

Computer Networks I

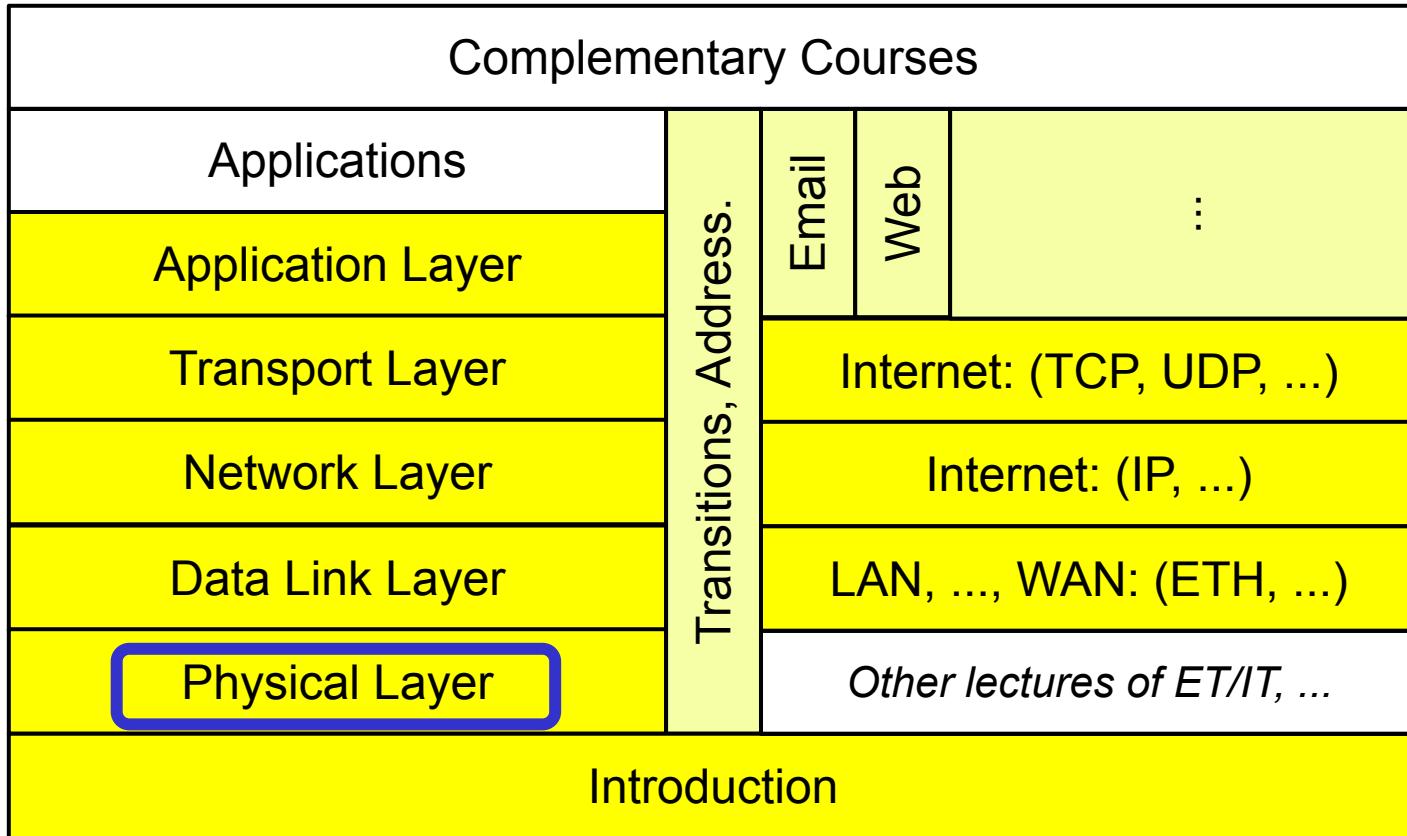
Physical Layer

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Scope

L5
L4
L3
L2
L1



Overview

1 Basics

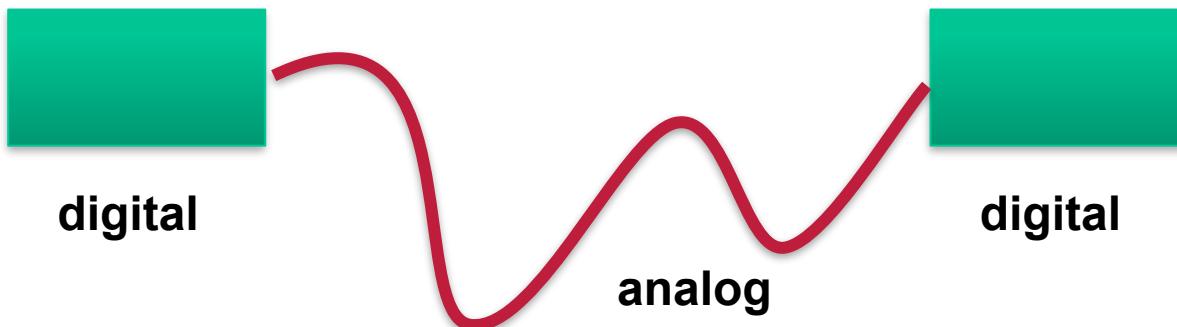
2 Digital Information – Encoding

3 Multiplexing Techniques

1 Basics

What is the purpose of the physical layer?

- Transfer the bits of a message over a link
 - Goal: transmit **digital** bits
 - But signals on a wire (in a medium) are **analog**



- How do physical components look like?
- Which properties do they have?

1.1 Characteristics According to Standards

ISO DEFINITION: the physical layer provides the

- mechanical,
- electrical,
- functional and
- procedural



FEATURES

to initiate, maintain and terminate physical connections between

- Data Terminal Equipment (DTE) and
- Data Circuit Terminating Equipment (DCE, "postal socket")
- and/or data switching centers.

Using physical connections, the physical layer ensures the transfer of a **transparent bitstream** between **data link layer entities**

A **physical connection** may permit the bitstream transfer either as

- duplex or
- semi-duplex

Characteristics

MECHANICAL:

- size of plugs
- allocation of pins
- ...

ELECTRICAL (or equivalent):

- voltage levels on wires
- ...

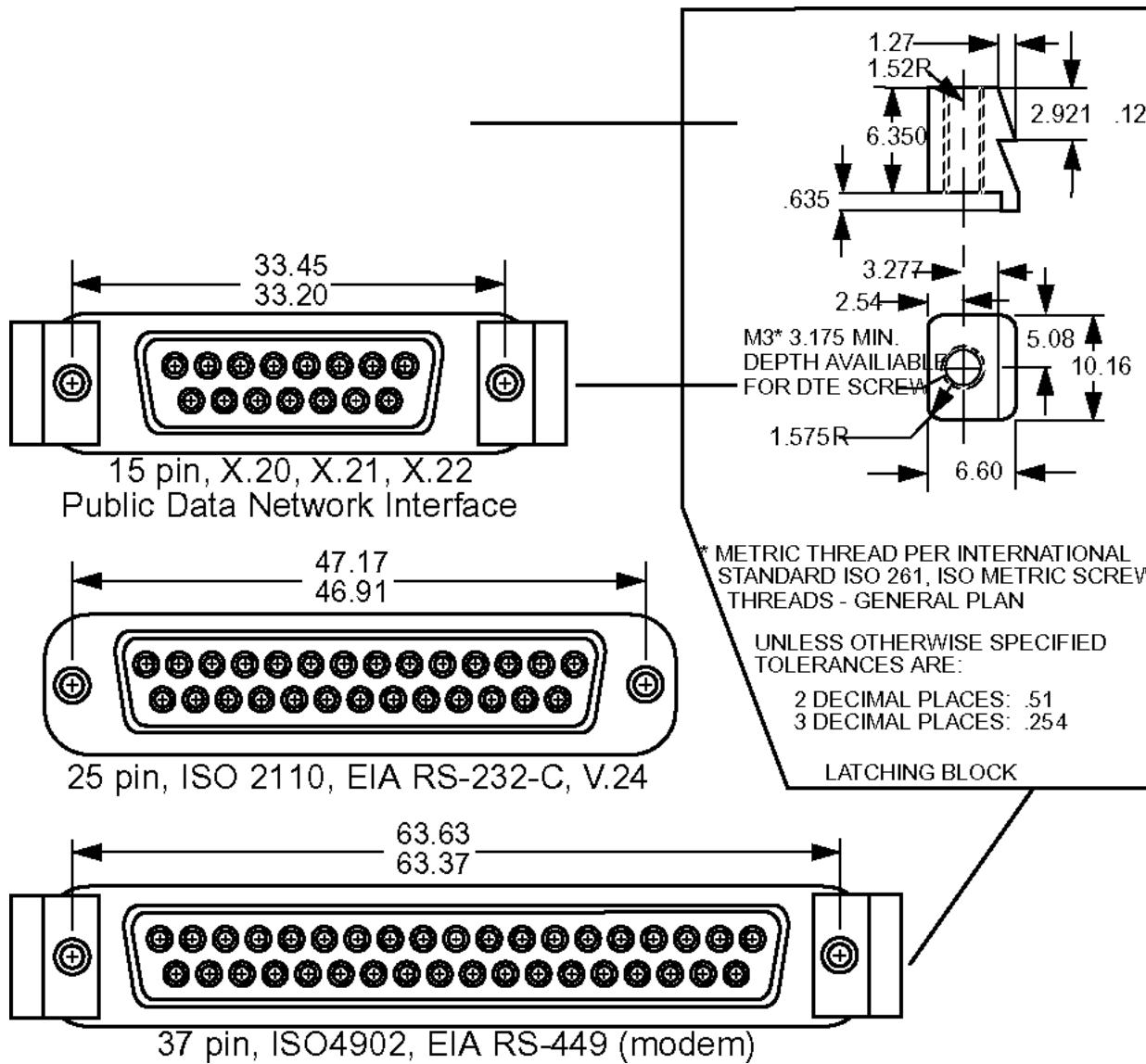
FUNCTIONAL:

- definition of switching functions;
- pin allocation (data, control, timing, ground)
- ...

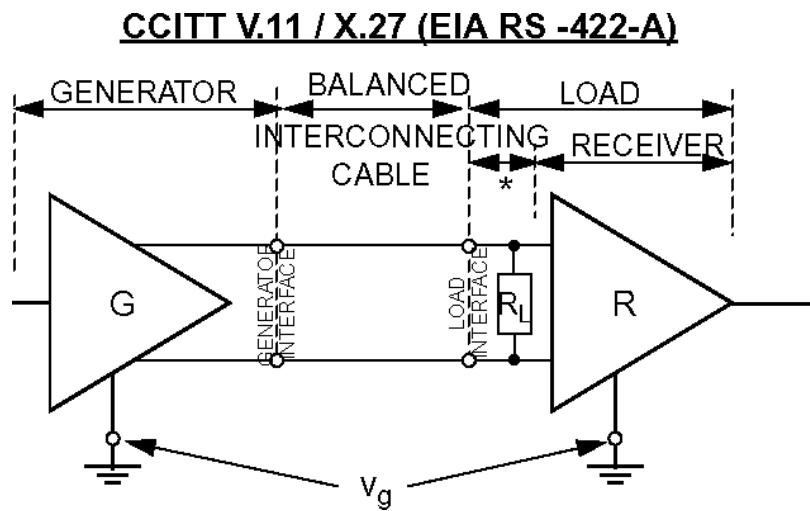
PROCEDURAL:

- rules for using switching functions
 - e. g. CCITT X.21: protocol between DTE and DCE for synchronized data transfer in public data networks

Mechanical



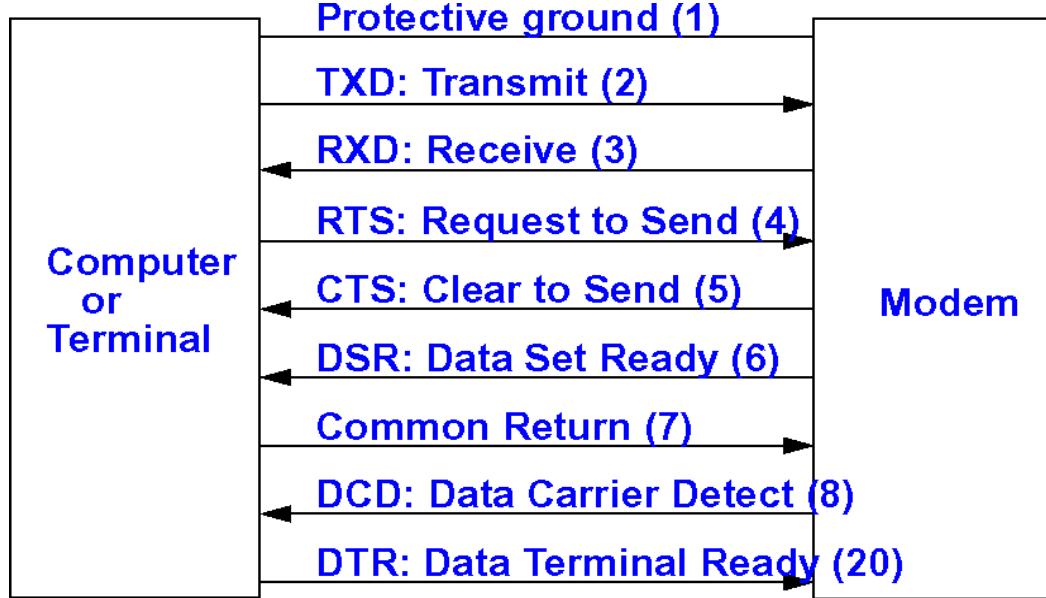
Electrical



e. g. .. "

- designed for IC Technology
- balanced generator
- differential receiver
- two conductors per circuit
- signal rate up to 10 Mbps
- distance: 1000m (at appr. 100 Kbps) to 10m (at 10Mbps)
- considerably reduced crosstalk
- interoperable with V.10 / X.26 ... "

Functional, Procedural



Example RS-232-C, functional specification describes

- connection between pins
 - e.g. "zero modem" computer-computer-connection (Transmit(2) - Receive(3))
- meaning of the signals on the lines
 - DTR=1, when the computer is active, DSR=1, modem is active, ...
 - Action/reaction pairs specify the permitted sequence per event
 - e. g. when the computer sends an RTS, the modem responds with a CTS when it is ready to receive data

1.2 Bit Rate and Baud Rate

BAUD RATE:

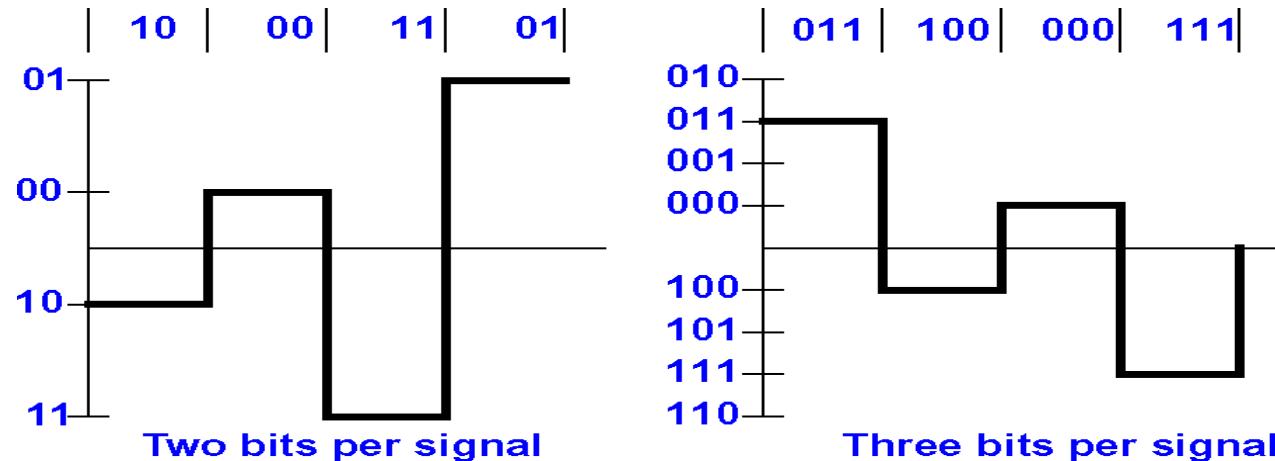
measure of number of symbols transmitted per unit of time

- signal speed, number of signal changes per second
 - changes in amplitude, frequency, phase
- each symbol normally consist of a number of bits
 - baud rate is equal to the bit rate if there is one bit per symbol

BIT RATE: Number of Bits transferred per Second (bps)

- bit rate may be higher than baud rate ("signal speed")
 - because one signal value may transfer several bits

Example:



Bandwidth of a channel: $B = f_{\max} - f_{\min}$

f_{\max} , f_{\min} : maximum resp. minimum frequency

Example:

- traditional phone: min. 3000 Hz

How many bits per second can be transmitted on a channel with a certain bandwidth B?

Note:

- Definition of term „bandwidth“ differs from typical use in computer science

Basics: Nyquist Theorem

Nyquist theorem:

For a **noise free** channel,
the maximum achievable bit rate is

$$\text{max. bitrate} = 2 B \cdot \log_2 V \text{ bps}$$

- B: signal bandwidth (low pass filter)
- V: number of discrete levels

Example:

3000 Hz channel, binary signal ($V=2$):

- max. bitrate = 6000 bps

But in reality, we do not have **noise free** channels ...

Basics: Shannon Theorem

Shannon theorem:

For a **noisy** channel, the maximum achievable bit rate is
max. bitrate = $B \cdot \log_2 (1 + S/N)$

- B signal bandwidth (low pass filter)
- S/N Signal to Noise ratio
 - $10 \log_{10} S/N$ decibels

Example:

3000 Hz channel,

$S/N = 1\ 000$ (30 dB)

- maximum bitrate = 30 000 bps

Independent of number of levels !

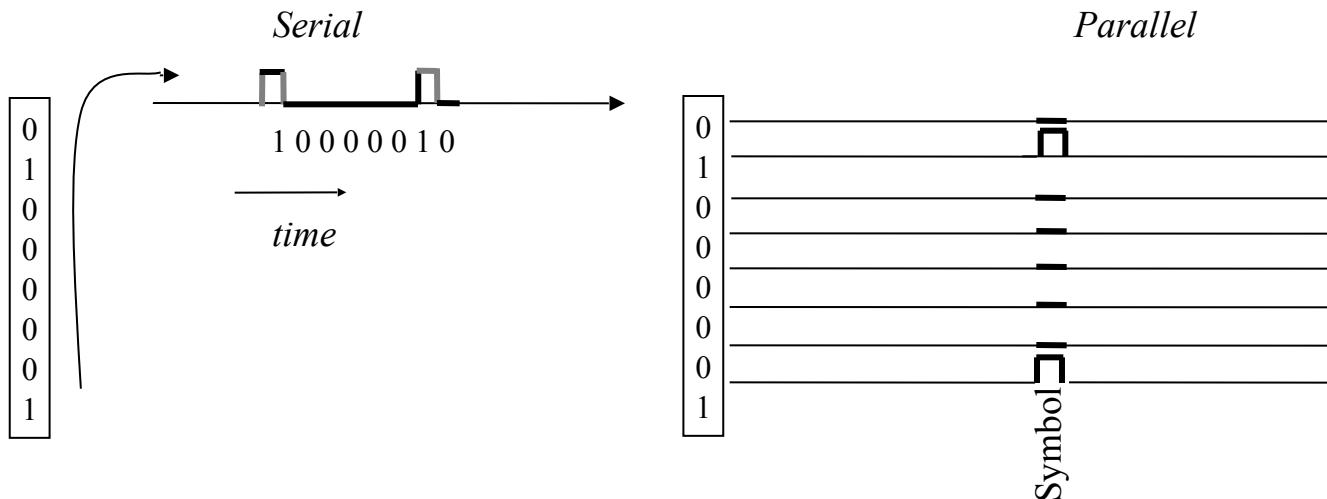
1.3 Operating Modes

Transfer directions (temporal parallelism)

- **simplex communication:**
 - data is always transferred into one direction only
- **(half-duplex) semi-duplex communication**
 - data is transferred into both directions
 - but never simultaneously
- **full-duplex communication**
 - data may flow simultaneously in both directions

Serial and parallel transmission

- serial:
 - signals are transmitted sequentially over one channel
- parallel:
 - signals are transmitted simultaneously over several channels



Operating Modes: Synchronous Transmission

Definition

- exact time when a bit exchange occurs is pre-defined by a regular clock pulse (requires synchronization)

Implementation

- receiving clock pulse
 - on a separate line or
 - gained from the signal
- bit synchronous or frame synchronous
(in fact, frames are on data link level)

Operating Modes: Asynchronous Transmission

Definition

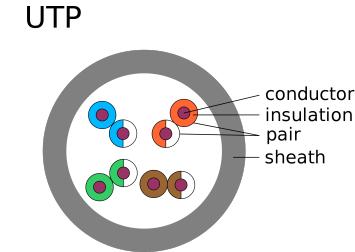
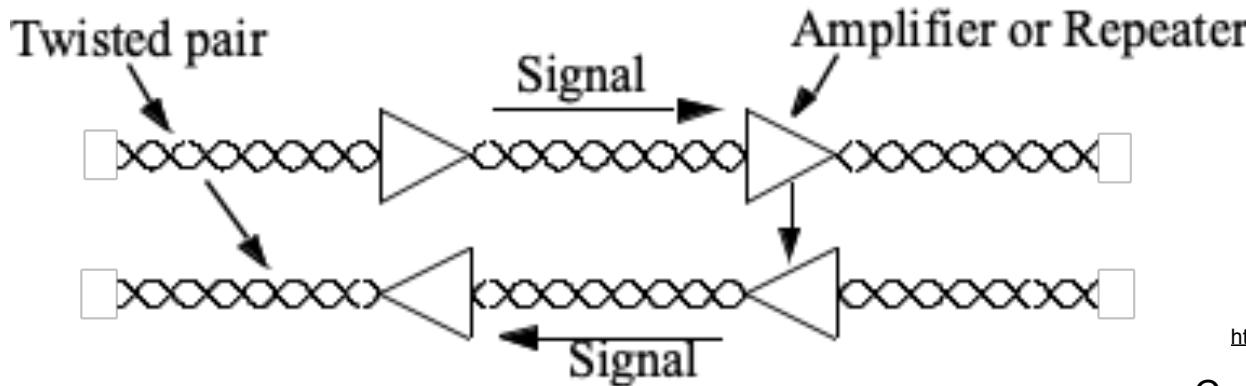
- clock pulse fixed for the duration of a signal
- termination marked by
 - stop signal (bit) or
 - number of bits per signal

Implementation

- simple:
 - sender & receiver generate clock pulse independent from each other
- classical example: RS-232-C
 - UART (universal asynchronous receiver and transmitter) IC module
 - In former times often used between
 - computer & printer or
 - computer & modem

1.4 Media: Twisted Pair and Coax

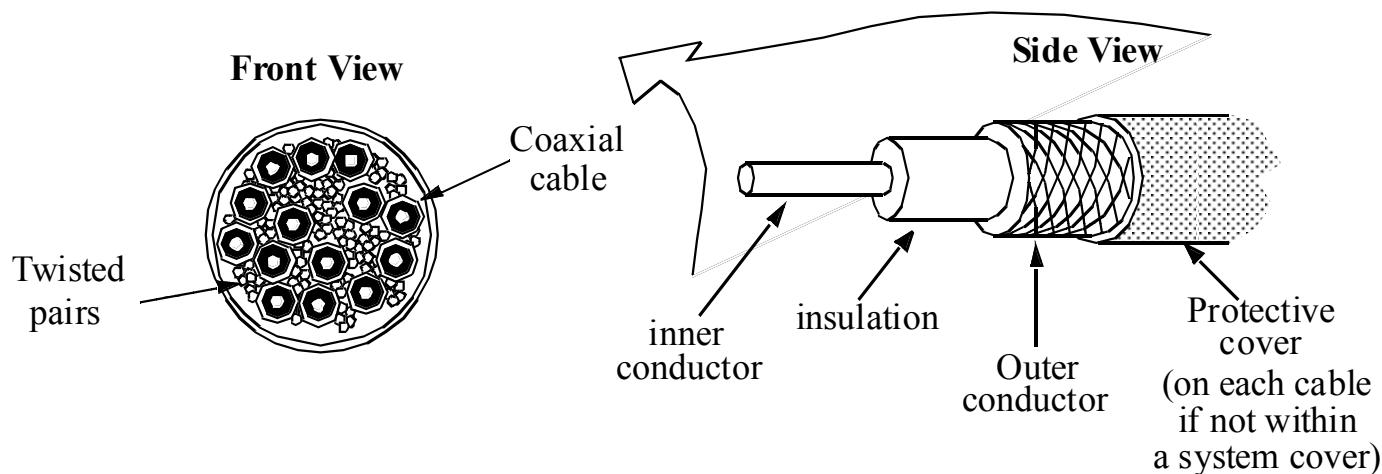
UTP: unshielded twisted pair



<https://en.wikipedia.org/wiki/File:UTP-cable.svg>

Cross-section of cable with four unshielded twisted pairs

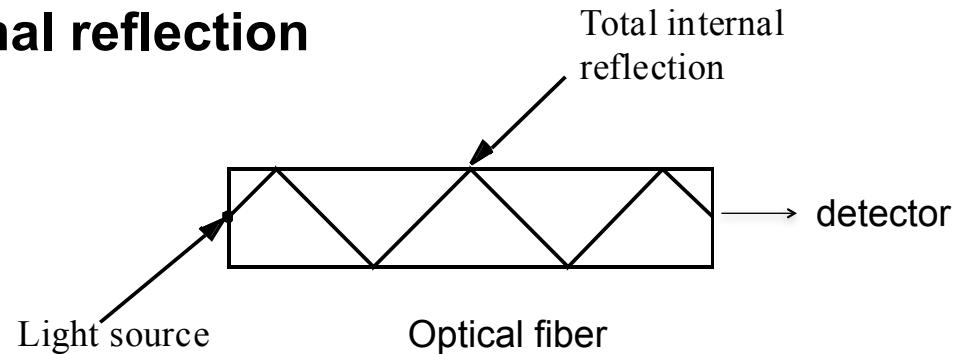
Coaxial cable



Fiber

Long, very thin strand of glass

Light trapped by total internal reflection



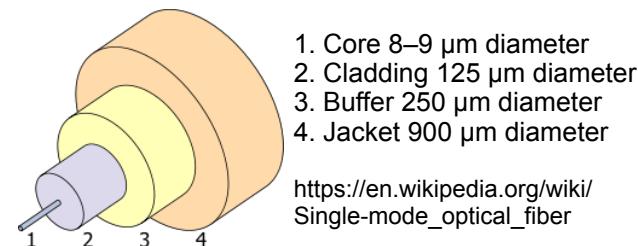
2 Types:

- **Multi-mode**

- Larger diameter (50 micrometer up to 100's of micrometer)
- several rays with different angles ('modes')
- shorter links (e.g., up to 1000 m), cheaper

- **Single-mode**

- fiber diameter very small, often used fibers: 8-9 micrometer (few wavelengths of light)
- light can propagate in straight line
- better properties, more expensive

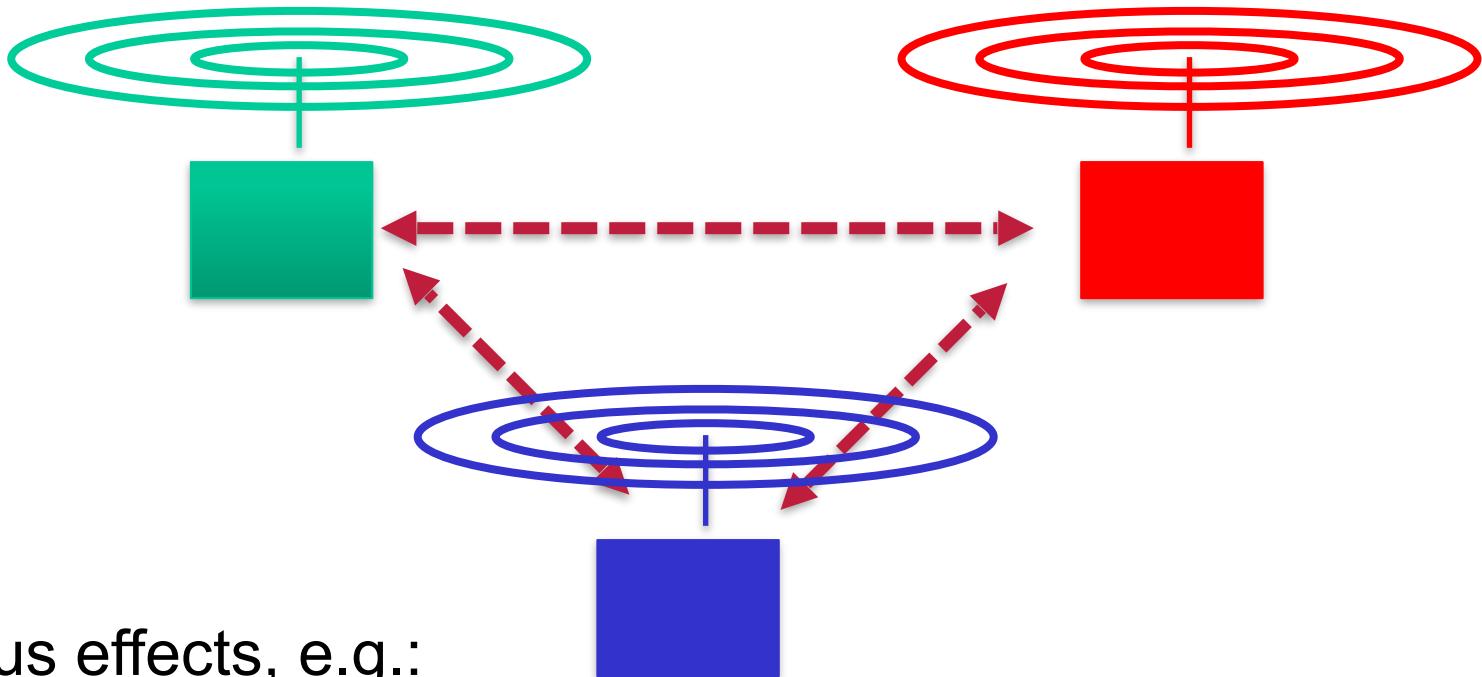


1. Core 8–9 μm diameter
2. Cladding 125 μm diameter
3. Buffer 250 μm diameter
4. Jacket 900 μm diameter

https://en.wikipedia.org/wiki/Single-mode_optical_fiber

Wireless

Sender radiates signal using an antenna



Various effects, e.g.:

- attenuation
- interference
- multipath
- ...

2 Digital Information – Encoding

Digital information at end system

- E.g., TTL-Logic ("1" : 3V, "0" : 0V)

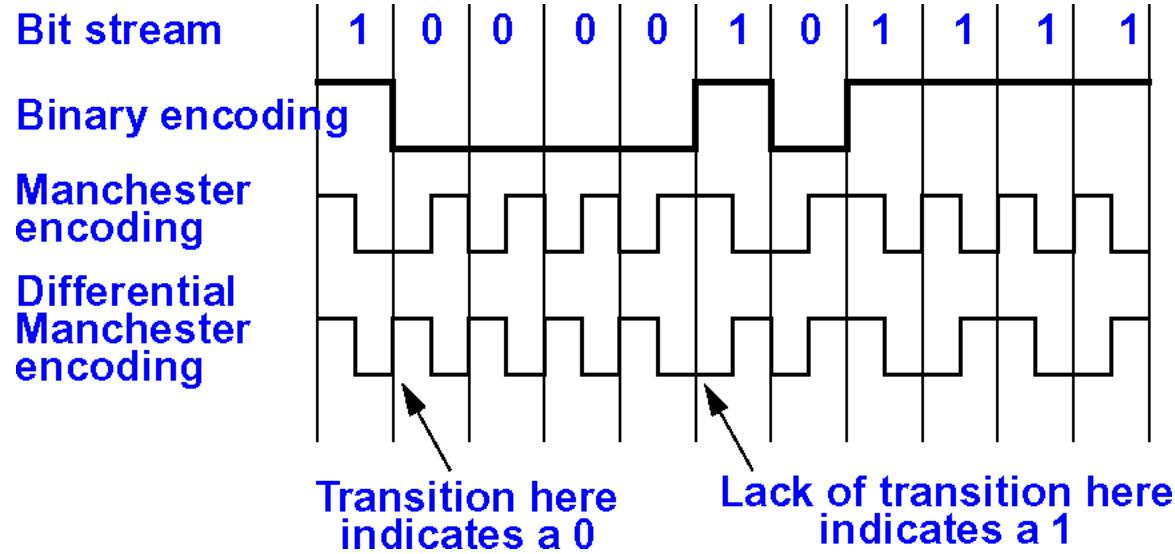
Digital transmission

- sender/receiver synchronization
 - signal levels around 0V (lower power)
- Conversion

Coding techniques

- binary encoding, non-return to zero-level (NRZ-L)
 - 1: high level
 - 0: low level
- return to zero (RZ)
 - 1: clock pulse (double frequency) during interval
 - 0: low level
- ...
- Manchester Encoding
- Differential Manchester Encoding
- ...

Binary Encoding



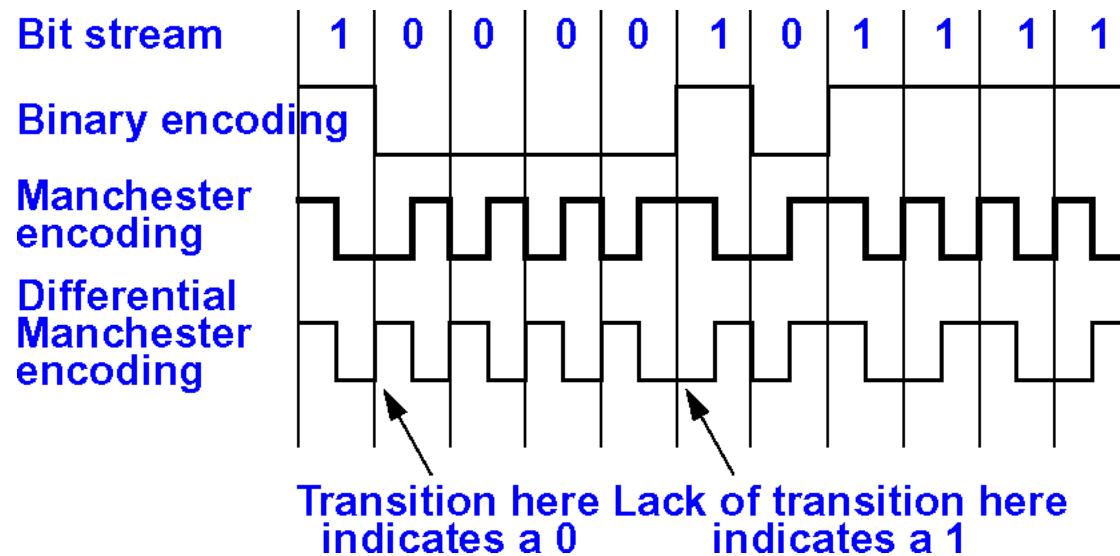
Binary encoding (Non-return to zero):

- "1": voltage on high
- "0": voltage on low

i. e.

- + simple, cheap
- + good utilization of the bandwidth (1 bit per Baud)
- no "self-clocking" feature

Manchester Encoding

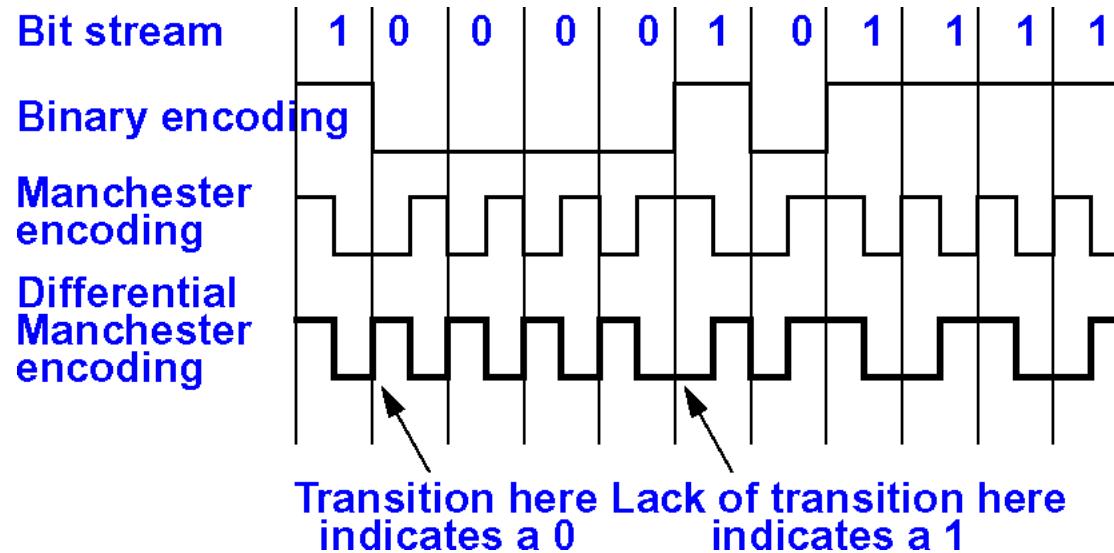


Bit interval is divided into two partial intervals: I₁, I₂

- "1": I₁: high, I₂: low
- "0": I₁: low, I₂: high
- + good "self-clocking" feature
- 0,5 bit per Baud

Application: 802.3 (CSMA/CD)

Differential Manchester Encoding



Differential Manchester Encoding:

- bit interval divided into two partial intervals:
 - "1": no change in the level at the beginning of the interval
 - "0": change in the level
 - + good "self-clocking" feature
 - + low susceptibility to noise because only the signal's polarity is recorded. Absolute values are irrelevant.
 - 0,5 bit per Baud
 - complex

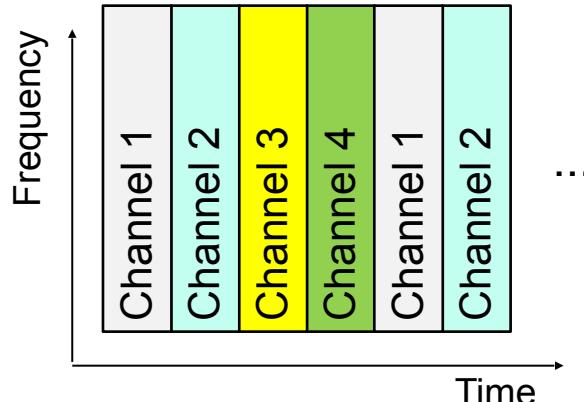
3 Multiplexing Techniques

The cost for implementing and maintaining either a narrowband or a wideband cable are almost the same
→ multiplexing many conversations onto one cable

FDM (FREQUENCY DIVISION MULTIPLEXING)



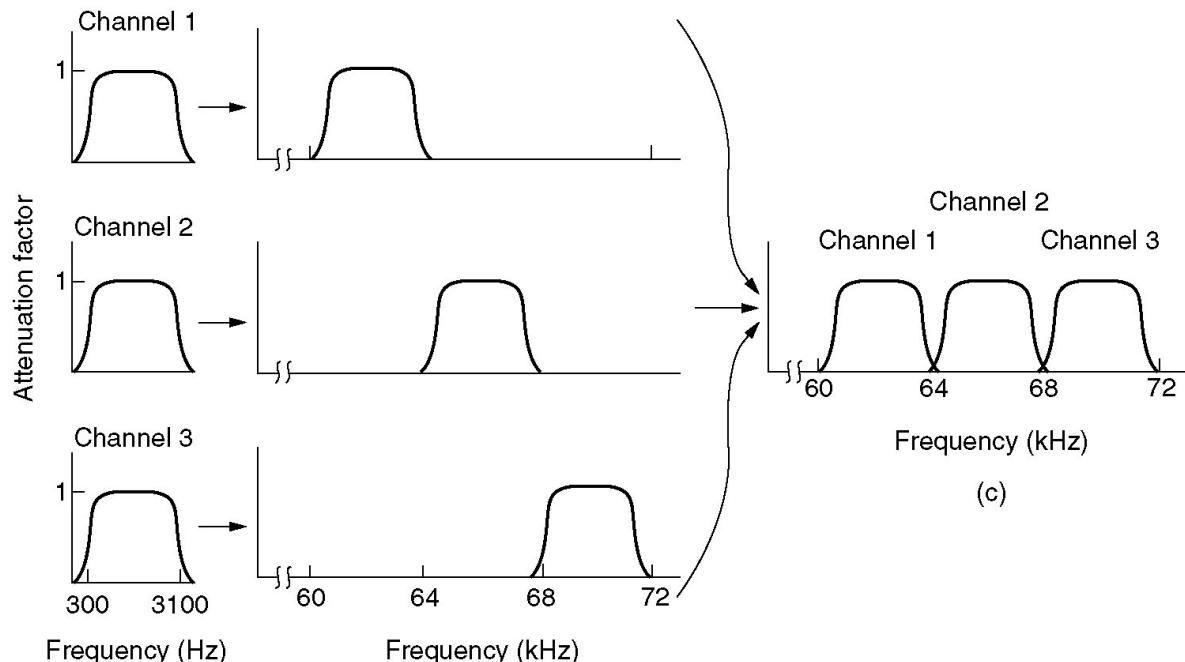
TDM (TIME DIVISION MULTIPLEXING)



Frequency Multiplexing

Principle:

- frequency band is split between the users
- each user is allocated one frequency band



Application example:

- multiplexing of voice telephone channels^(a)
- filters limit voice channel to 3 000 Hz bandwidth^(b)
- each voice channel: 4 000 Hz bandwidth (2 x 500 Hz gap (guard band))
- Quality of filters and guard bands important:
→ Otherwise adjacent channels overlap → noise

Time Division Multiplexing

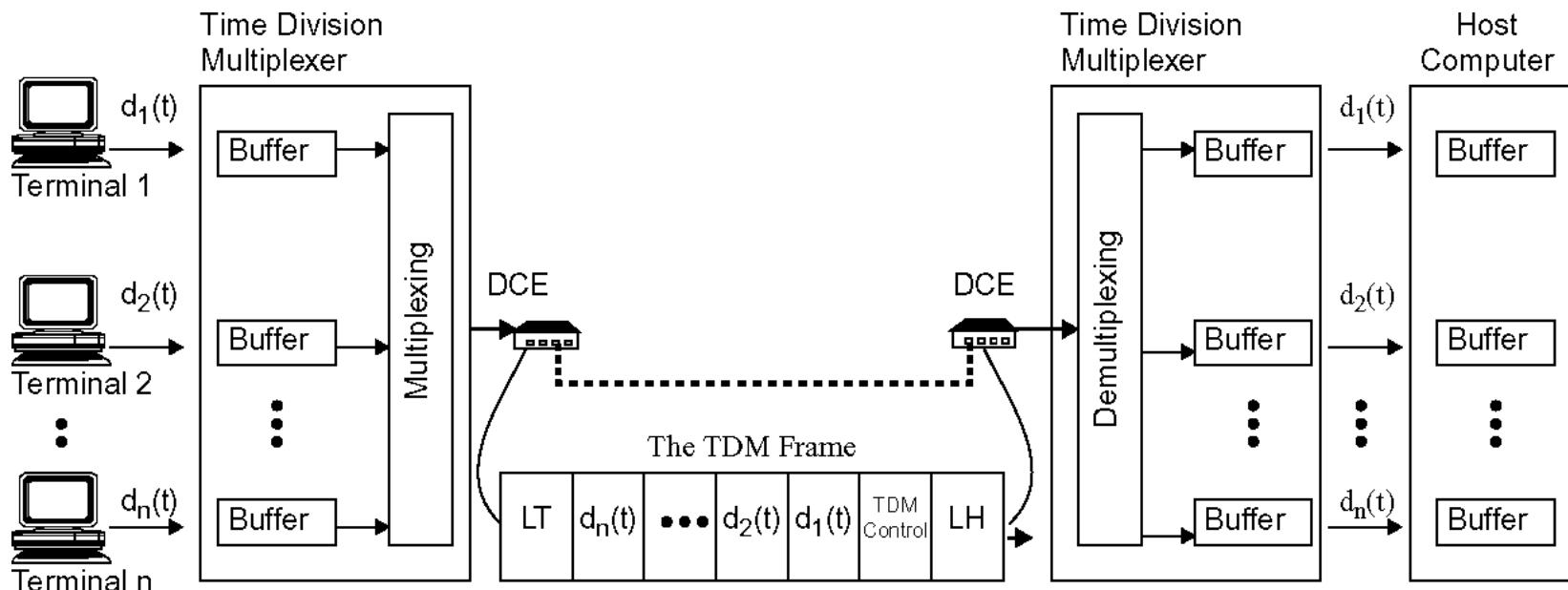
Principle:

- user receives a **time slot**
- during this time slot user has the full bandwidth

$$\sum_{i=1}^n d_i(t) = d_0(t)$$

Application:

- multiplexing of end systems, but also
- in transmission systems



LT: Link Trailer, LH: Link Header, $d_i(t)$: Fixed, predetermined slots for each device, TDM Control: Identification of specific TDM controls (may not exist on some TDMs)