Telecommunication Systems and Networks

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Telecommunication Systems and Networks 2020/2021

PART 1

Objective of the course

To gain fundamental understanding of the key concepts behind communication systems and networks engineering - in order to provide basic skills in design and performance analysis of these networks and services offered for end users.

Prerequisites:

mathematics (probability and statistics), basic electrical engineering, physics, IT.

Syllabus

1. *Introduction to Communication Networks*
2. *The Way Networks Work*
3. *OSI*
4. *Protocols*
5. *Medium Access Control*
6. *Security and Compression*
7. *Performance Evaluation and Monitoring*

Telecommunication System & Telecommunication Network

- **Telecommunication – the field of science and technology that covers problems of transmitting messages to remote receivers with the help of SIGNALS**

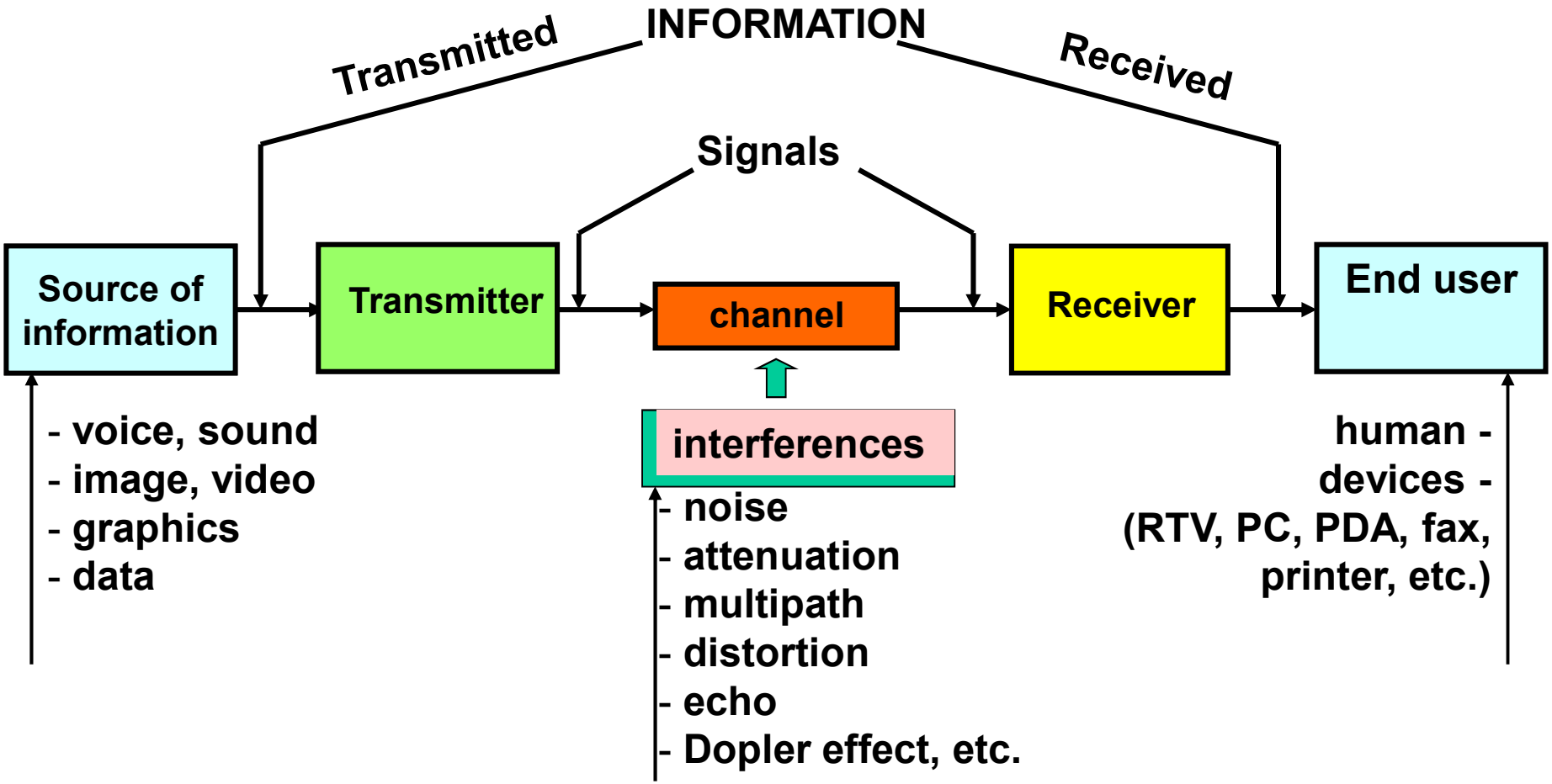
- **The word *remote* may mean very various distances in telecommunication**

- **Telecommunication systems are used for transmitting messages (information)**

1. Introduction to communication systems and networks

- Communication networks are arrangements of hardware and software that allow users to exchange information
- Telephone network – most familiar and ubiquitous communication network (PSTN - Public Switched Telephone Network)
- Data transmission networks; computer networks
- Internet – global network of computer networks
- Difference in the information that the networks transmit and in the way they are used
- End users – mostly are humans, but also: computer programs, devices, subsystems, etc.
- Digital transmission – reduces the transmission errors, but can deform the source information.

Communication system



A communication network is a set of nodes that are interconnected to permit the exchange of information.

Two types of nodes: *terminal nodes* and *communication nodes*.

Terminal nodes – phone sets, computers, printers, file servers, video monitors, etc.

Communication nodes – telephone exchanges, switches, routers, gates, repeaters, etc.

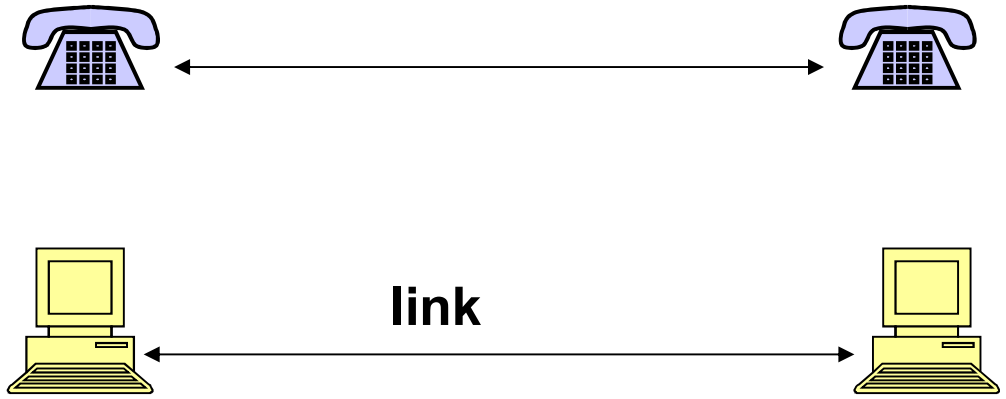
Terminal nodes generate or use the information transmitted over the network. Communication nodes transport the information.

The core network is the network connecting switching (communication) nodes.

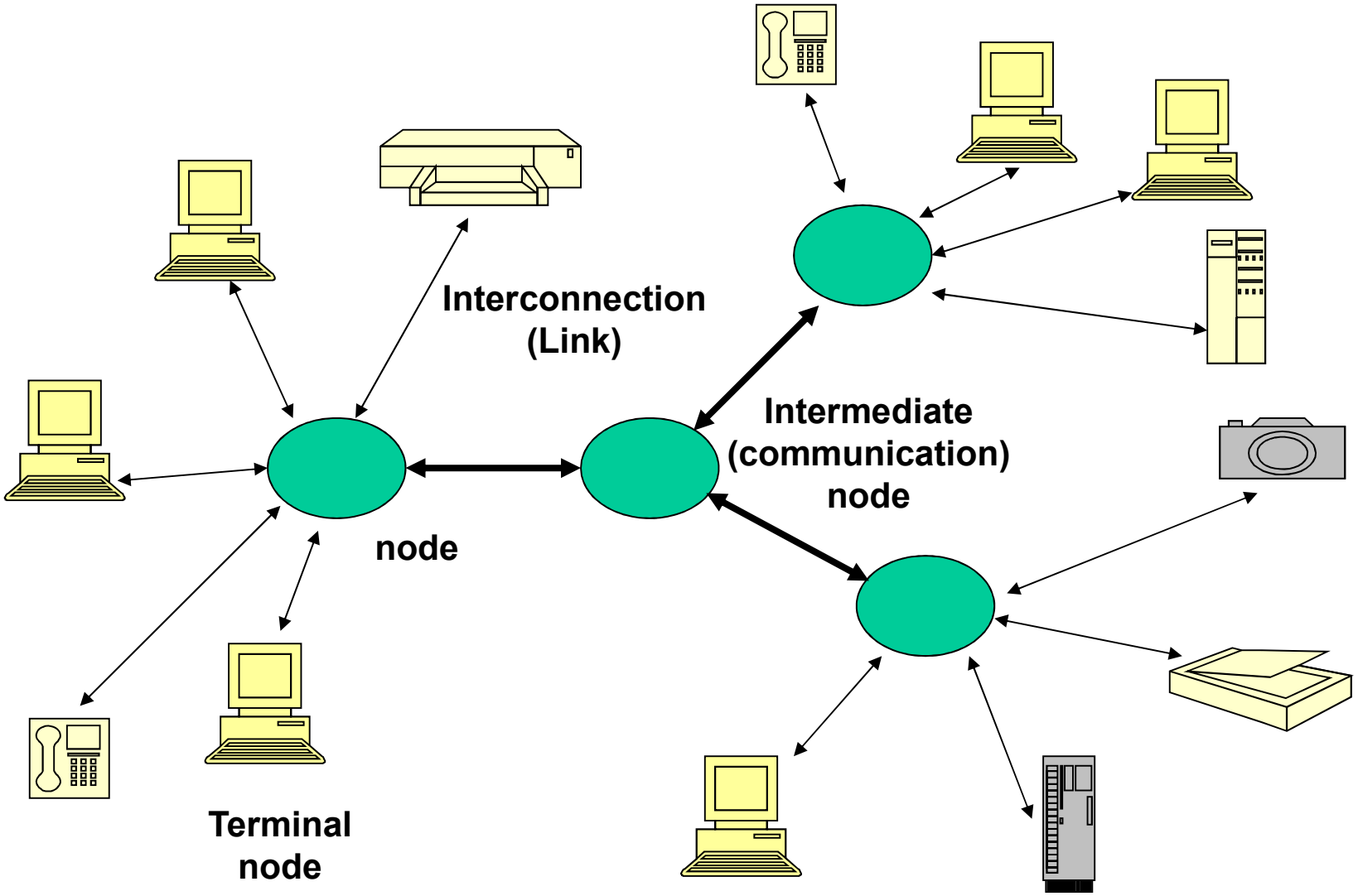
The access network is the part of the network which allows users to access the core network. It consists of a network of terminal nodes and switching nodes. Access network – „edge" of a network.

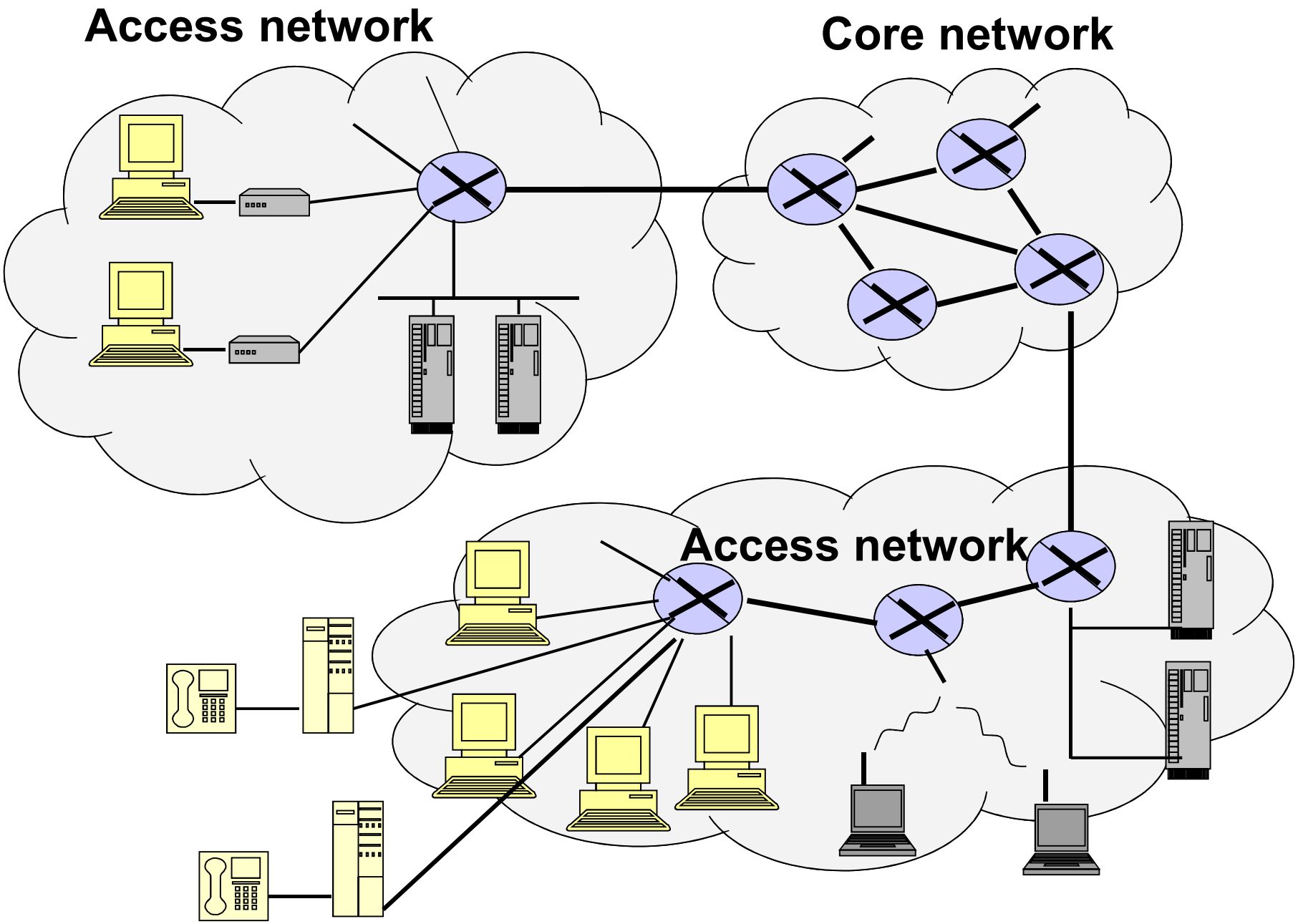
Network Configurations

Single point-to-point link



The communication link can be anything from a simple pair of copper wires, through coaxial cables, radio waves, up to optical fibres.


Interconnection
(Link)
Intermediate
(communication)
node
node
Terminal
node


Access network
Core network
Access network

Network Topologies:

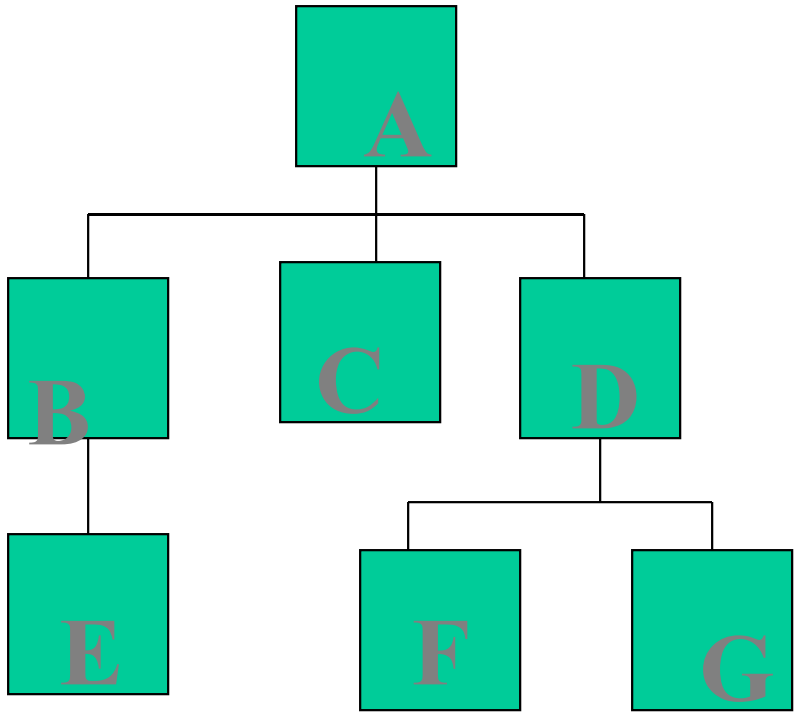
- Provide maximum possible reliability to assure proper receipt of all traffic (alternative routing)
- Route the traffic across the least-cost path within the network between the sending and receiving DTEs
- Give the end user the best possible response time and throughput

The more common network topologies:

- The hierarchical topology (TREE)
- The horizontal topology (BUS)
- The star topology
- The ring topology (HUB)
- The mesh topology

The hierarchical topology (Tree Topology, Vertical Topology)

- Advantages:
  - a simplicity of control
  - a concentration point for error resolution
  - clear lines of authority
  - subordinate DTEs can be added relatively easily

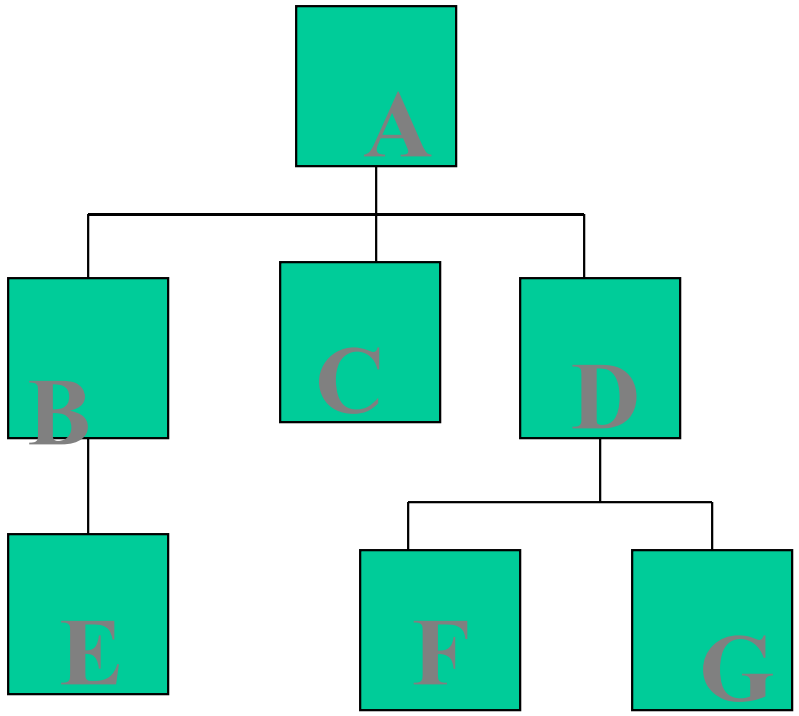


The hierarchical topology (Tree Topology, Vertical Topology)

- Disadvantages:

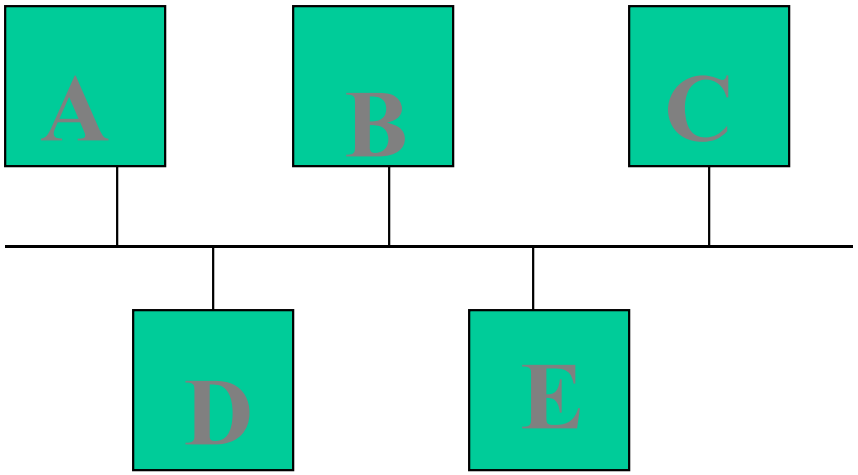
  - A BOTTLENECK!!

  - reliability problems



Horizontal Topology (Bus)

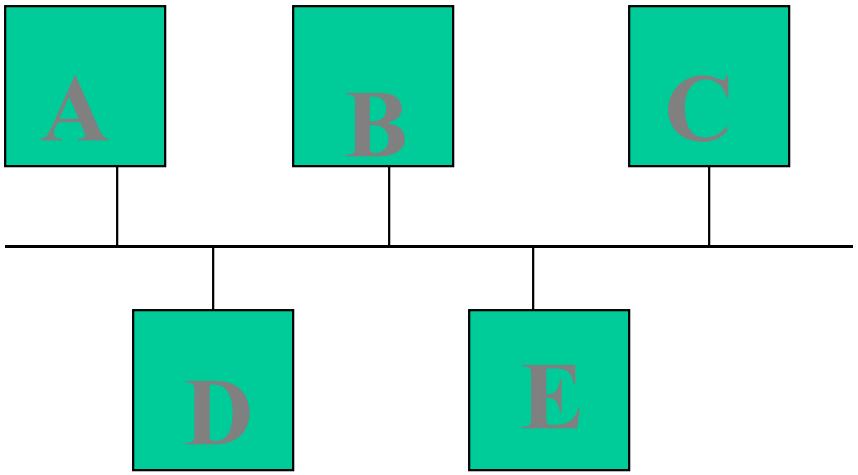
- A single station *broadcasts* to multiple stations. All the stations receive every transmission
- Advantages: relatively simple and cheap



Horizontal Topology (Bus)

- **Disadvantages:**

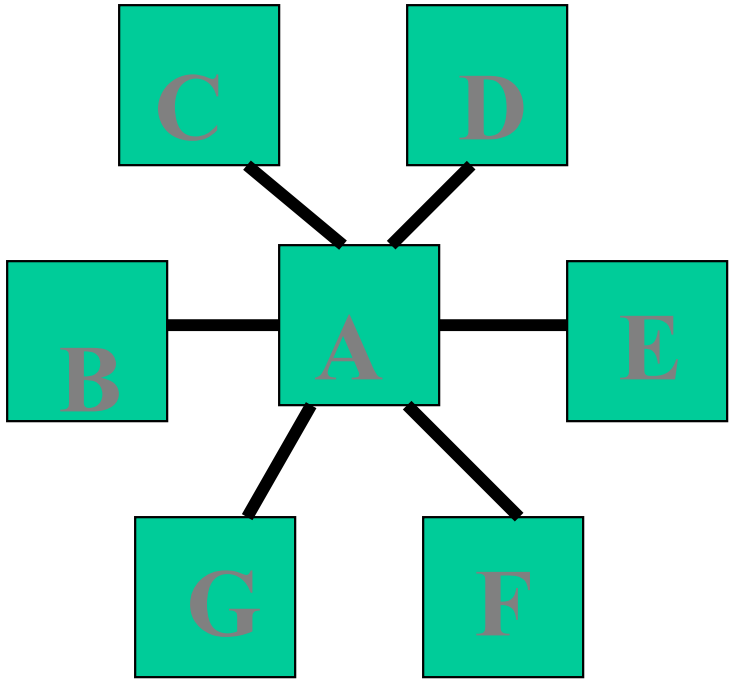
  Only one channel exists to service all the devices on the network – A RISK OF FAILURE!
  Difficulties in isolating faults



- **Remedies: fully redundant channels, bypass switches**

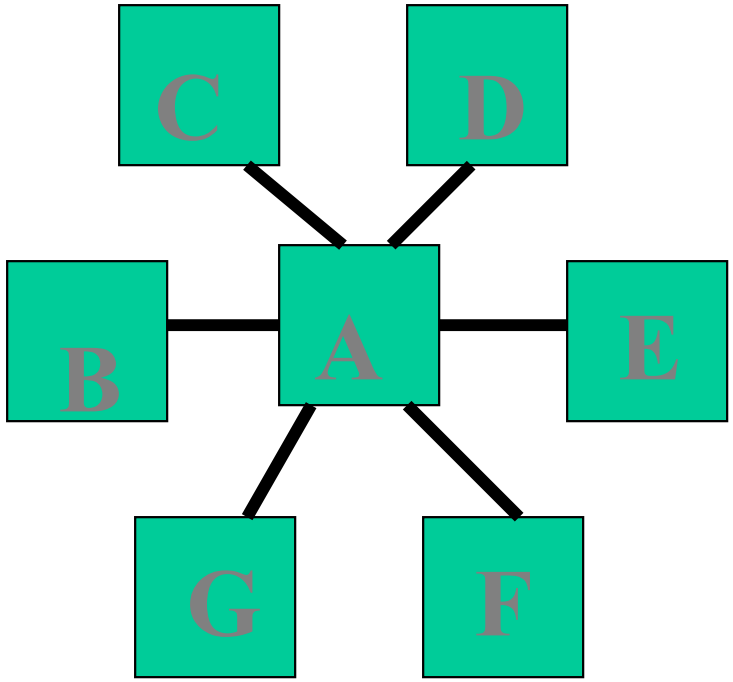
Star Topology

- Historically the first one,
  - easy to control;
  - the software isn't complex,
  - the traffic flow is simple
  - the fault isolation is rather simple



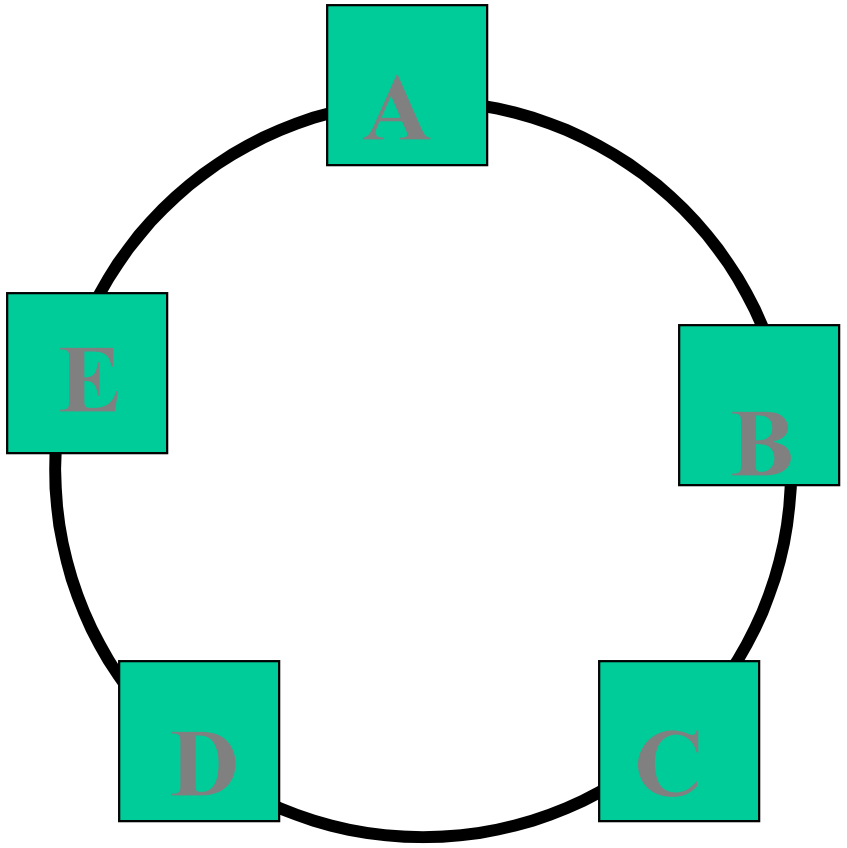
Star Topology

- Disadvantages: Limited distributed processing capabilities, others like the hierarchical topology
- Remedies: fully redundant hub node



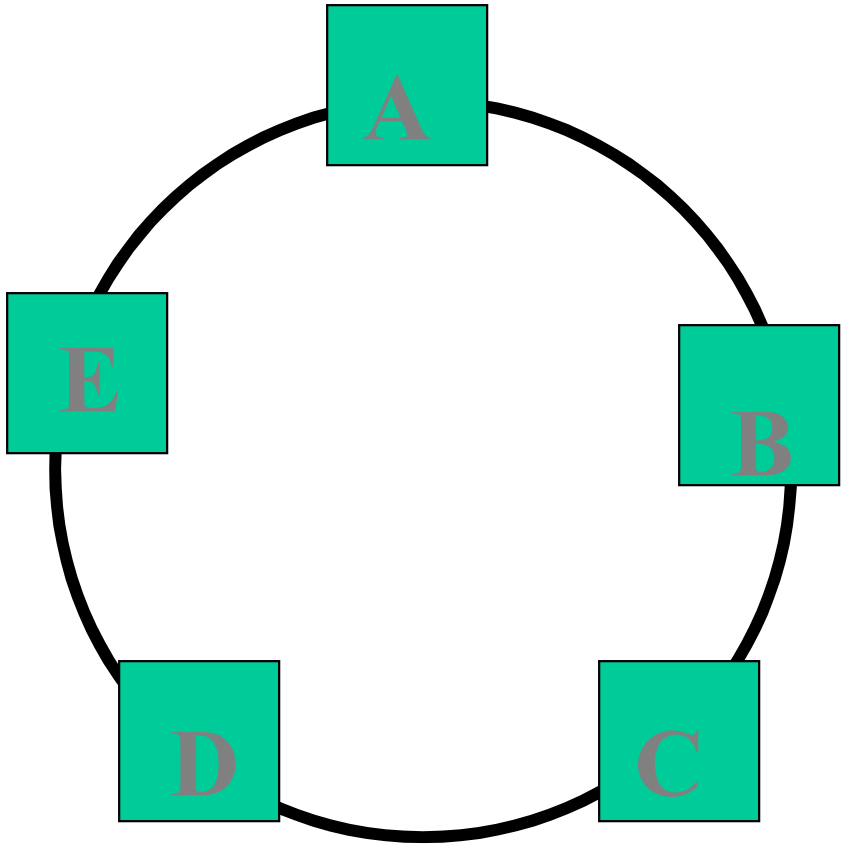
Ring Topology

- Data flow in one direction only, with one single station receiving the signal and relaying it to the next station on the ring.
- No bottlenecks
- The logic is relatively simple



Ring Topology

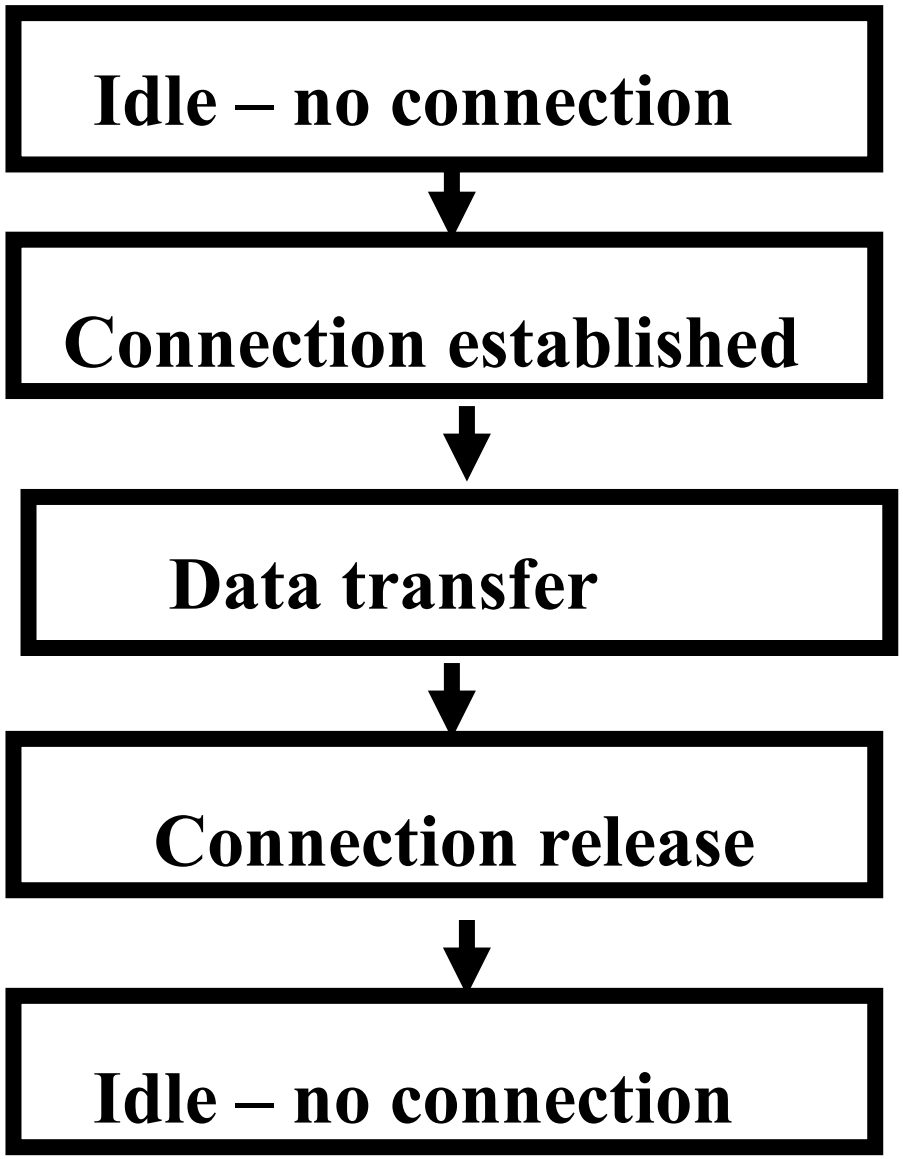
- Disadvantages: One channel ties all the components (one failing part causes the entire net is lost)
- Remedies: switches to route the data around the failed node; the use of dual rings



CONNECTION-ORIENTED & CONNECTIONLESS NETWORKS

- Connection- oriented – no logical connection initially exists between the DTEs and the network (idle state)
  In order to communicate a ‘handshake’ is needed
  The user data are exchanged through a preestablished protocol
  The DTEs perform a connection release – a return to the idle condition

Connection oriented



ACKs

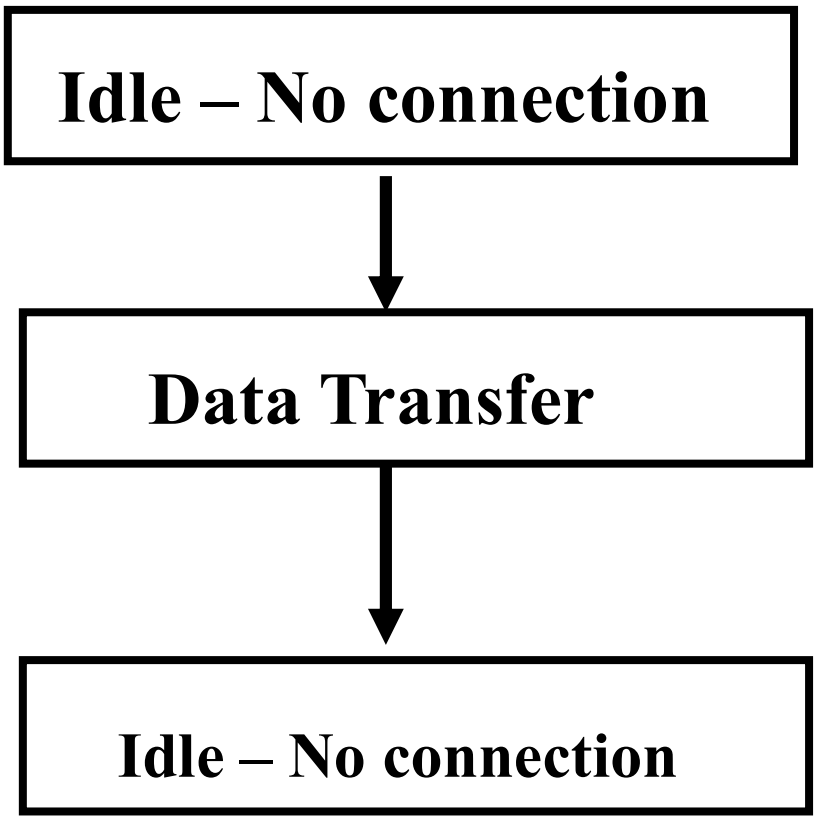
flow control

error recovery

- **Connectionless (datagram)** network
  goes directly from an idle condition into a data-transfer mode, followed directly by the idle condition

- Comparable to mailing a letter (a message is placed into the postal system with the assumption it will arrive at its destination)

Connectionless



No ACKs, no flow control, no error control

But one can push error control up into the application process (or a higher-level protocol)

What should be considered?

General parameters:

1. **Delay – the total delay shoul be as low as possible**

2. **Effectivity – the resources should be used (frequency band, bandwidth) in the higest degree; nothing should be inactive.**

3. **Cost – investment, modernization, maintenance; as low as possible.**

Signals' destiny

The exchange of information requires solving different problems, especilly:

1. teletransmission
2. telecommuting
3. signalling

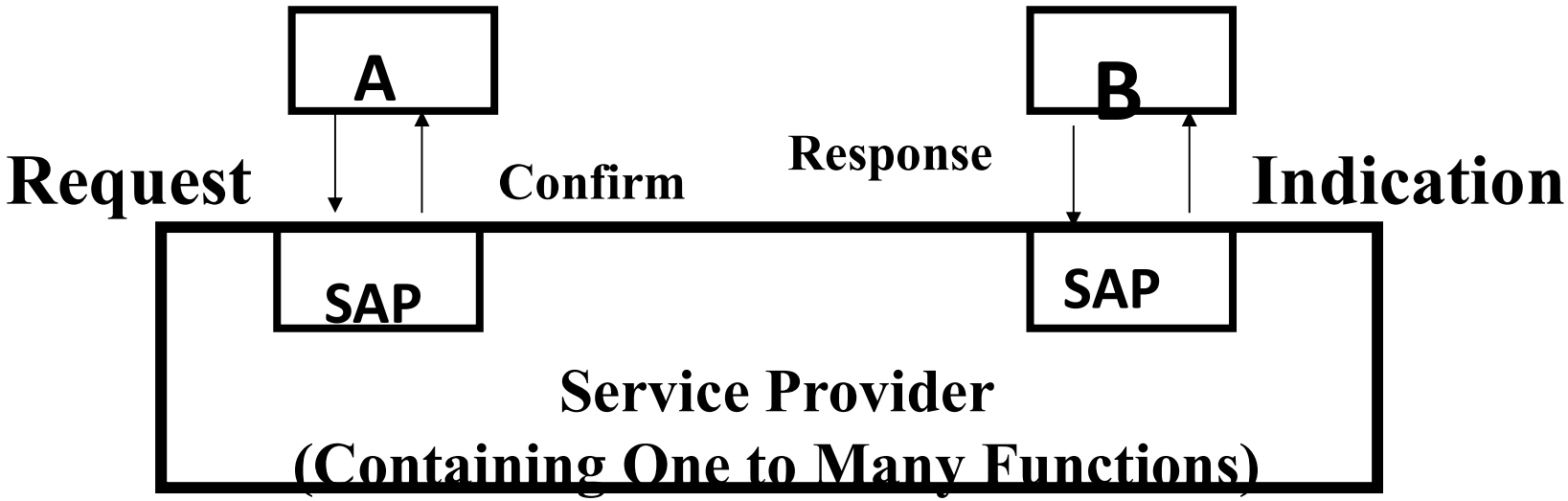
Teletransmission **deals with the transport of information between end points (Edge devices) in the telecommunication system.**

Telecommuting **deals with the structure and functions of switching nodes and solves the problems of establishing and realizing links between node's input and output.**

Signalling **describes rules to exchange control signals among nodes and between nodes and users.**

SAP – Service Access Point

- The identifier interfacing with a layer or a service provider

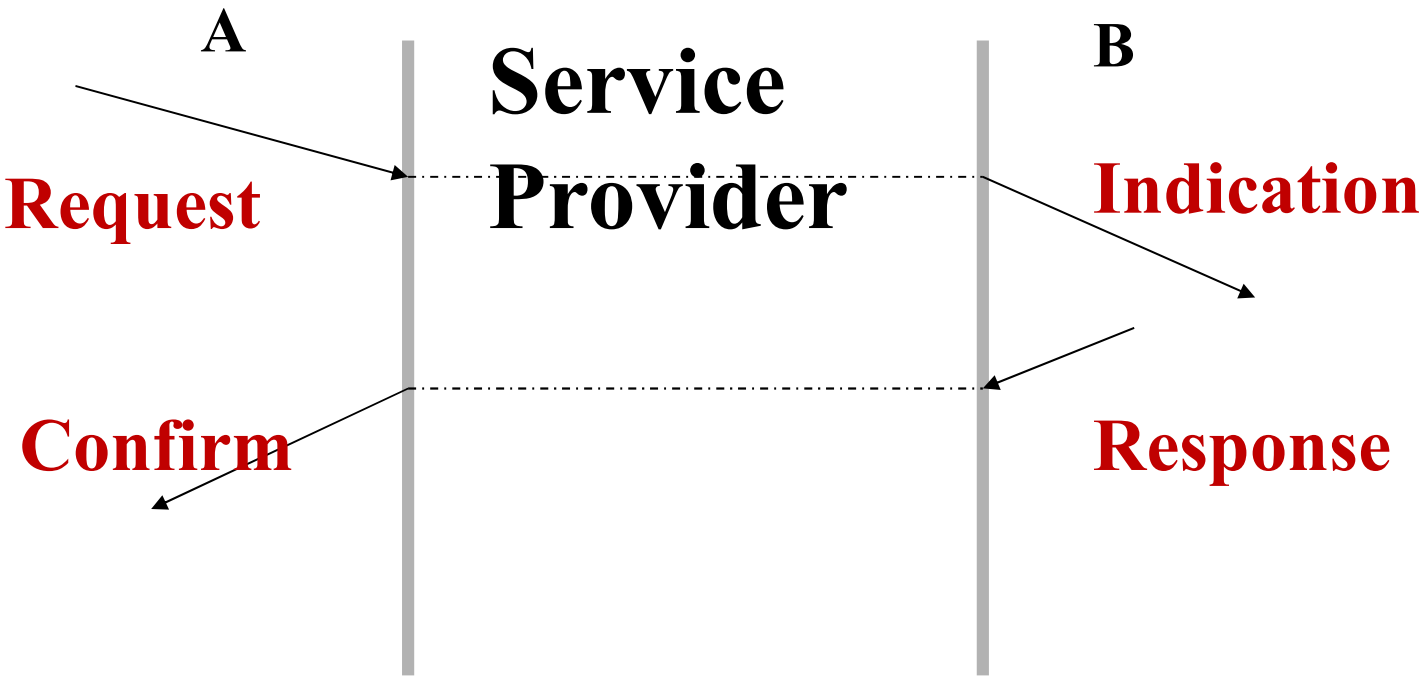


Four transactions, called *primitives* are invoked to and from the layer through SAP

Primitives

- Request – primitive by service user to invoke a function
- Indication – primitive by service provider to
  a) invoke a function or
  b) indicate a function has been invoked at a SAP
- Response - primitive by service user to complete a function previously invoked by an Indication at that SAP
- Confirm - primitive by service provider to complete a function previously invoked by a Request at that SAP

The request is sent to the service provider, which sends user B an indication. User B provides a response, which is transmited through the service provider as a confirm to A.



Layered Protocols are developed to meet the goals:

- Provide a logical decomposition of a complex network into smaller parts (layers)
- Provide for standard interfaces between network functions
- Provide for symmetry in functions performed at each node
- Provide for a means to predict and control any changes made to network logic
- Provide a standard language to clarify communications between and among network designers, managers, vendors, and users

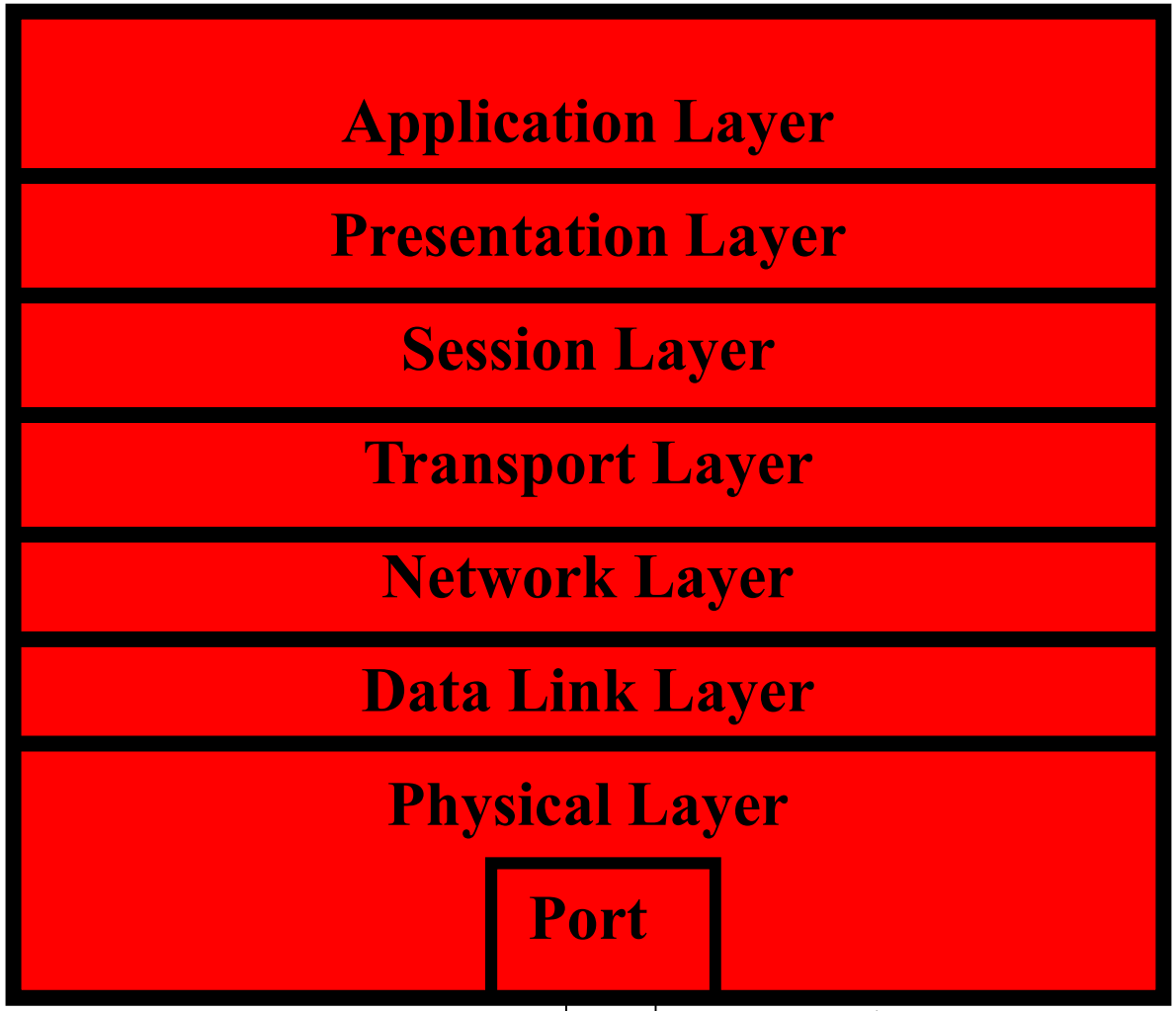
OSI Open Systems Interconnection

- Each layer may represent any vendor's own approach to design, to develop the hardware, and the software for the networks etc…..
- All of them must use common 'railroad gauges' – COMMUNICATION BETWEEN LAYERS

The basic model of OSI – a seven-layer standard – THE GOALS:

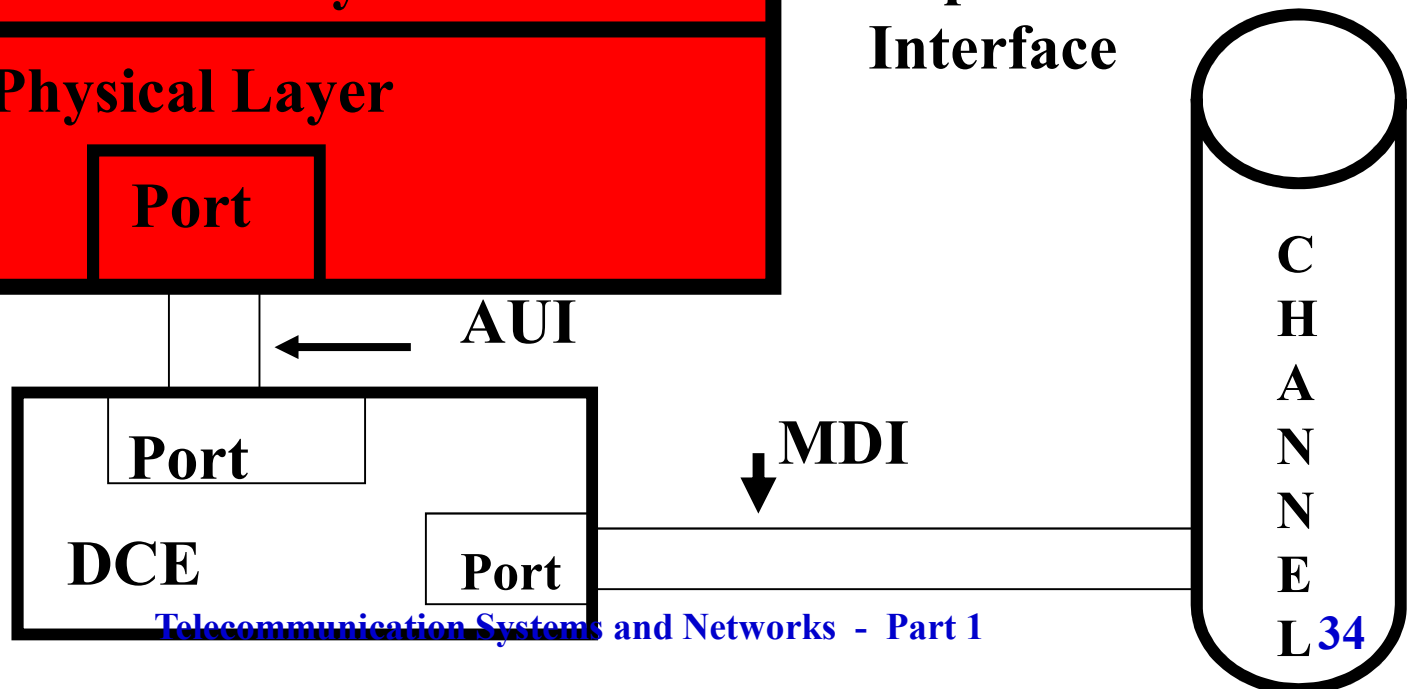
- To provide standards for communications between systems
- To remove any technical impediment to communication between systems
- To remove concern with description of the internal operation of a single system
- To define the points of interconnection for the exchange of information between systems
- To narrow the options in order to increase the ability to communicate without conversions
- To provide a reasonable point of departure from the standards in the event they do not meet all needs

Layers of OSI Network Model



AUI: Attachment Unit Interface

MDI: Medium Dependent Interface



The five-layer TCP/IP model and examples of used protocols

- 5. Application layer (DHCP – *Dynamic Host Configuration Protocol,* DNS – *Domain Name Service,* FTP – *File Transfer Protocol,* TELNET, SSH – *Secure Shell Encryption*…)
- 4. Transport layer (TCP – *Transport Control Protocol,* UDP – *User Datagram Protocol,* IGMP – *Internet Group Management Protocol,* ICMP – *Internet Control Message Protocol (*also v. 6*), …)*
- 3. Network/Internet Layer (IPv4, IPv.6, OSPF – *Open Shortest Path First,* ARP – *Address Resolution Protocol*, …)
- 2. Data link layer (Token Ring, Ethernet, GPRS – *General Packet Radio Service*, …)
- 1. Physical layer (Modems, optical fiber,…)

The physical layer

- Is responsible for activating, maintaining, and deactivating a physical circuit between a DTE and DCE
- There are many standards published for it
- IT COVERS TECHNOLOGIES
- It’s very complex and divided

The data link layer

- It is responsible for the transfer of data over the channel
- It provides for the synchronization of data to limit the flow of bits from the physical layer
- It provides for the identity of the bits
- It ensures that data arrive safely at the receiving DTE
- It provides for flow control and for detection of transmission errors
- It provides mechanisms to recover from lost, duplicated, or erroneous data

The network layer

- Specifies the interface of the user DTE into a packet-switched network, as well as the interface of two DTEs with each other through the packet network
- Specifies network routing and the communications between networks (internetworking)

It is quite detailed and rich in function

The transport layer

- Provides the interface between the data communications network and the upper three layers
- Should give the user options in obtaining certain levels of quality and cost from the network itself
- Keeps the user isolated from some of the physical and functional aspects of the packet network
- Provides for end-to-end accountability

The session layer

- Serves as a user interface into the transport service layer
- Provides for an organized means to exchange data between users

- Has specific services, primitives, and protocol data units

The presentation layer

- Provides for the syntax of data in the model (accepts the data types – character, integer… from the application layer and then negotiates with its peer layer as to the syntax representation: ASCII, teletype, Videotex, …..)
- It consists of many tables of syntax

The application layer

- Supports an end-user application process
- Is concerned with the semantics of data; contains service elements to support for example financial data exchange, programming language send/receives, etc…
- Supports the virtual terminal and virtual file concept

AUI (the attachment unit interface)

Is a cable or a circuit card connecting the DTE to the DCE

MDI (the medium dependent interface)

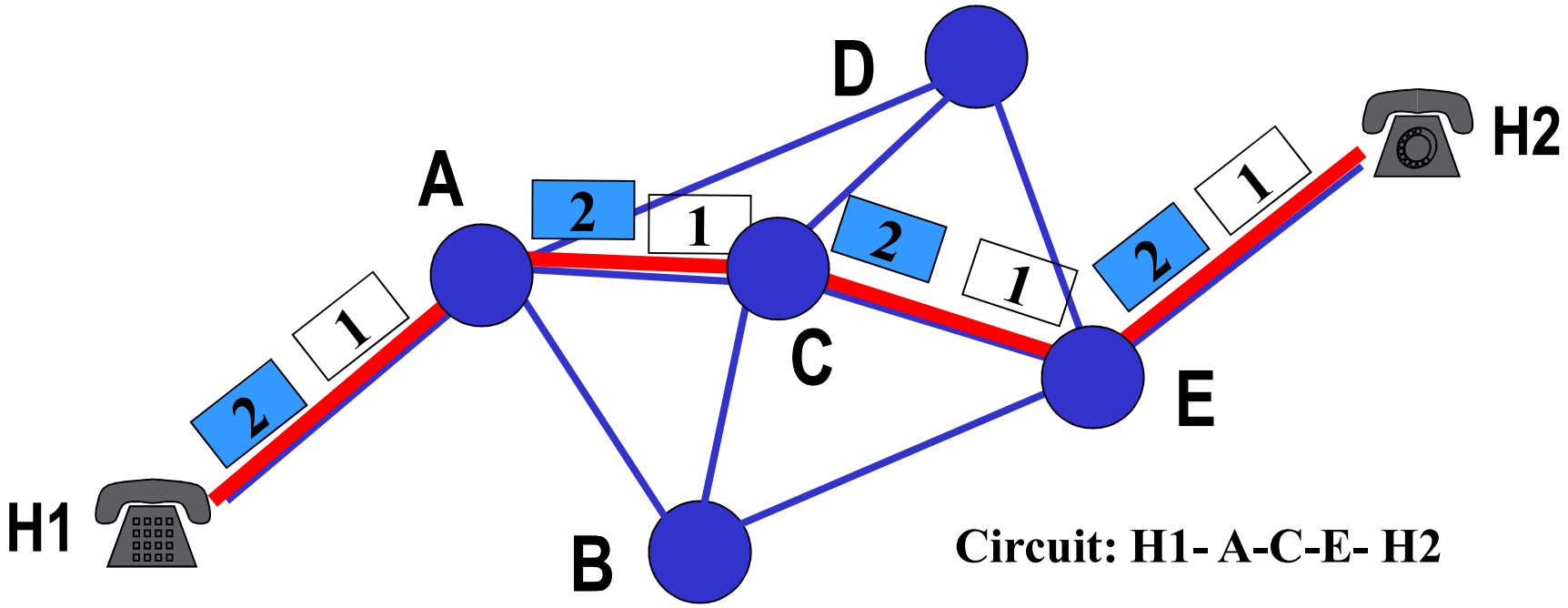
Connects the DCE into the physical channel, which may be a pair of wires, coaxial cable, microwave relay, optical fiber …….

Switching Techniques

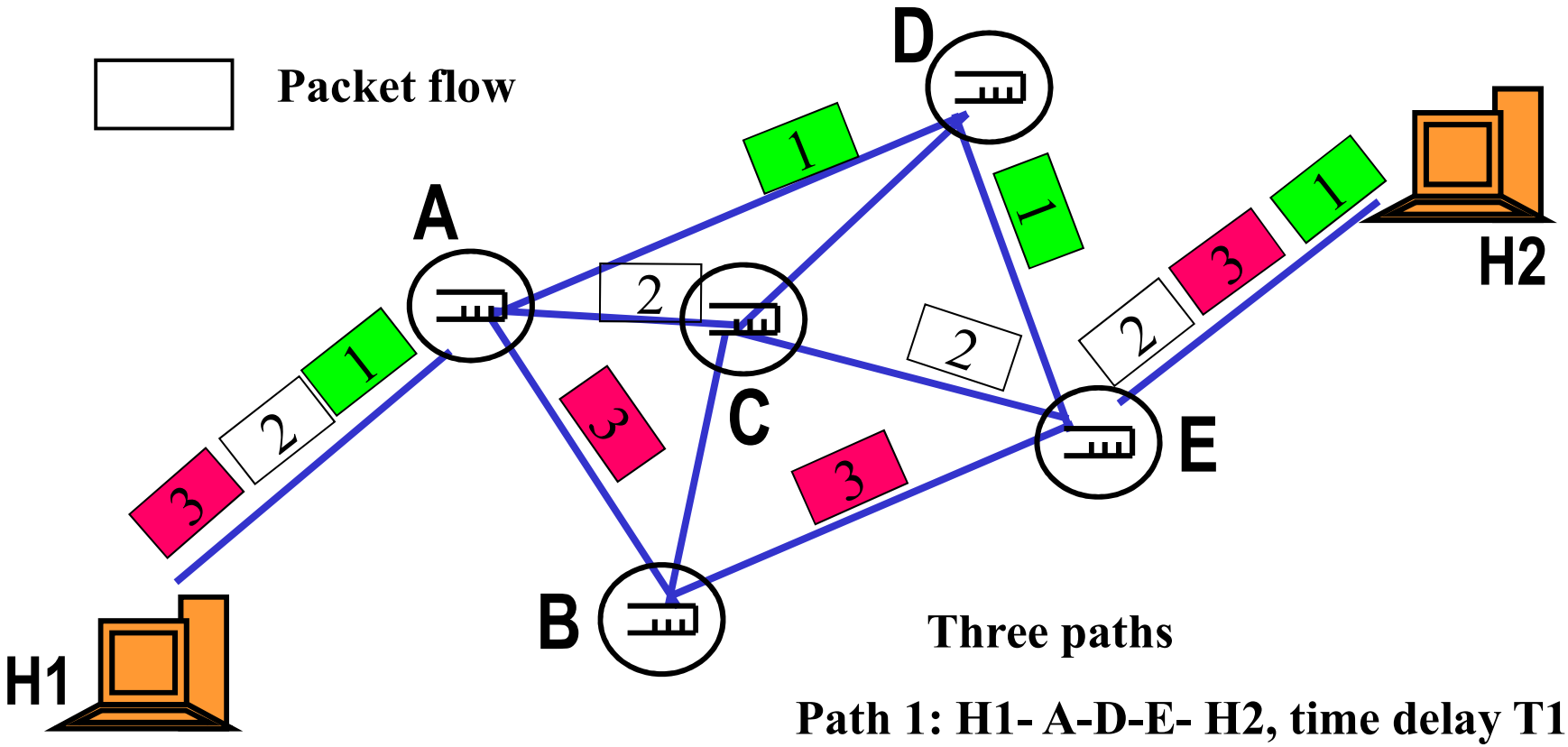
Two possible methods of arranging end-to-end communication through a network:

1. **Connection-oriented**
2. **Connectionless**

Connection-oriented (Circuit Switching)



Connectionless – Packet Switching



Three paths

Path 1: H1- A-D-E- H2, time delay T1

Path 2: H1- A-C-E- H2, time delay T2

Path 3: H1- A-B-E- H2, time delay T3

Signals

Signals carry pieces of info and can be:

- **electrical**
- **electromagnetical**
- **optical**

Signals (analogue) change vs. time and reflect characteristics of information:

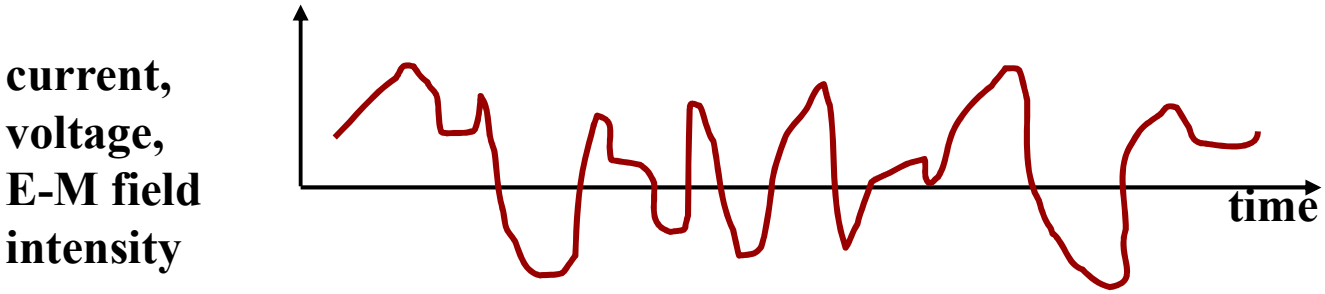
- acoustic pressure (sound, voice)

- brightness and colour (picture, graphics, data)

- measured values (velocity, acceleration, temperature, etc.)

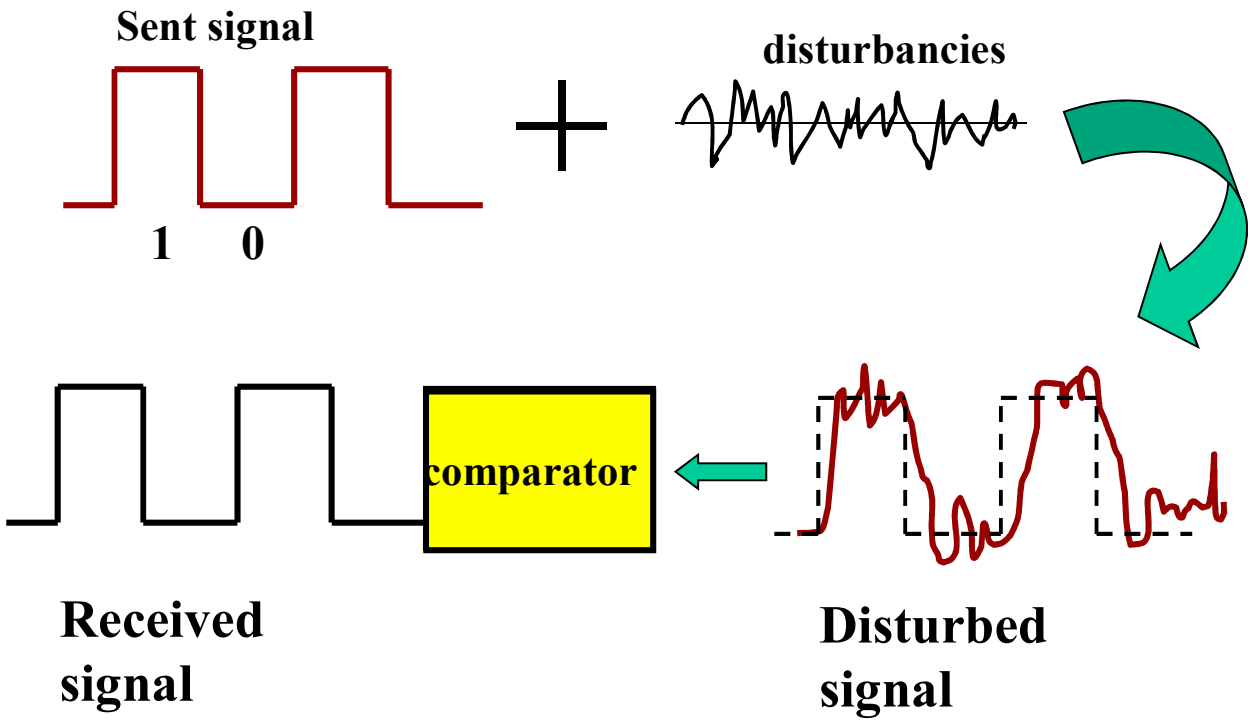
Representation of signals

- Analogue signal



- The analogue signal is extremely limited
- It is very susceptible to any disturbances
- There are difficulties in processing
- It is not accurate; it requires using devices of high standard, so very expensive

Digital signal

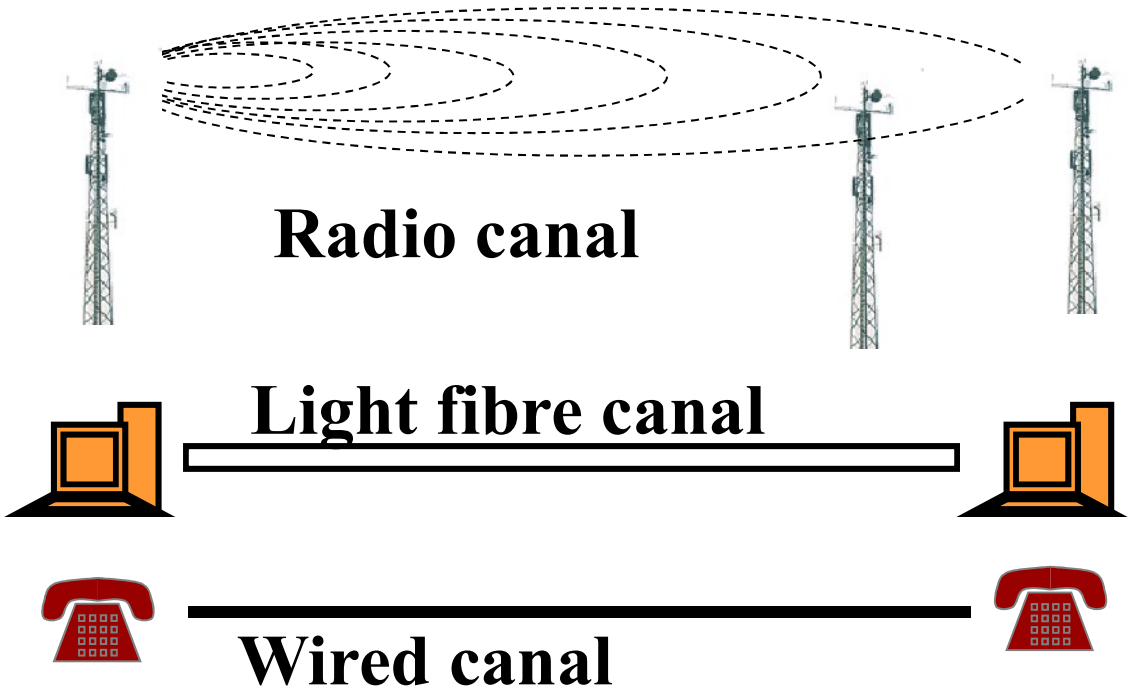


Sampling

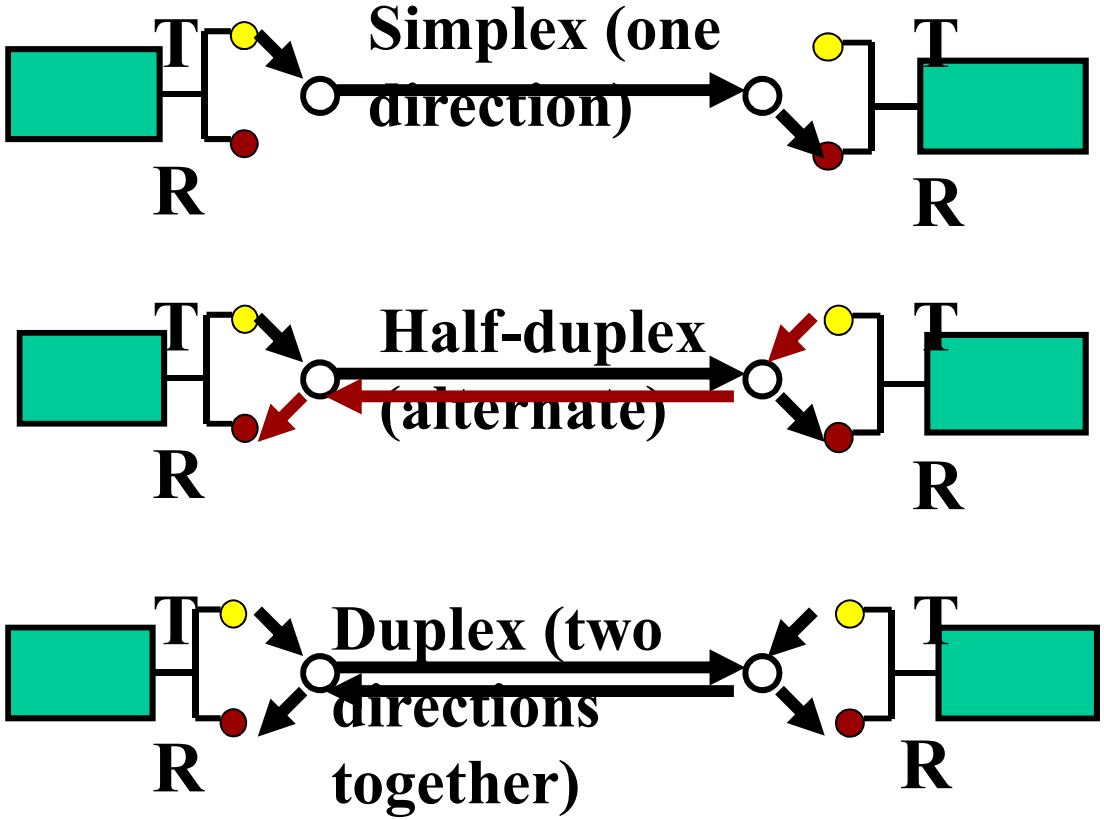
- If an analogue signal is regular sufficiently, one may introduce it as a sum of sinusoidal signals with various frequencies – frequency spectrum
- The analogue to digital signal conversion is possible thanks to so called: sampling rule
- To make the analogue signal be reproduced as Hi-Fi (high fidelity) basing on the samples, THE SAMPLING FREQUENCY MUST BE TWICE THE HIGHEST SPECTRUM FREQUENCY OF THE ANALOGUE SIGNAL

Example: Speech signal of 4 kHz requires 8000 samples per second, and with 8 bits' quantization it gives the digital signal: 8000 samples x 8 = 64 kb per second

Transmission Media

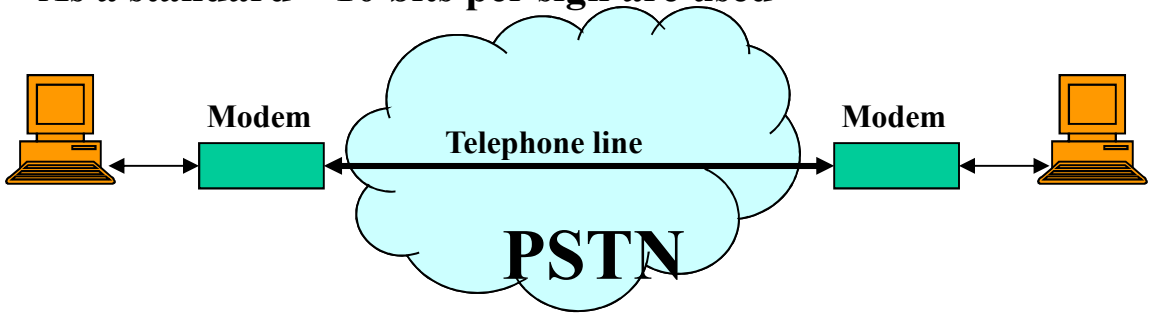


Communication modes – transmission direction



Modem Modulator/Demodulator

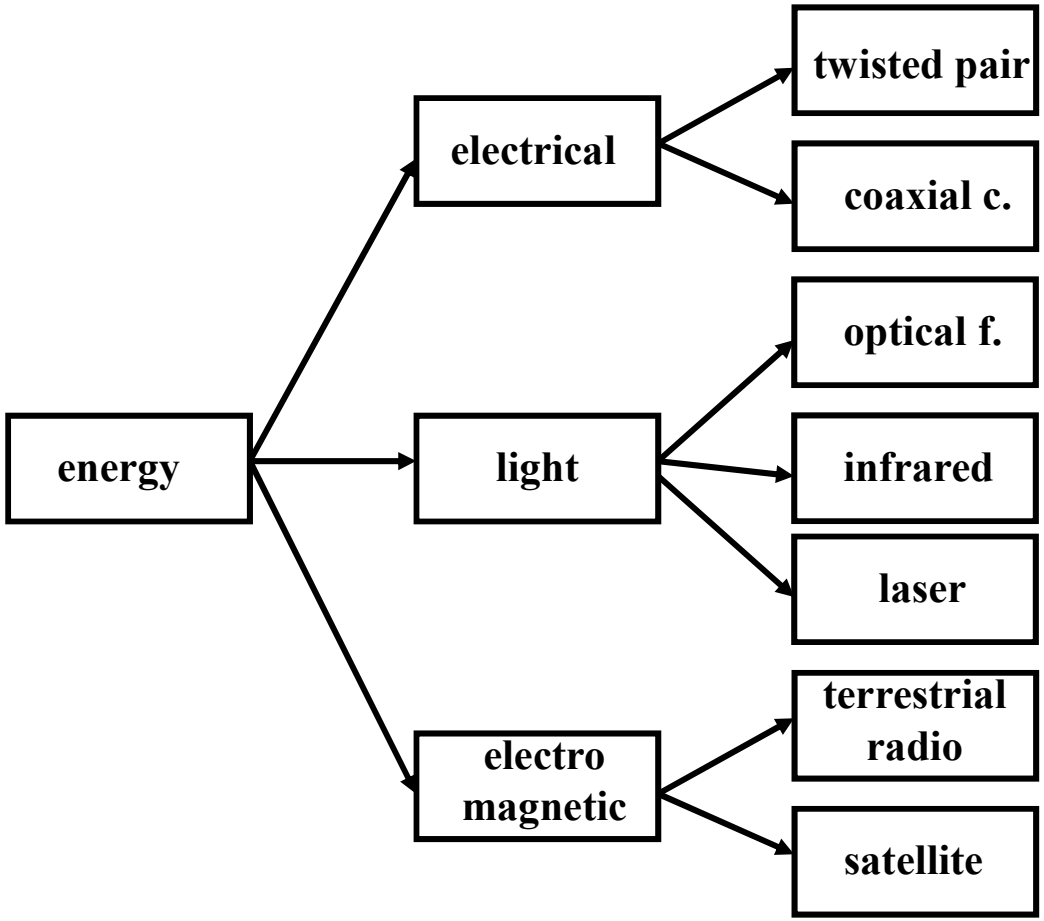
- It is the device to assure the cooperation between a digital terminal (for example a computer) with the conversational phone channel of the typical frequency range 300 Hz – 3.4 kHz
- Modems exchange info with the speed from 300 b/sec. to 33.6 kb/sec.
- As a standard – 10 bits per sign are used



Transmission Media

1. Based on type of path; communication can follow an exact path (e.g. wire), or can have no specific path (radio wave).

2. Based on the form of energy; electrical or electromagnetic.



Transmission

Transmission is the process of transporting information between end points of a system or a network. Four basic media for information transfer can be used:

- **Copper** cables
- **Optical** fiber cables
- **Radio** waves (cellular and satellite transmissions)
- **Free-space optics** (such as infrared remote controllers)

Signalling

It is the mechanism that allows network entities to establish, mantain and terminate sessions in a network.

It is carried out with the help of specific signals or messages that indicate to the other end what is requested of it by this connection.

Some Definitions

- Digital technique – uses discrete signals
- Discretisation in time – sampling
- Discretisation of signal values – quantisation and coding of the obtained discrete signal
- Discrete bivalent signal (‘1’ or ‘0’) – digital signal, numerical signal, binary signal, logical signal

… Definitions …

- Maximum frequency: the highest allowable frequency of input signal changes at which the system works correctly
- Margin of interferences (*noise margin*): such a value of interfering signal that added to the input signal value will not cause any change in the logical value of the signal, still
- Power of losses *(rated dissipation*)*:* the difference between the applied power and the power output; ***it can be heat emmission in devices***

Power Ratios

- The earliest measurement used to categorize the quality of transmission on a circuit (to define the gain or loss in power) was the bel (B):

$$1\,B = \log_{10}\left(\frac{P_0}{P_1}\right) \qquad \log_{10}\left(\frac{10}{100}\right) = -\log_{10} 10 = -1B$$

$$1dB = 10\log_{10}\left(\frac{P_0}{P_1}\right) \qquad 0\ dB\ is\ when\ P_0 = P_1$$

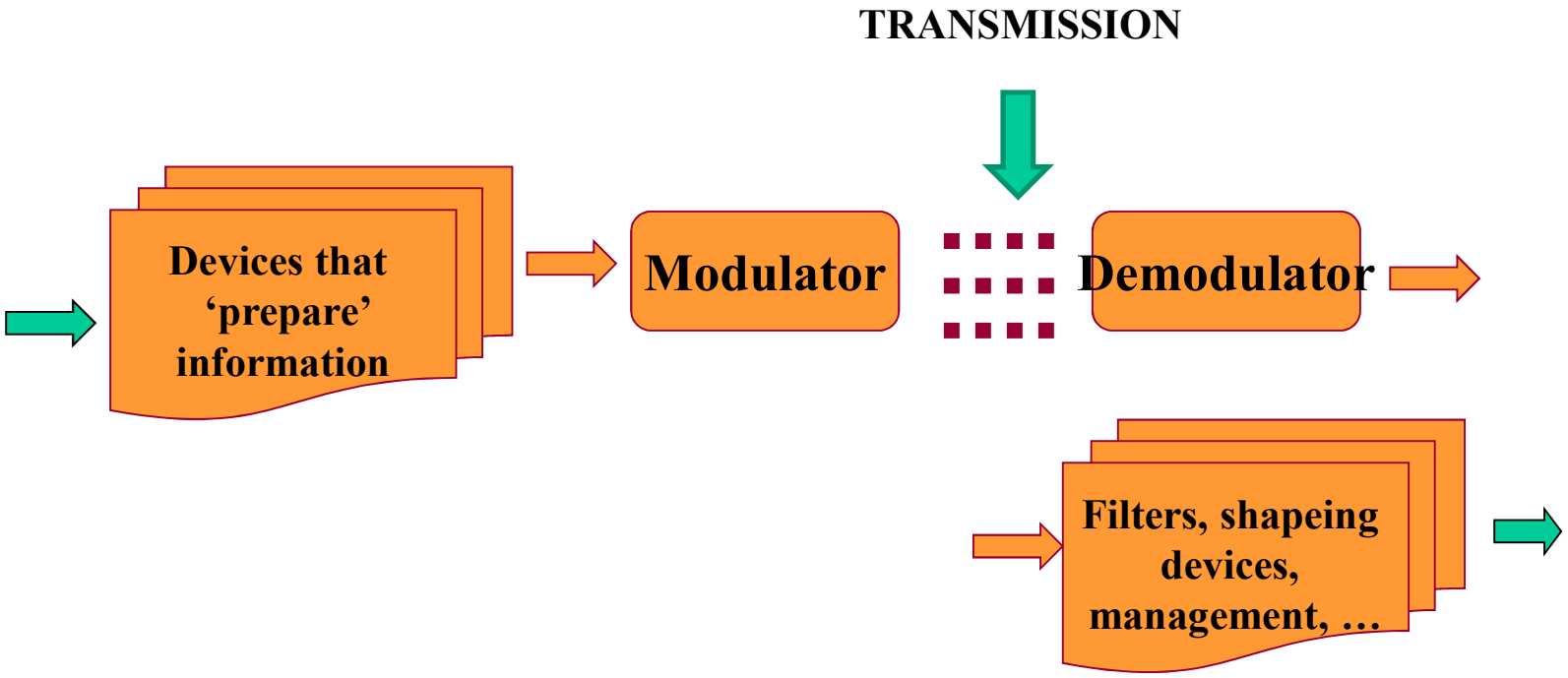
Physical Limits

- SHIFT IN PHASE: As a signal propagates down a transmission medium, its phase can become distorted with respect to its frequency
- NOISE: Two types of noise affect the ability to recognize the signal – impulse noise and thermal noise
- FREQUENCY SHIFT (or PHASE JITTER): A short deviation in or a displacement of the pulses in a high-frequency signal; also known as the difference of delays

Modulation

- Amplitude (AM)
- Frequency (FM)
- Phase (PM)
- MODEM = MODulator + DEModulator

Channel


TRANSMISSION
Devices that 'prepare' information
Modulator
Demodulator
Filters, shapeing devices, management, …

Some definitions

- AMPLITUDE – a measurement in relation to its voltage which can be zero, a plus or minus value
- CYCLE – the complete oscillation
- FREQUENCY [*in Hertz*] – the number of oscillations per second
- Band – the rate of signal changes in the channel for example: 1800 Hz signal can be changed 1200 times per second – then ‘1800 Hz’ describes the carrier and ‘1200’ the band

The signals use subchannels

- Several transmissions at different frequencies occupy the same physical medium
- The communications channel is described by its capacity in the number of bits per second transmitted

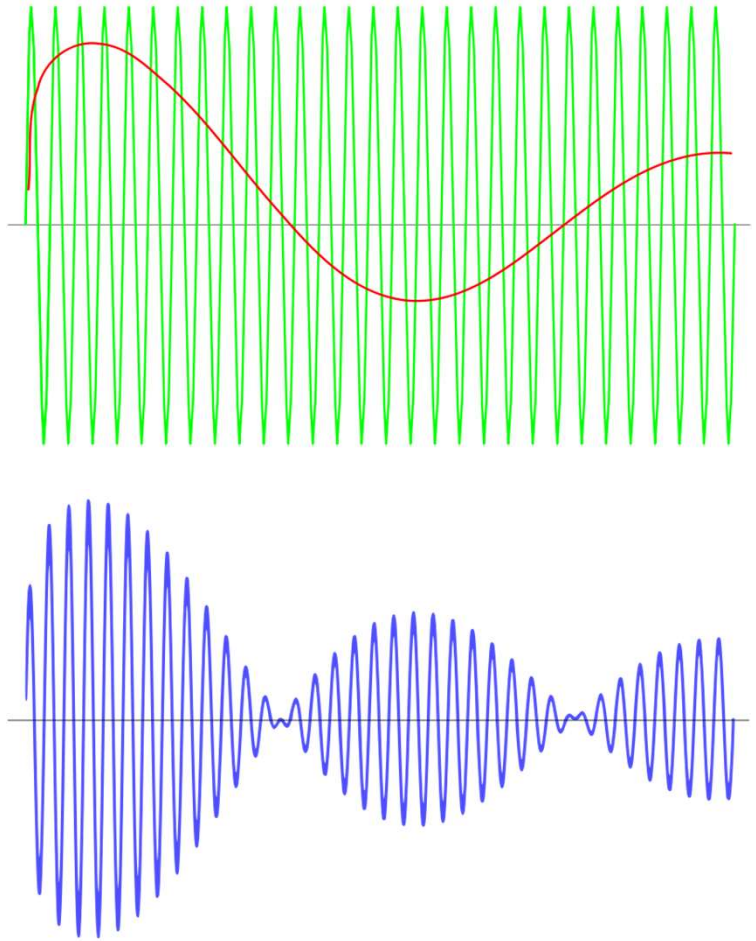
Bandwidth and Frequency Spectrum

- A telephone channel in Europe occupies a band from 300Hz to 3400Hz (in North America: 300-3300Hz)

- For example: the bandwidth between the frequency spectrum $10^3 – 10^4$ is 9000Hz, but $10^4 – 10^5$ is 90000 so is equivalent to more channels by 3100Hz

Amplitude Modulation

- Information (wideband and low frequency) signal is coded as temporary carrier amplitude changes (in carrier wave). The obtained signal is a narrowband type.



Amplitude Modulation

- If a carrier wave is defined as:

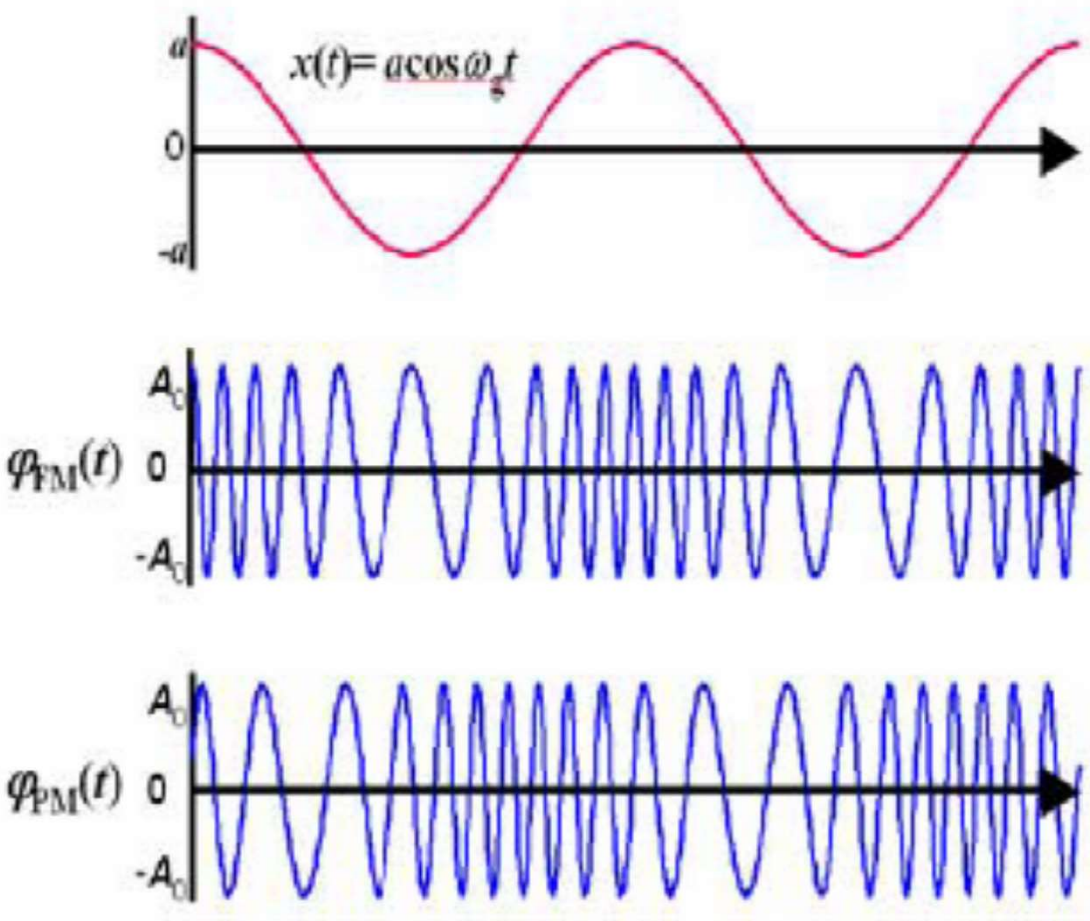
  $x(t) = A_x \cos(2\pi f_x t)$

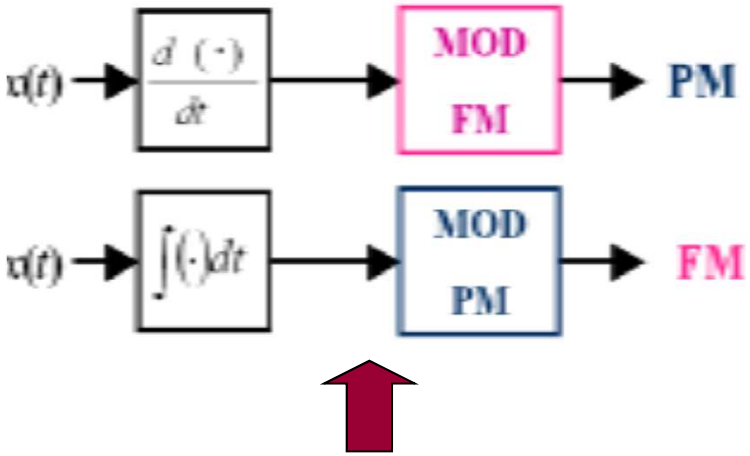
- Then AM wave for the modulating signal m(t):

  $s(t) = A_x[1+k_a m(t)]\cos(2\pi f_x t)$

  where k_a – is a amplitude modulator sensitivity

Frequency and Phase Modulation





One type modulation causes the second one

Digital Modulation

- The process of binary course changes into an analogue, electrical one, convenient to be sent in the transmission channel; the demodulation is made in the receiver

Types of Pulse Modulation

- PCM – pulse-code modulation,
- PWM – pulse-width modulation,
- PAM – pulse-amplitude modulation,
- PPM – pulse-position modulation,
- PDM – pulse-density modulation.

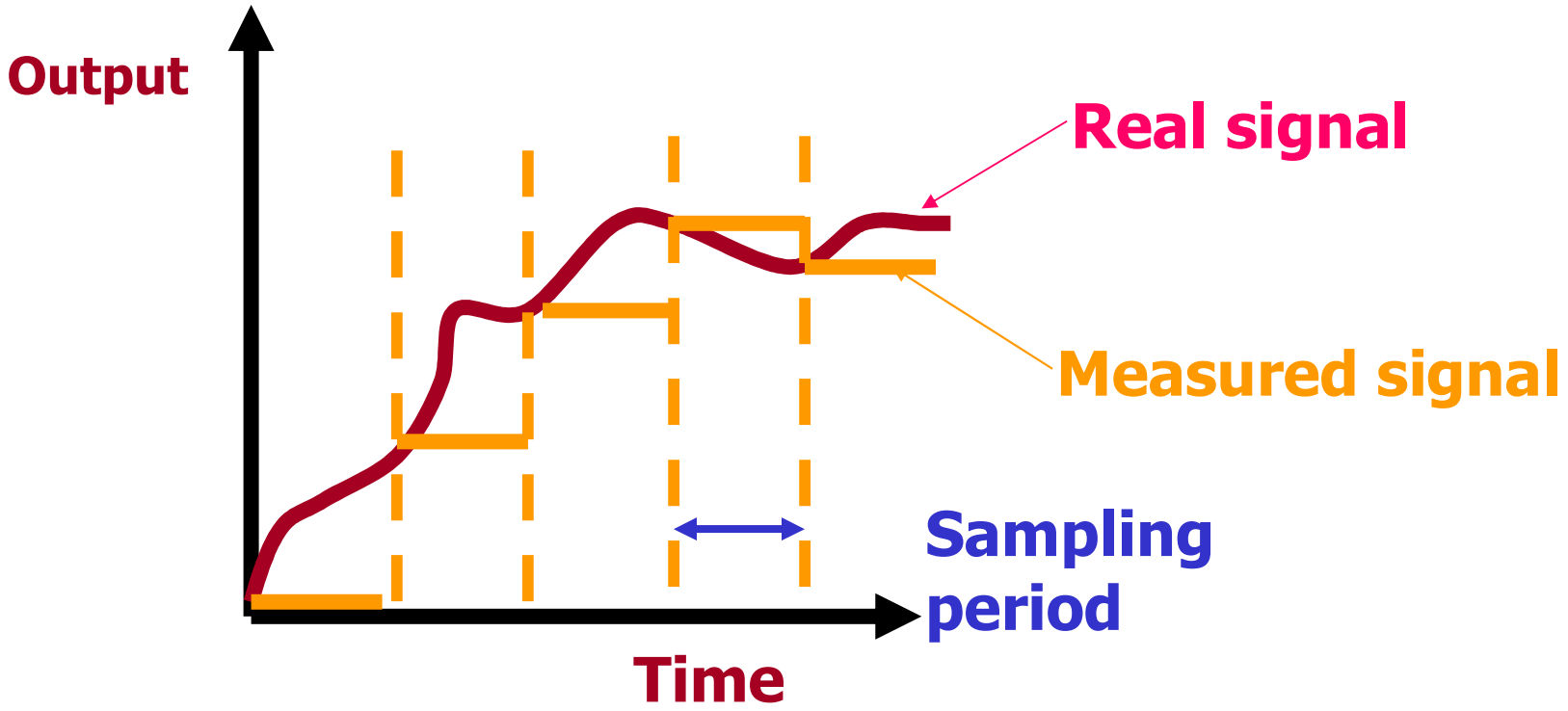
Quality of Data Transmission

- **SNR**: Signal to Noise Ratio (or S/N) – power of signal to power of noise ratio

- **BER**: Bit Error Rate – number of bits sent with errors to the total

Discretisation in time – sampling

Discretisation of signal value – quantisation and coding

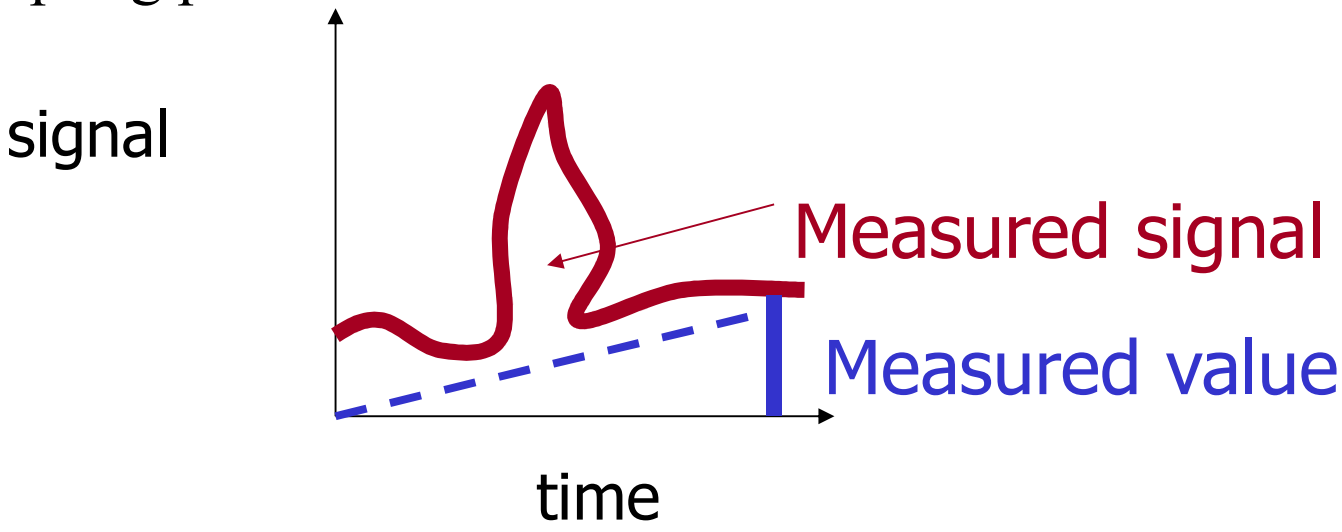


Discretisation

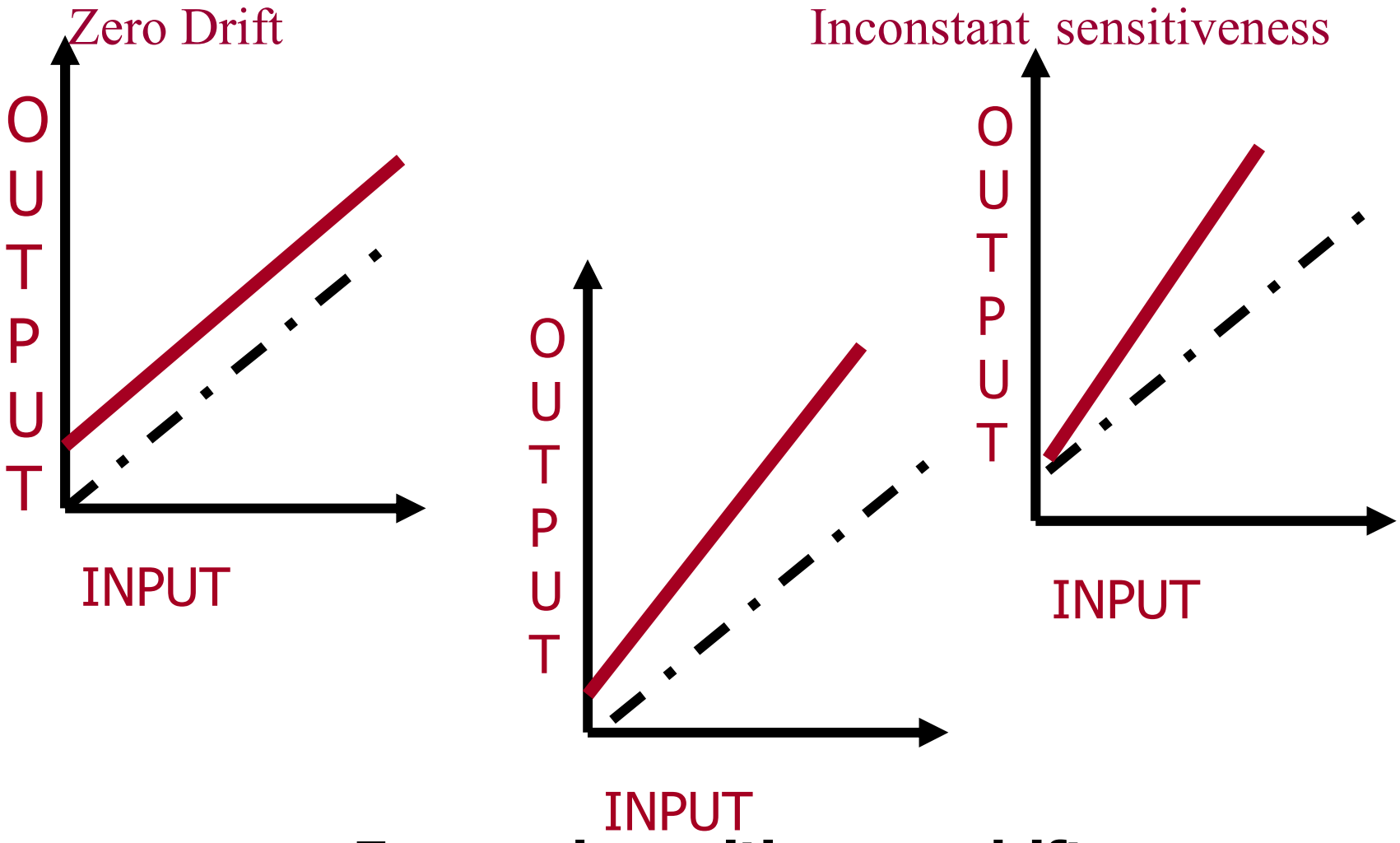
- Discretisation of a continuous signal is connected with a loss of some information.
- The continuos signal may be recovered form a discrete one, only if it was sampled with a minimum frequency twice the limit frequency of its changes.
- This is **Nyquist frequency.**

Conclusions

- Sampling must be performed with a higher frequency than the signal changes (**twice**…)
- The single measurement must not be longer thab the sampling period

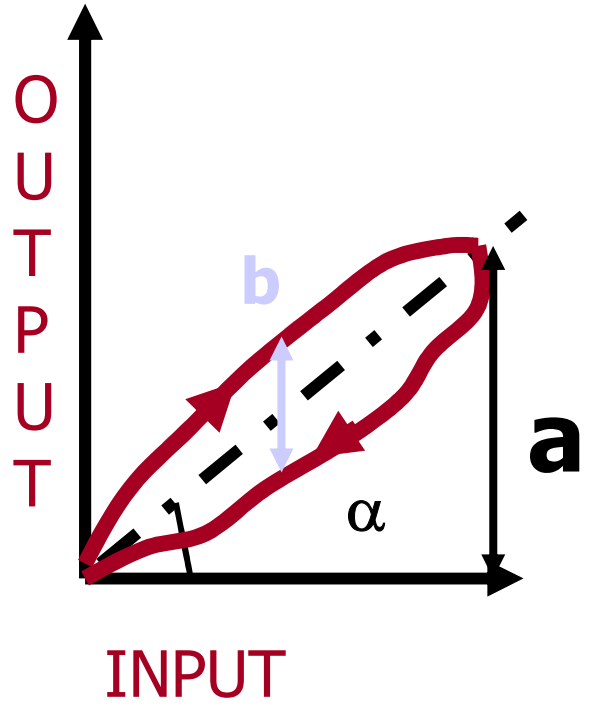


Transducer errors



Zero and sensitiveness drift

Nonlinearity

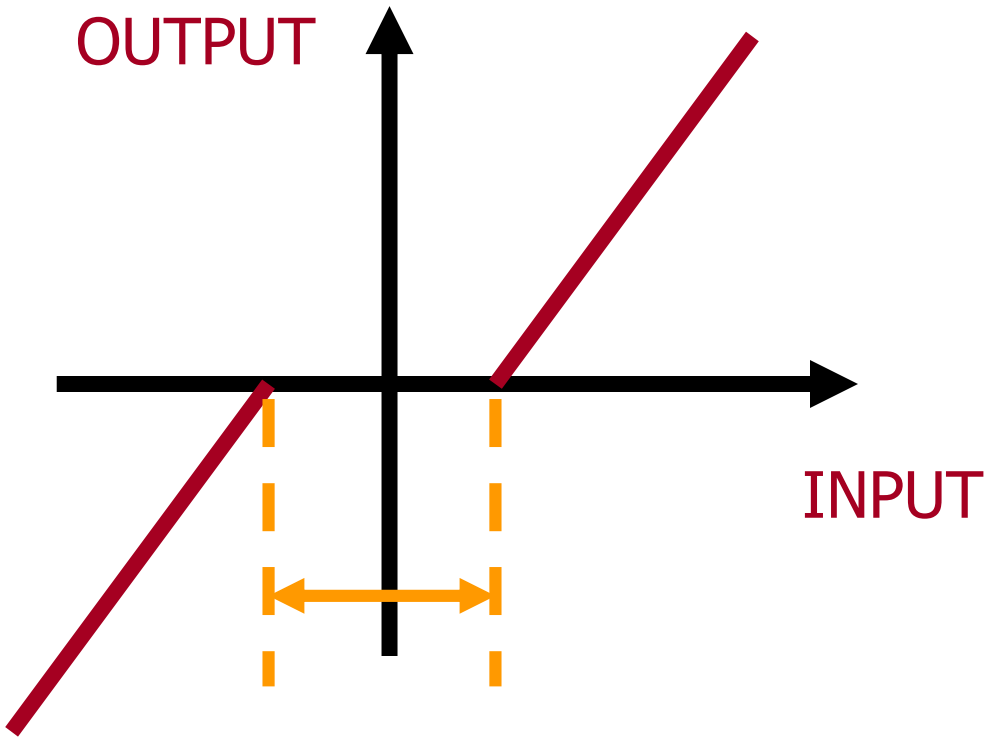


a – measuring range

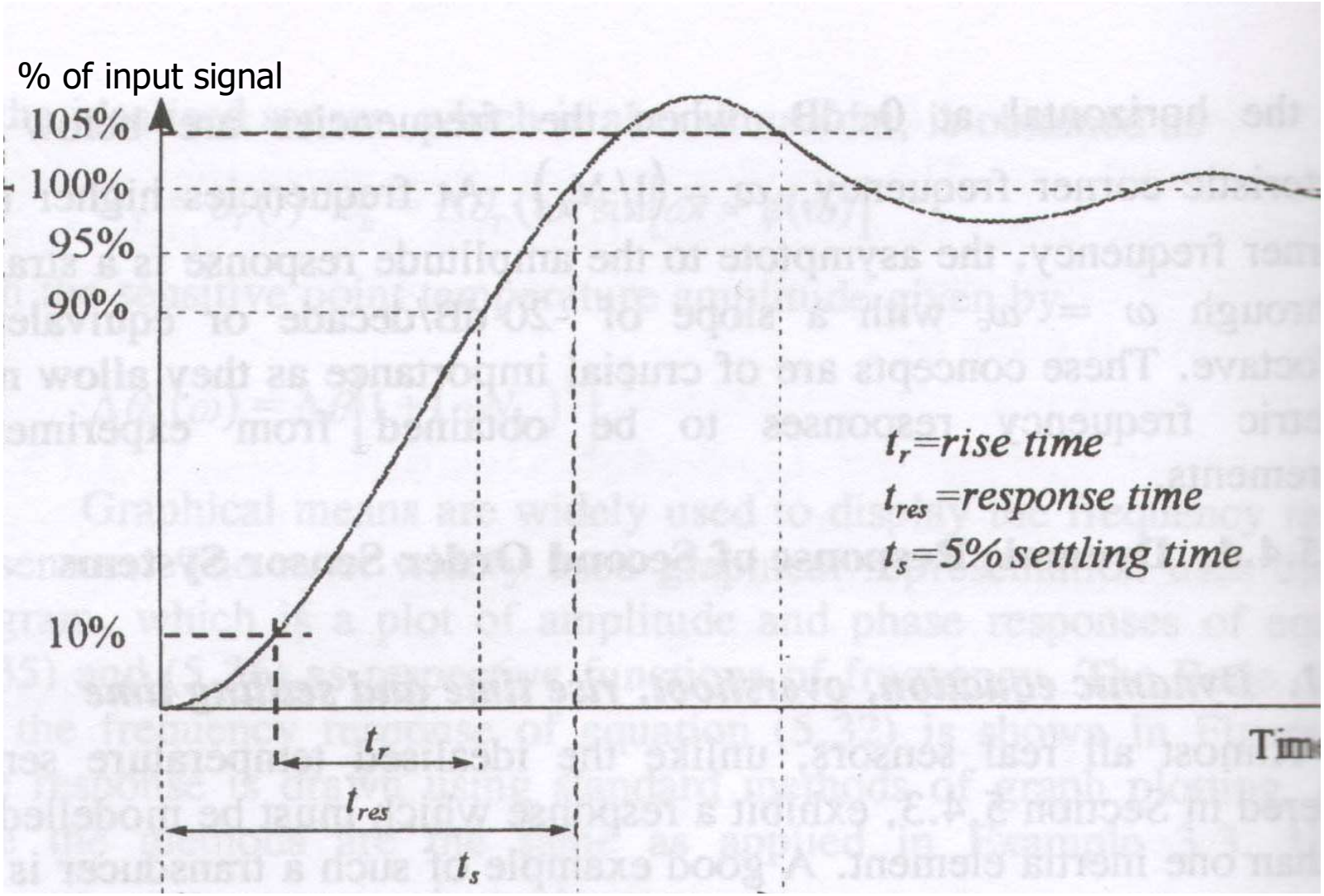
B – linearity deviation

Nonlinearity [%] = 100·b/a

Insensitivitness threshold– Measurement Dead Zone



Inertion of Measurement at Measured Signal Stroke

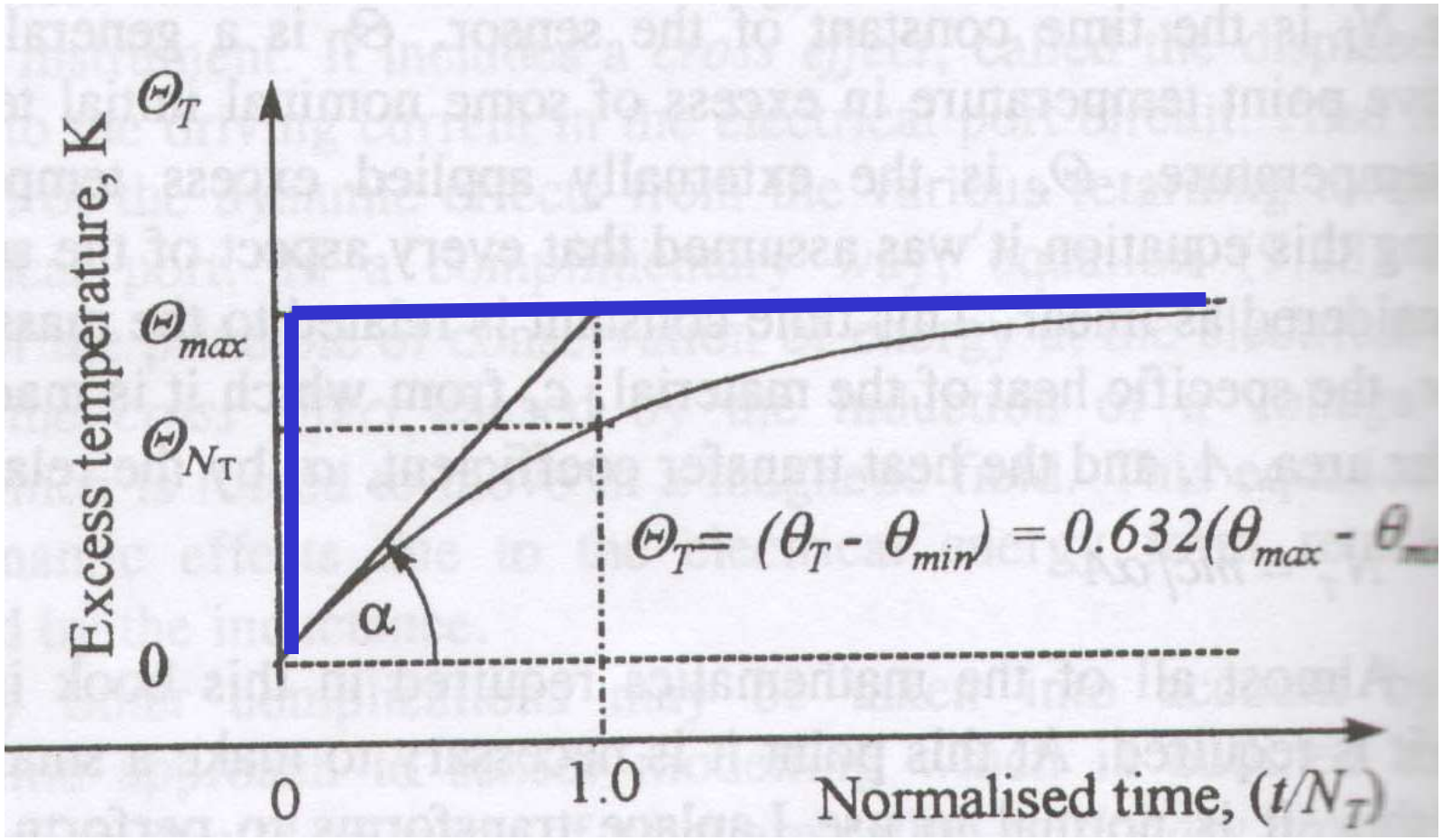


- **Rise time**– t_r – between 10% and 90% of rising output value that is measured

- **Response time**– t_{res} – needed till the moment when the measurement value reaches 100% output value that is measured , the first time

- **Settling time**– t_s – till the moment when the measured value is no more higher than 105% output value that is measured

Time constant and dynamical error



Parameters to describe signal properties

- Current, voltage, power
- Electrical field intensity, magnetic field intensity
- Frequency
- **Bandwidth** – the difference between upper and lower frequencies
- Output to input power ratio is defined in decibels

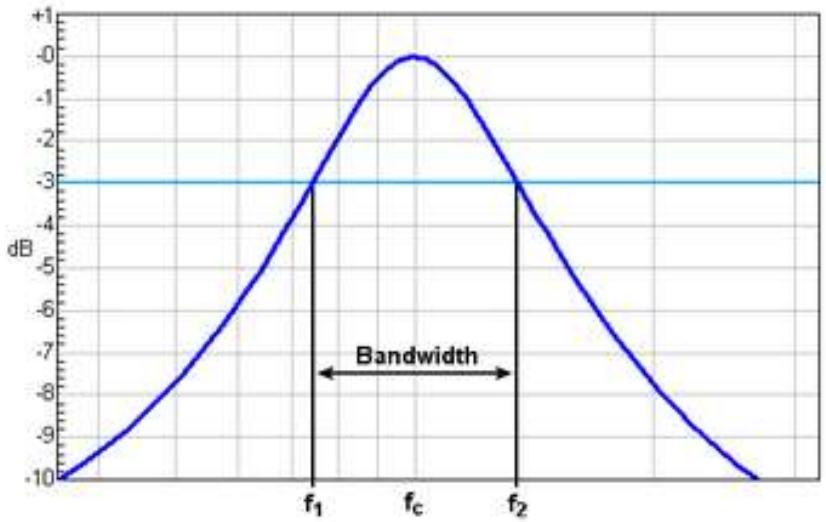
- Power ratio [dB] =10 log (Po/Pi)
  Attenuation or loss of 3 dB decreases power TO HALF (50%) and corresponds voltage drop from 1 to 0.707

Broadband

- **Broadband**(also: *bandwidth*) – frequency range, where signal attenuation is not higher than

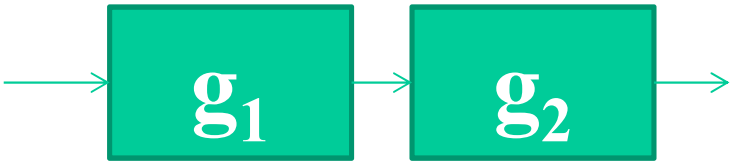
  3 dB

Bell shape



Gain, Loss and Decibels

Gain	Gain in dB
$g = P_{out}/P_{in}$	$g_{dB} = 10 \log 10(P_{out}/P_{in})$
Loss	Loss in dB
$L = P_{in}/P_{out}$	$L_{dB} = 10 \log 10(P_{in}/P_{out})$



Overall gain	$g = g_1 * g_2$
Overall gain in dB	$g_{dB} = g_{1.dB} + g_{2,dB}$

For example: a gain of 100000000 corresponds to the gain of 80 dB

$$g_{dB} = 10\log_{10}\left(\frac{P_{out}}{P_{in}}\right) = 20\log_{10}\left(\frac{V_{out}}{V_{in}}\right) + 10\log_{10}\left(\frac{Z_{out}}{Z_{in}}\right)$$

The level of absolute power can be expressed in dBm where the actual power is compared to 1 mW power,

Then: $P_{out,dBm} = g_{dB} + P_{in,dBm}$

Problem

- The input power of a 4.0 km cable system is 2W. An amplifier with a 64 dB gain is installed 2.4 km from the input. The attenuation of the cable is 2.5 dB/km

- Define the signal power level, dBm and absolute power at
  - the input of the amplifier
  - the output of the system

Communication Requirements of Different Applications

Transmission Characteristics	Voice	Video	File Transfer	Interactive Media
Bandwidth	Low, fixed	Very high, fixed	High, variable	High, variable
Data loss	Tolerant	Tolerant	Nontolerant	Tolerant or nontolerant
Fixed delay	Low	Tolerant	Tolerant	Low
Jitter	No	No	Tolerant	No
Peak information rate	Fixed	Fixed	High	Very high

Telecommunication Systems and Networks

PART1 – END