24 (very similar) (CCITT is a UN organization)**

CCITT: Comite Consultatic International de Télégraphique et Téléphonique

The RS-232-C interface

- **The mechanical definition:**
  - 47.04+-0.13 mm wide 25-pin (D-CANNON) connector
  - The top row needles are numbered 1-13 from left to right, the bottom 14-25.
- **The electrical specification**

  A voltage less than -3 V means a binary 1,

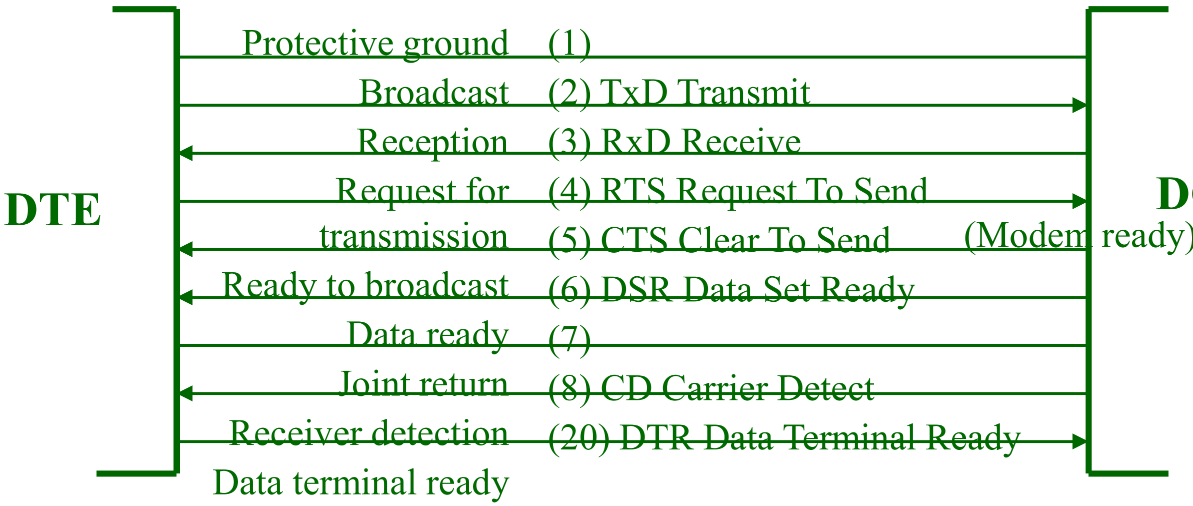
  Greater than +4 V: binary 0.

  Cables up to 15 m,

  20 Kbps speed is allowed.

The RS-232-C interface

- **Functional specification:**
  designation of circuits associated with pins and their description



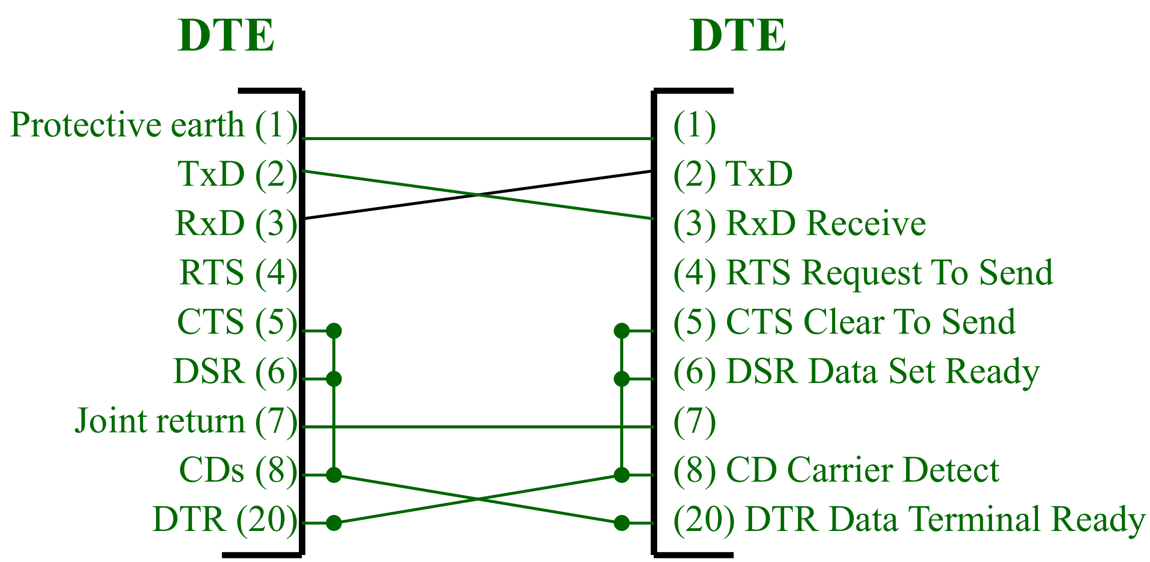
- **For example, a "procedure":**
  - **DTE turns on ⇒ DTR =1**
  - **DCE turns on ⇒ DSR =1**
  - **DCE detects carrier ⇒ CD =1**
    ⇓
  - **DTE:RTS=1 – request to send**
  - ⇓
  - **DTE:CTS=1 – ready to send**
    ⇓
  - **DTE: Transmit** (send data)

The circuits not shown are circuits for synchronous transmission or other signals, e.g. ringing signal detection.

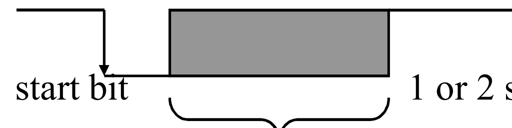
- **The procedure specification:**
  a protocol that defines the valid sequences of events.
  It is based on action-reaction event pairs.

The null modem

- **Cable suitable for DTE-DTE connection:**
  - **R - T/T - R swap and some crossovers (and loopbacks)**



Detecting bit times



- **Asynchronous case: start-stop bit solution**
  - **The timing must be so precise that the bit time does not fall out during the transmitted data.**
  - **standard speeds are needed that DTE and DCE agree on (or manually configure): 1200, 2400, 4800, 9600 bps, etc.**
  - **Start-stop bits: loss (poor channel utilization)**
- **Synchronous case: separate bit timing spike**
  - **The DCE (modem) dictates the transmission speed.**
  - **no speed needs to be configured in the DTE**
  - **(sync character or flag) for frame boundaries .**

Analog signals on a digital line

- **In telephony, trunks are digital**
- **Subscriber loops, on the other hand, are analog.**
- **It is therefore necessary:**
  - **Coder-decoder (codec): which converts analog signals into digital bit sequences (back and forth)**

Digital data on an analog voice channel

- **The analog voice channel**
  - **The bandwidth is 0-4 KHz, this is (according to Nyquist)**
  - **written at 8000 samples/sec . That is**
  - **125 μ sec/sample (one frame every 125 μsec) and convert this to an 8-bit (7-bit in the US) number**
  - **its name is PCM (Pulse Code Modulation)**
  - **One audio channel has a speed of 2*4K*8 → 64Kbps (in America only 7 bits → there only 56 Kbps)**

Standard PCM rates

USA, Japan (CCITT, Bell System)	Europe (CCITT)
T_1 : 1.544 Mbps → 24 PCM channels	E_1 : 2.048 Mbps : → 30PCM + 2 signal channels.
T2 : 6.312 Mbps	E_2 : 8.848 Mbps
T3 : 44.736 Mbps	E_3 : 34.304 Mbps
T4 : 274.176 Mbps	E_4 : 565.148 Mbps

PCM carriers

- **The T1 carrier multiplexes 24 PCM channels**
  - **7 data + 1 control bit per channel, 56 Kbps;**
  - **one frame: 24 * 8 bits + 1 framing bit = 193 bits;**
  - **1 frame (193 bits)/ 125 μsec: 1.544 Mbps**
- **The E1 carrier bundles 30 PCM+2 signaling channels**
  - **in the 125 μsec frame;**
  - **256 bits / 125 μsec : 2.048 Mbps**

Standard PCM rates

USA, Japan (CCITT, Bell System)	Europe (CCITT)
T_1 : 1.544 Mbps → 24 PCM channels	E_1 : 2.048 Mbps : → 30PCM + 2 signal channels.
T2 : 6.312 Mbps	E_2 : 8.848 Mbps
T3 : 44.736 Mbps	E_3 : 34.304 Mbps
T4 : 274.176 Mbps	E_4 : 565.148 Mbps

Coding systems

How could the number of bits to be transmitted be reduced by coding?

- **With differential pulse code modulation: the difference between the current and previous sample is transmitted**
- **With delta modulation: only 1 bit is used to indicate whether the signal is increasing or decreasing (it can be lost)**
- **With predictive encoding: extrapolating from a few previous values, the next value is predicted, and then the difference between the current and estimated values is transmitted.** (The decoder also estimates using the same method.)

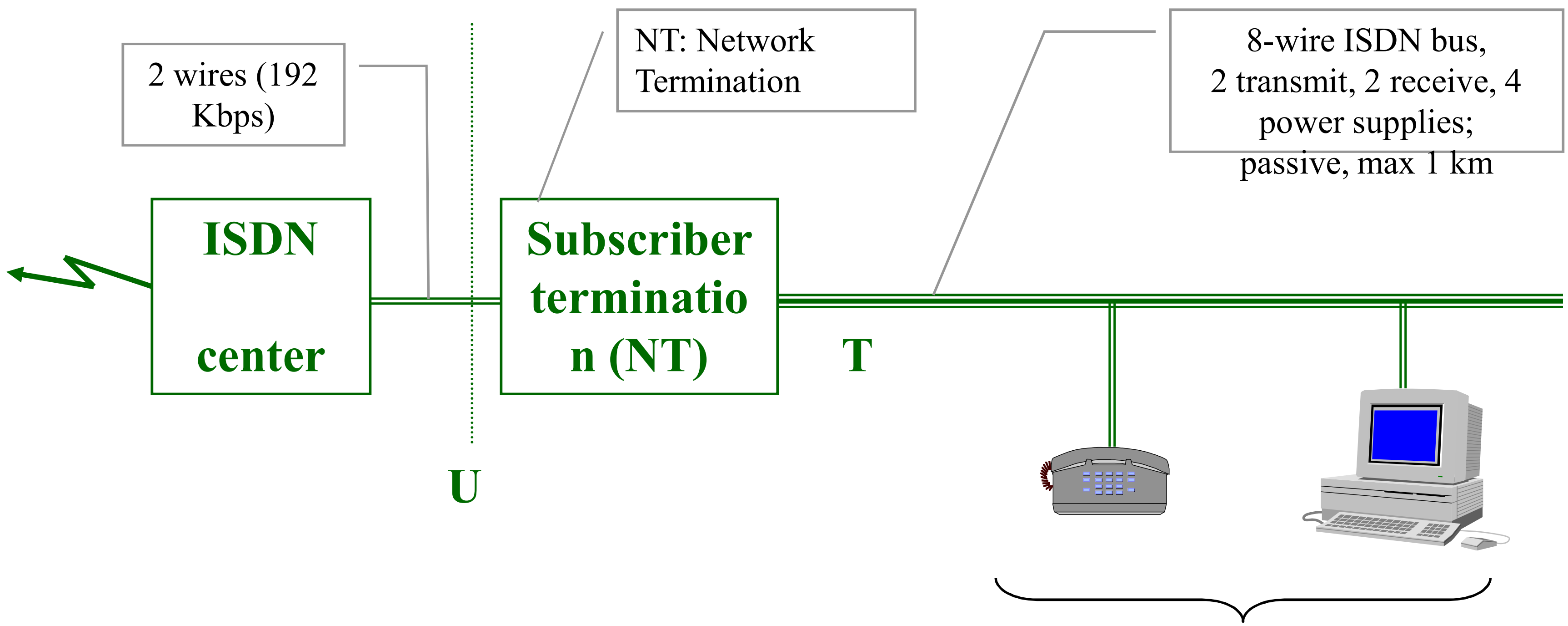
Fast circuit-switched network: ISDN

- ISDN (Integrated Services Digital Network): integrated services digital network
- Design goal:
  - integrate voice and digital transmission;
  - the telephone system needs to be redesigned...
  - therefore
- standardized by CCITT (not ISO).
- Approved in 1984, refined in 1988...
- It's like line switching, only it builds/breaks very quickly...

The basic idea of ISDN

- **The digital bit pipe,**
  - **where bits can flow in both directions...**
  - **Separate signaling channel for connection management,**
  - **but once the connection is established, any digital data (telephone, fax, digital data such as images, etc.) can be transmitted.**
  - **The bitpipe is bundled: it supports multiple independent channels using time division multiplexing.**

The structure

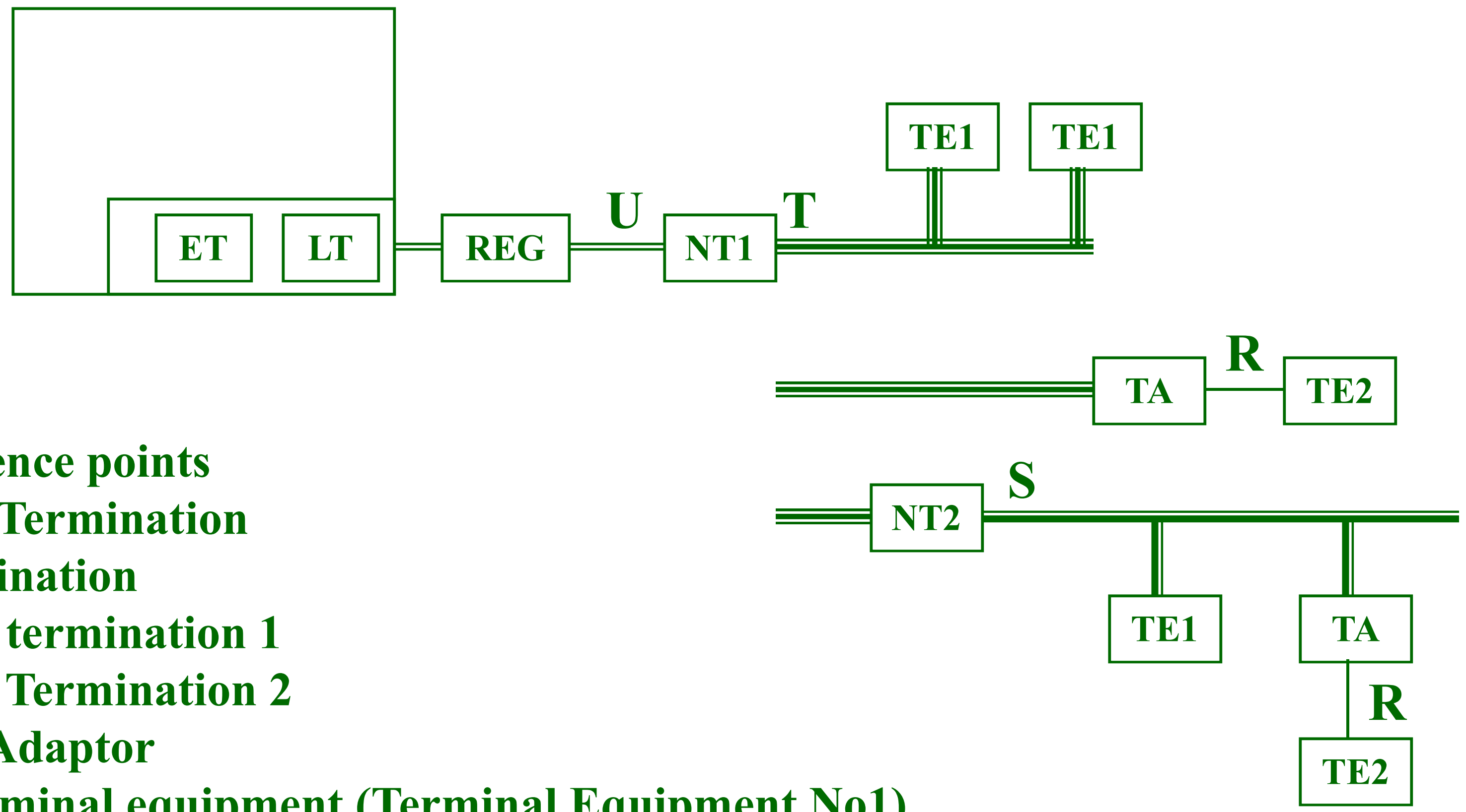


Addressable ISDN devices
The addresses are assigned by the NT at power-up.

After NT, there can be ISPBX, which can connect S reference point devices, e.g. LAN ...

The NT also handles "access" to the ISDN bitpipe. A maximum of 8 TE1 devices can be connected to the AT interface.

The structure



U,T,S,R: reference points
ET: Exchange Termination
LT: Line Termination
NT1: Network termination 1
NT2: Network Termination 2
TA: Terminal Adaptor
TE1: ISDN terminal equipment (Terminal Equipment No1)
TE2: Non-ISDN terminal equipment
REG: Regenerator

CCITT channel types

A: 4 KHz analog telephone channel
B: 64 Kbps PCM channel for voice and data transmission
C: 8 v. 16 Kbps digital channel
D: 16 v. 64 Kbps digital channel for out-of-band signals
E: 64 Kbps digital channel for in-band signaling
H: 384 v, 1536 v. 1920 Kbps digital channel

Standard combinations:

1) Basic access: 2 B + 1 D_{16}

2) Primary access:

USA and Japan: 23 B +1 D_{64} (~ T1)

Europe: 30 B + 1 D_{64} (~E1)

3) Hybrid: 1 A + 1 C (practically not used)

Exercise

- **Task 1: Data transfer rate**
  - **What is the minimum signal-to-noise ratio required to place an E1 carrier (2.048 Mbps) on a 50KHz bandwidth line?**

Shannon :

Max-data-transfer-speed = $H \log_2 (1 + S/N)$ [bps]

$2.048 * 10^6 = 50 * 10^3 * \log_2 (1 + S/N)$

$40.96 = \log_2 (1 + S/N)$

$2^{40.96} = 1 + S/N$

$2.14 * 10^{12} = 1 + S/N$

$S/N \approx 2.14 * 10^{12}$

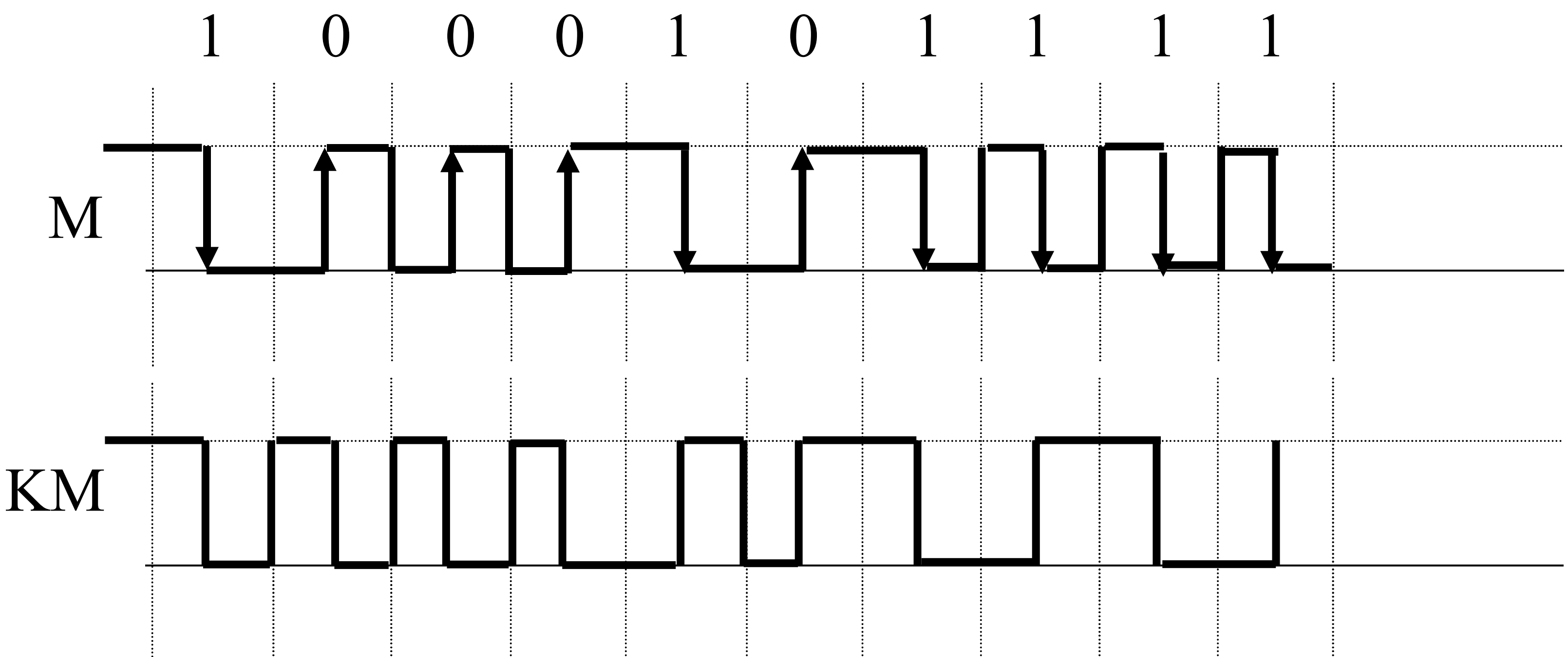
$S/N_{[DB]} \approx 10 * \log_{10} (2.14 * 10^{12})$

$\mathbf{S/N_{[DB]}} \approx 10 * 12.33 = \mathbf{123\ dB}$

Exercise

- **Task 2: Coding**
  - **Sketch the signal changes for the following bit stream: 0 0 0 1 1 1 0 1 0 1**
    - **a) binary,**
    - **b) Manchester and**
    - **c) differential Manchester coding!**

Manchester : in the middle
1 - ↓ transition; 0 - ↑ transition.
differential Manchester encoding :
1 - missing transition at the beginning of the bit time,
0 - transition at the beginning of the bit time .



Exercise

- **Task 3: Data transfer rate**
  - **What maximum signal-to-noise ratio can we expect for a telephone line if it is transmitted over a PCM channel? (H =4kHz, 64Kbps)**

Shannon :

Max-data-transmission-speed = $H * \log_2(1 + S/N)$

$64 * 10^3 = 4 * 10^3 * \log_2(1 + S/N)$

$16 = \log_2(1 + S/N)$

$2^{16} = 1 + S/N$

$65536 = 1 + S/N$

$S/N = 65535$

$S/N_{[DB]} = 10 \log_{10}(S/N) = 10 * \log_{10} 65535 = 10 * 4.82$

$\mathbf{S/N_{[DB]} = 48.2\ dB}$ max .

Exercise

- **Task 4: Data transfer rate**
  - **The bandwidth of a data transmission channel is 30 MHz, on which we want to transmit data at a maximum speed of 120 Mbps.**
    - **a) At least how many signals do we need to be able to distinguish on the physical medium to achieve this maximum data transfer rate?**
    - **b) What is the maximum signal speed on the channel?**
    - **c) What minimum signal-to-noise ratio do we need to ensure for this maximum speed ?**

a) Nyquist : data rate = $2 H \log_2 V$
$120 * 10^6 = 2 * 30 * 10^6 * \log_2 V$
$2 = \log_2 V$, $\mathbf{V = 4}$ **You must be able to distinguish at least 4 signs .**

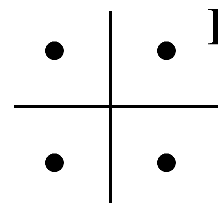
b) $\log_2 V \rightarrow$ bit/Baud
Max . signaling speed : $2 * H = 2 * 30 * 10^6 = \mathbf{60 * 10^6}$ **B aud**

c) Shannon
$120 * 10^6 = 30 * 10^6 * \log_2 (1 + S/N) \rightarrow 4 = \log_2 (1 + S/N) \rightarrow 16 - 1 = 15 = S/N$
$\mathbf{S/N_{[DB]}} = 10 * \log_{10} 15 = \mathbf{11.76\ [dB]}$

Exercise

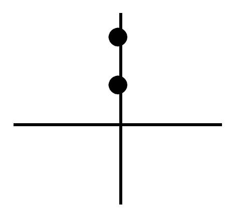
- **Task: 5 Data transfer rate**
  - **The data points of a modem's operating diagram can be characterized by the following coordinates :**
    - **a) (1,1); (1,-1); (-1, 1); (-1, -1)**
    - **b) (0, 1); (0, 2)**
  - **How many bps of data transfer speed can the modem achieve with these parameters at a signaling rate of 1200 baud? What modulation does the modem use?**

a) $V = 4$; $\log_2 V = 2$, **2 bits/baud ,** data bit = signal bit * bit/baud ,
data transfer rate = 12000 * 2 **= 2400 bps**



Phase modulation.

b) $V = 2$; $\log_2 V = 1$ bit/baud **data rate = 1200 bps**



Amplitude modulation.

Exercise

- **Task 6: Comparison of line and packet switching**
  - **X bit message transmission a., line-switched, or b., on a packet-switched network (non-interleaved).**
  - **Parameters :**

Vonalkapcsolt hálózat	Áramkör felépítési idő	s [sec]
	Adatátviteli sebesség	b [bps]
Csomagkapcsolt hálózat	Ugrások száma	k
	Ugrásonként késleltetés (feldolgozási idő)	d [sec]
	Csomagméret	p [bit]
	Adatátviteli sebesség	b [bps]

Questions:

- **How long will the delay time be? (when does the first bit arrive)? $T_k = ?$**
- **What will be the data transfer time? $T_{átv} = ?$**

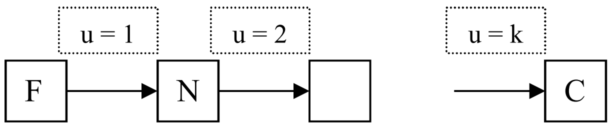
Exercise

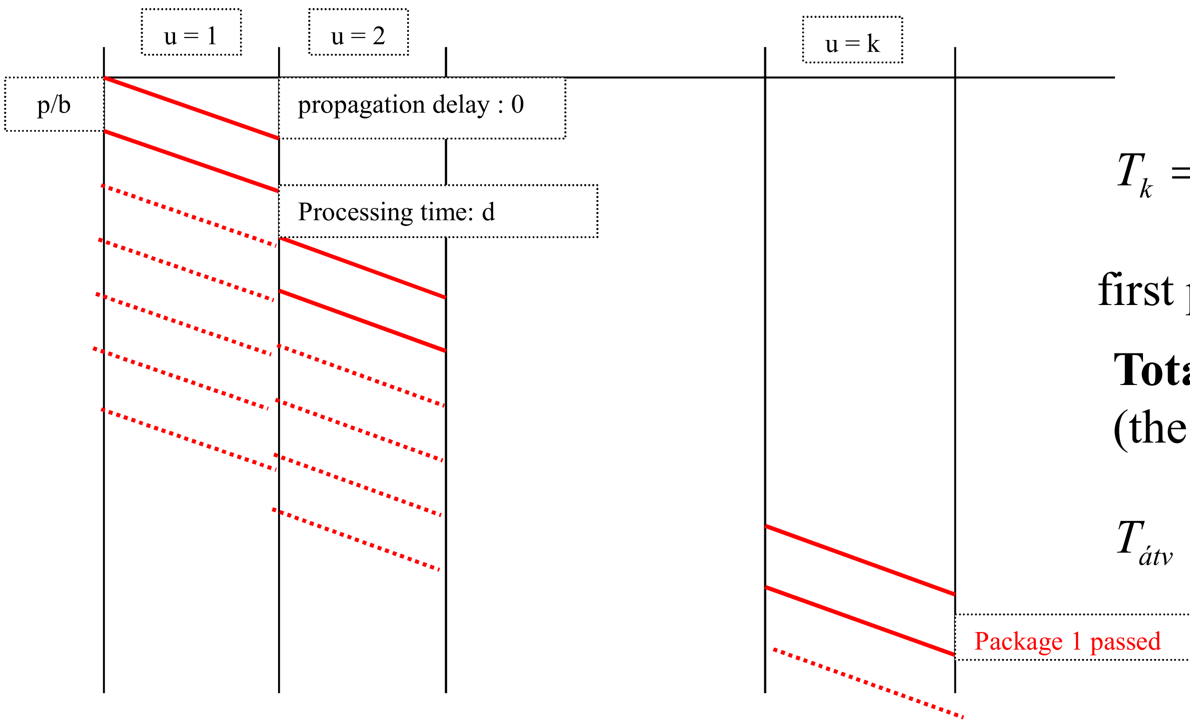
- ## Problem 6 solution

Line- connected network : T_k = circuit setup time = s [sec] , $\mathbf{T_{átv} = s + X/b}$ **[sec]**

Packet switched network :

Number of packets: $\mathbf{n = X/p}$; number of hops : **k**
1 jump requires **p/b + d** time
(packet transfer + delay time)





Delay time: T_k
(first package arrival start)

$$T_k = \underbrace{k\left(\frac{p}{b} + d\right)}_{\text{first package arrives completely}} - \frac{p}{b} = k \cdot d + (k-1)\frac{p}{b}$$

Total transfer time: $T_{transfer}$
(the end of last package arrival)

$$T_{átv} = k\left(\frac{p}{b} + d\right) + \underbrace{(n-1)\left(\frac{p}{b}\right)}_{\text{the rest will arrive completely}}$$

Exercise

- ## Problem 6 solution

Packet switched network :

Total transfer time: T $_{\text{transfer}}$
(last package arrival end)

Number of packages: $n = \frac{X}{p}$

$$T_{\acute{a}tv} = \underbrace{k\left(\frac{p}{b}+d\right)}_{\text{first package arrives completely}} + \underbrace{(n-1)\left(\frac{p}{b}\right)}_{\text{the rest arrive completely}}$$

first package arrives completely the rest arrive completely
(interleaved processing, the packets follow each other directly)

$$T_{\acute{a}tv} = k\left(\frac{p}{b}+d\right)+\left(\frac{X}{p}-1\right)\frac{p}{b} \Rightarrow k\cdot d+\frac{p}{b}\left(k-1+\frac{X}{p}\right)$$

Packet switched network :

$$T_{\acute{a}tv} = k\cdot d+(k-1)\frac{p}{b}+\frac{X}{b}$$

Line- connected network :

$$T_{\acute{a}tv} = s+\frac{X}{b}$$

It is better if:

$$k\cdot d+(k-1)\frac{p}{b} < s$$