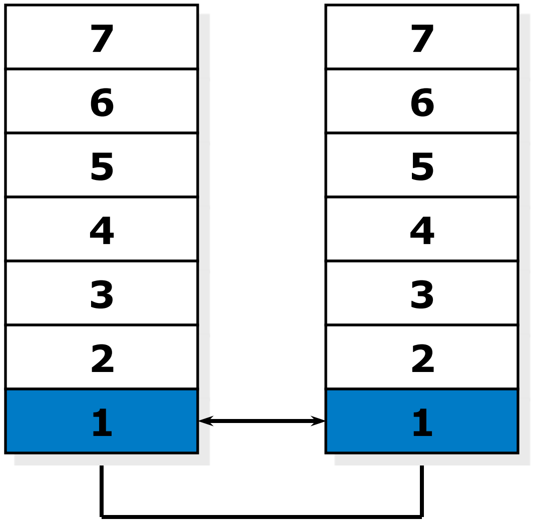
Operating Systems & Computer Networks
Host-to-Network I



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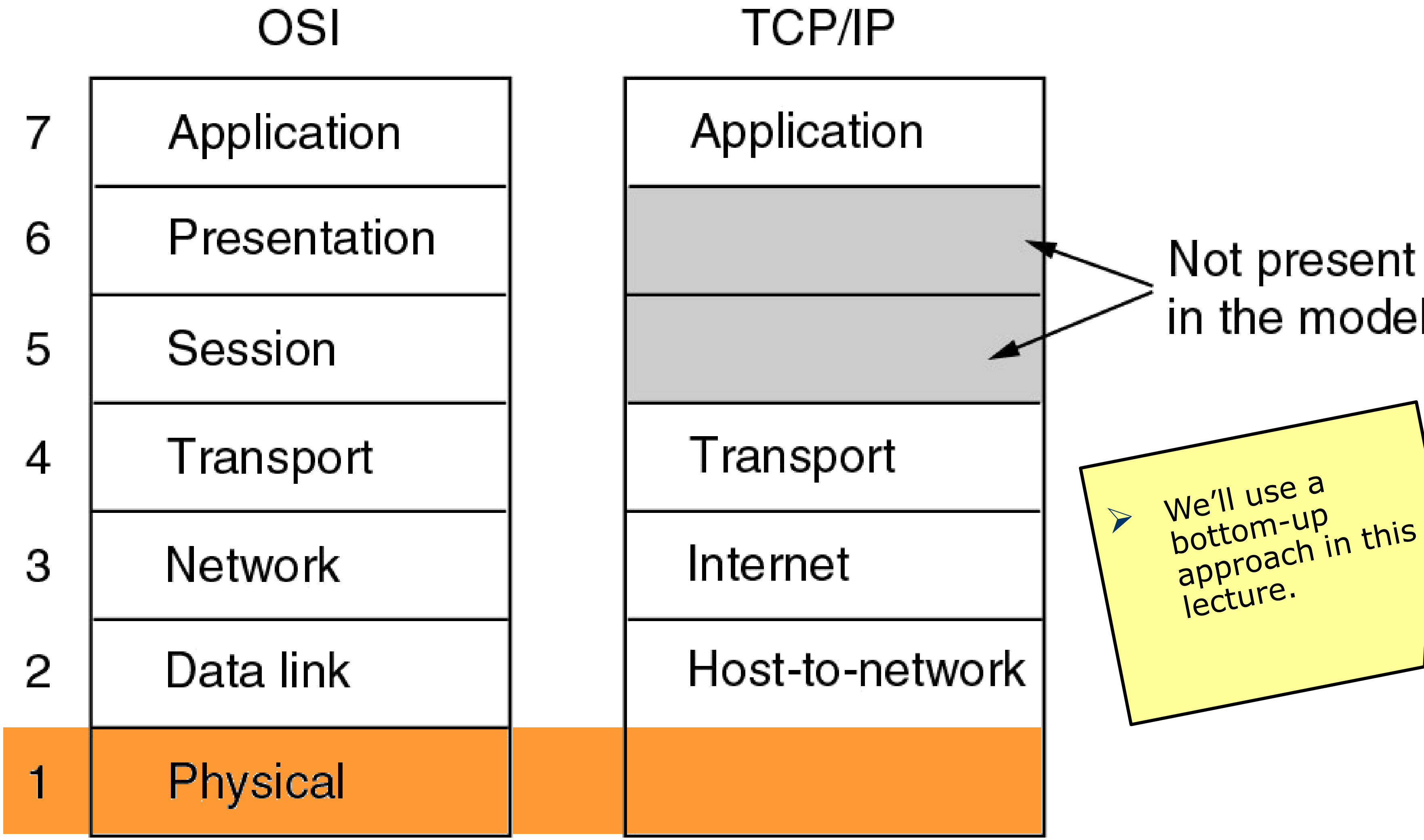
Physical Layer

	OSI
7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data link
1	Physical

Physical Layer



- We'll use a bottom-up approach in this lecture.

Tasks of Physical Layer

- Responsible for turning a logical sequence of bits into a physical signal that can propagate through a medium
  - Many forms of physical signals
  - Signals are limited by their propagation in a physical medium
  - Limited bandwidth, attenuation, dispersion, and by noise
- Includes connectors, media types, voltages, …
- No error correction!

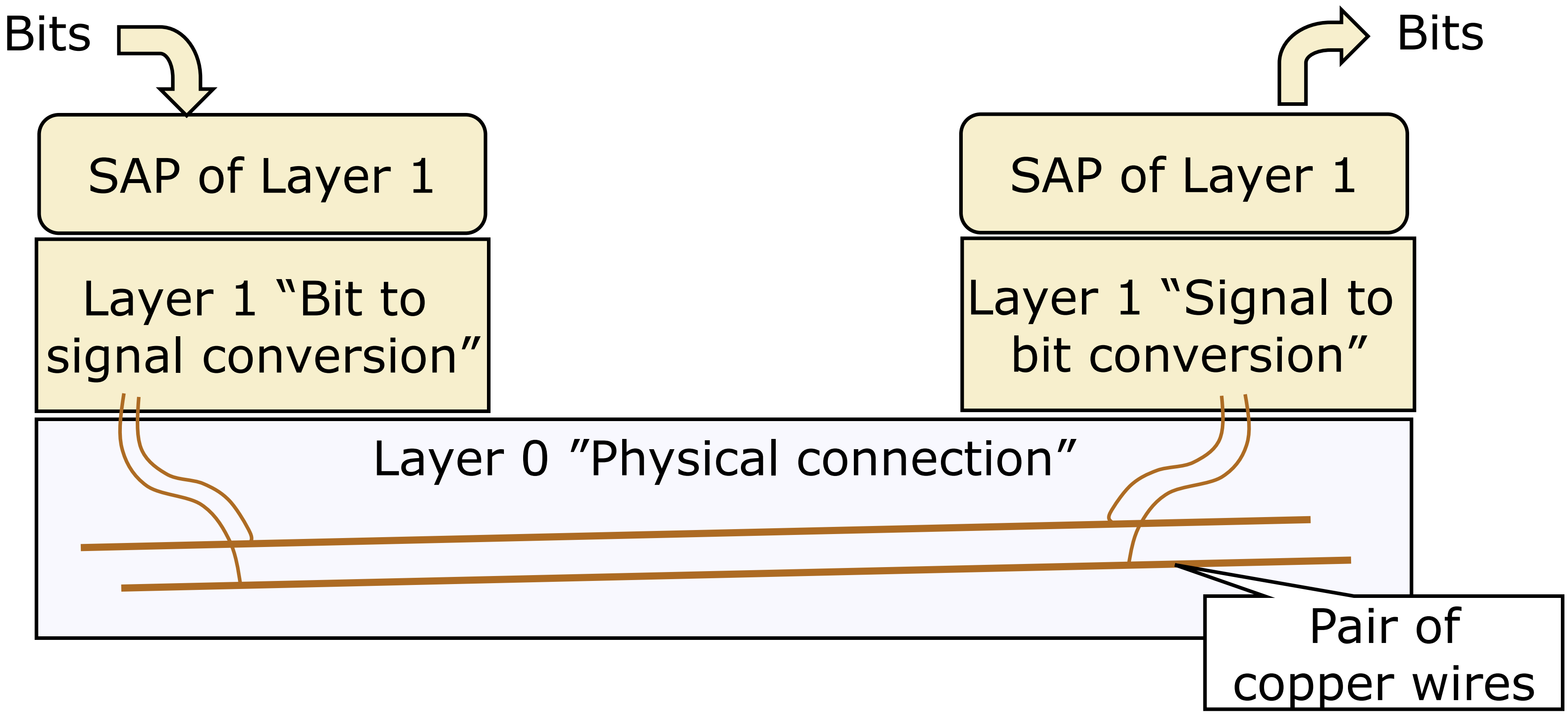
Tasks of Physical Layer

- Bits can be combined into multi-valued symbols for transmission
  - ➢ Gives rise to the difference in **data rate** (bits per sec, bit/sec) and **baud rate** (symbols per sec)

- Two types
  - Baseband transmission
  - Broadband transmission

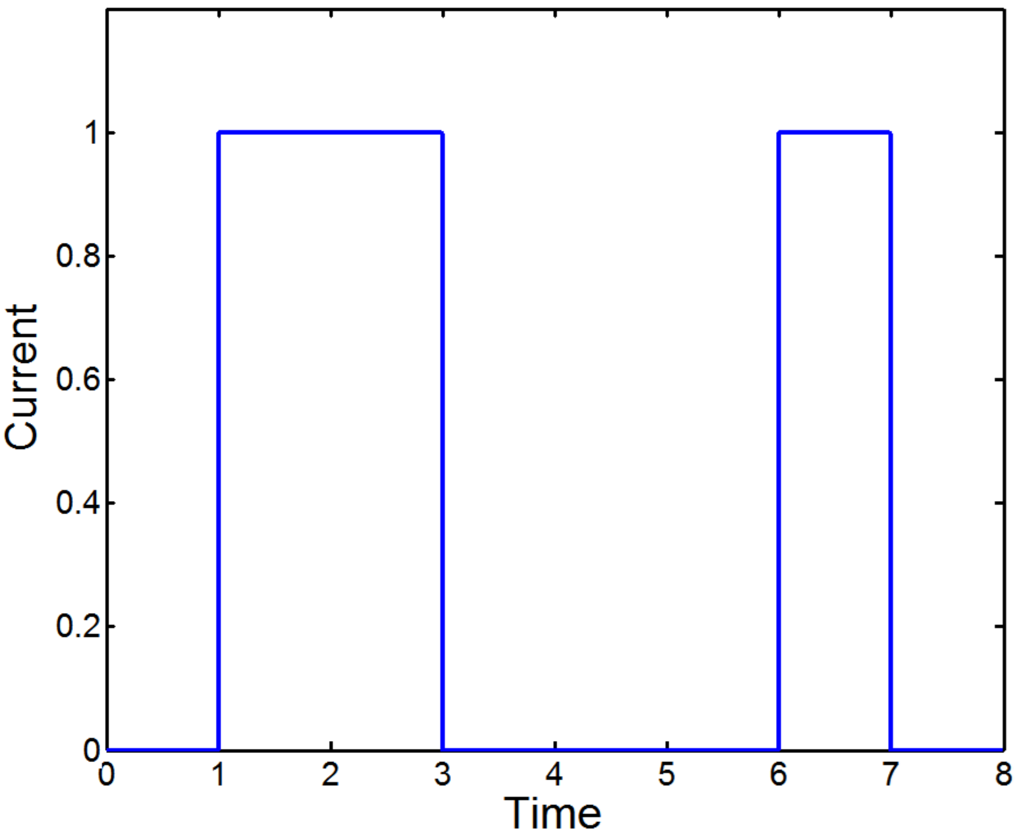
Basic Service of Physical Layer: Transport Bits

- Physical layer should enable transport of bits between two locations A and B
- Abstraction: Bit sequence (in order delivery)
  - But no guarantee on correct transmission of bits



Example: Transmit Bit Pattern for Character "b"

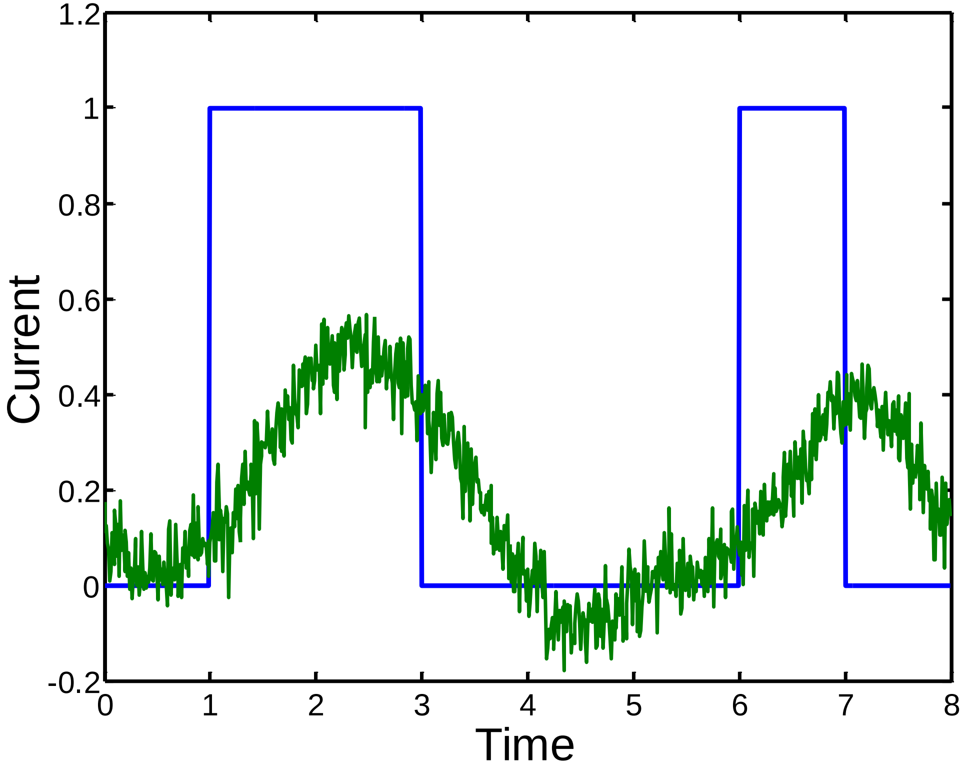
- Represent character "b" as a sequence of bits
- Use ASCII code → "b" = 98, as binary number 01100010
- Resulting current on the wire:



Note: Abstract ***data*** is represented by physical ***signals*** – changes of a physical quantity in time or space!

What Arrives at the Receiver?

- Typical pattern at the receiver:

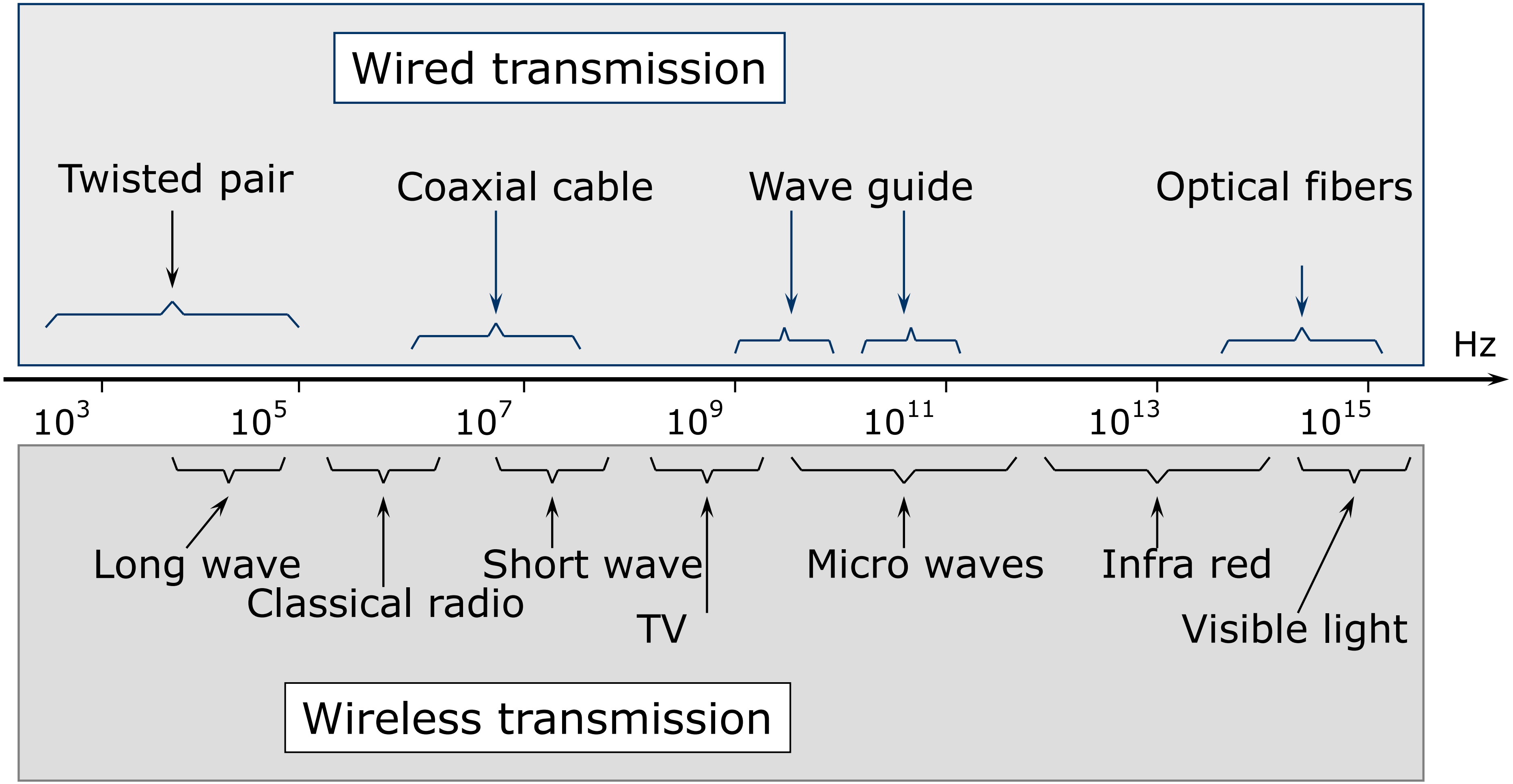


Physical effects:

- Attenuation
- Dispersion
- Refraction
- Phase shift
- Background noise

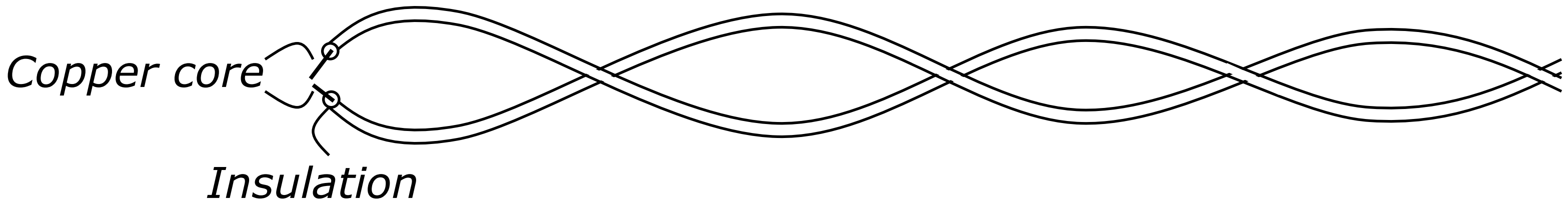
➢ What is going on here and how should we convert the signal back to a “b”?

Electromagnetic Spectrum

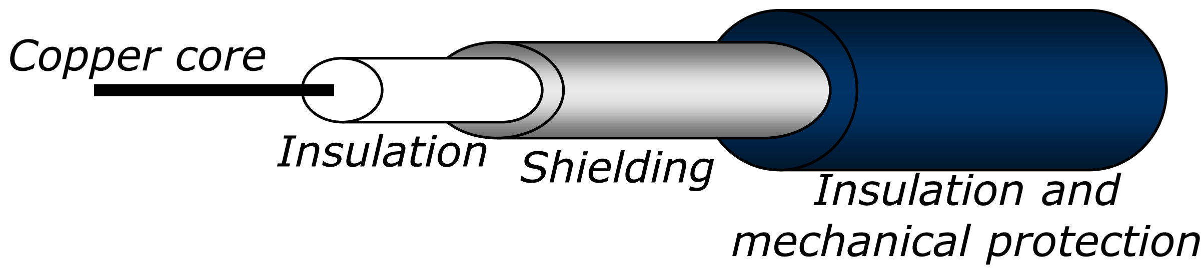


Wires

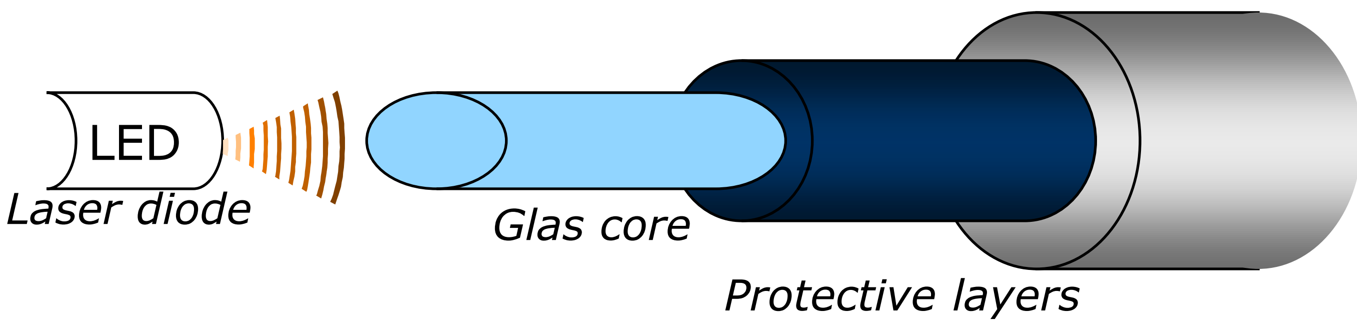
Twisted pair



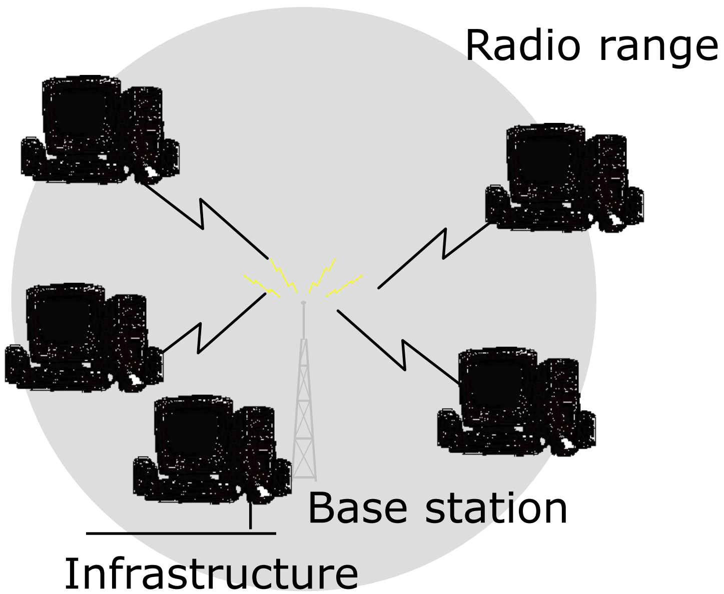
Coaxial

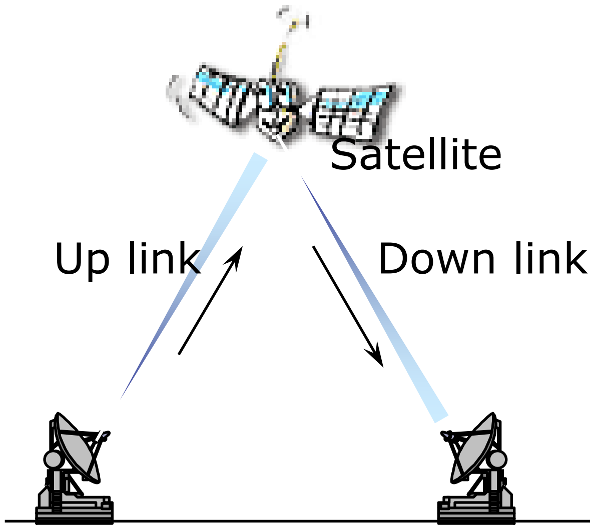


Optical fiber



Wireless Transmission





- Examples: 802.11 (WLAN), mobile phones, Bluetooth
- Examples: Television, deep space communication

Multiplexing

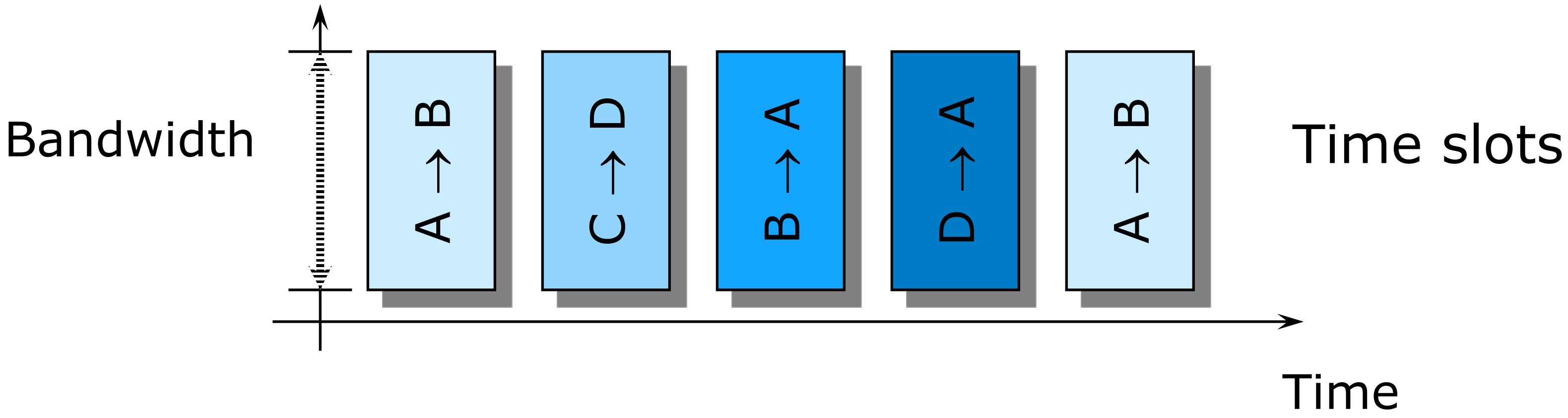
- Communication medium is scarce resource
➢ Optimize medium usage by *multiplexing*

- Space Division Multiplexing (SDM)

Bundling of wires

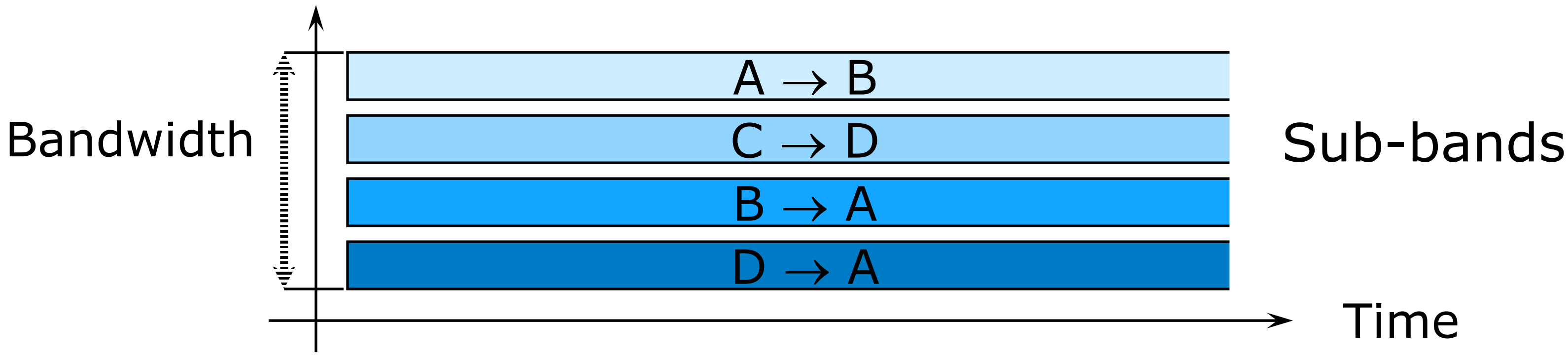
Multiplexing

- Time Division Multiplexing (TDM)



Multiplexing

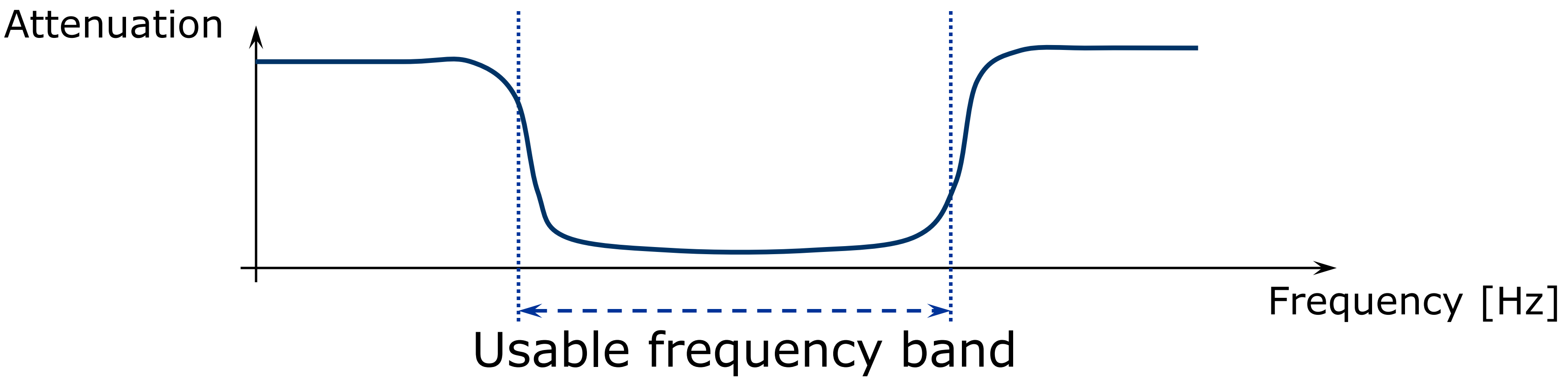
- Frequency Division Multiplexing (FDM)



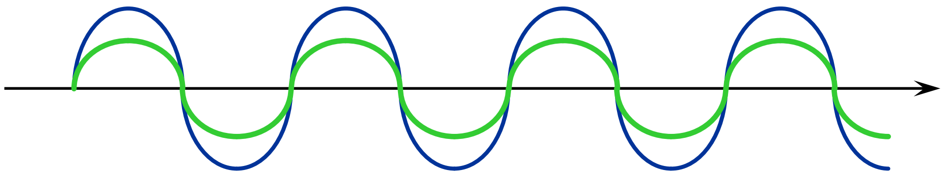
➢ Multiplexing in general allows for a more efficient usage of a medium
  - Discretized resource can be managed, allocated, scheduled...

Typical Effects of Transmission

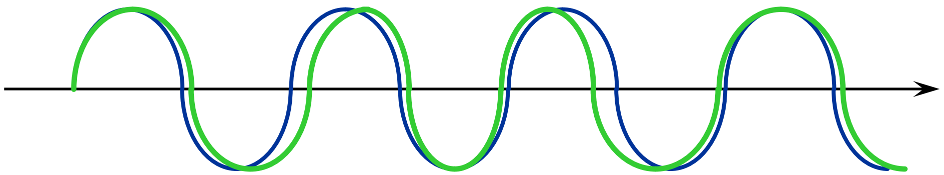
- Limited bandwidth



- Signal attenuation



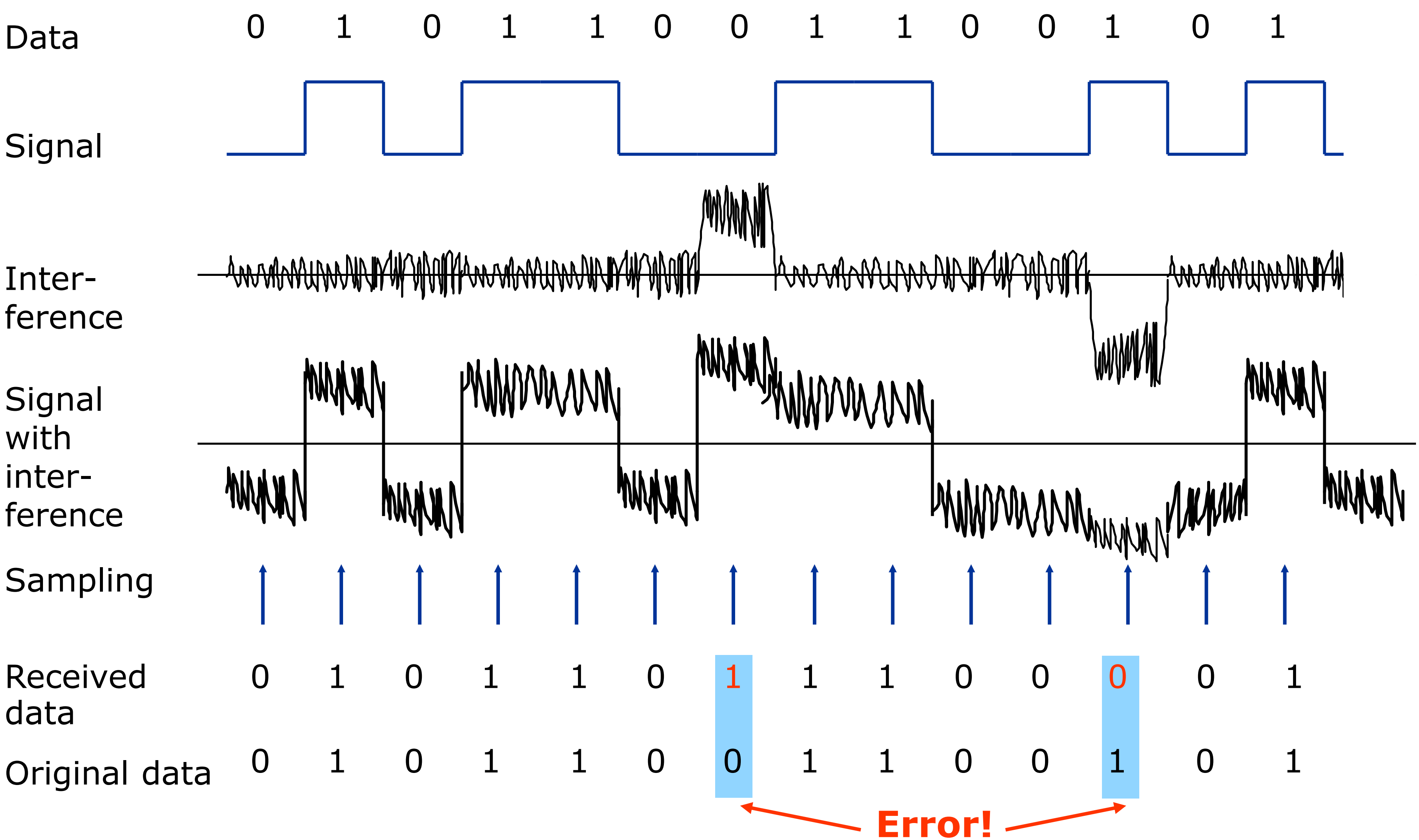
- Jitter, dispersion, …



Interference

- Noise
  - Background noise
  - Thermal
- Echoes
  - E.g. at connections
- Crosstalk
  - E.g. interference across wires
- ELF
  - Extreme low frequency, e.g. 50/60 Hz AC
- Spikes
  - Short, high amplitude
- …

Example: Results of Interference



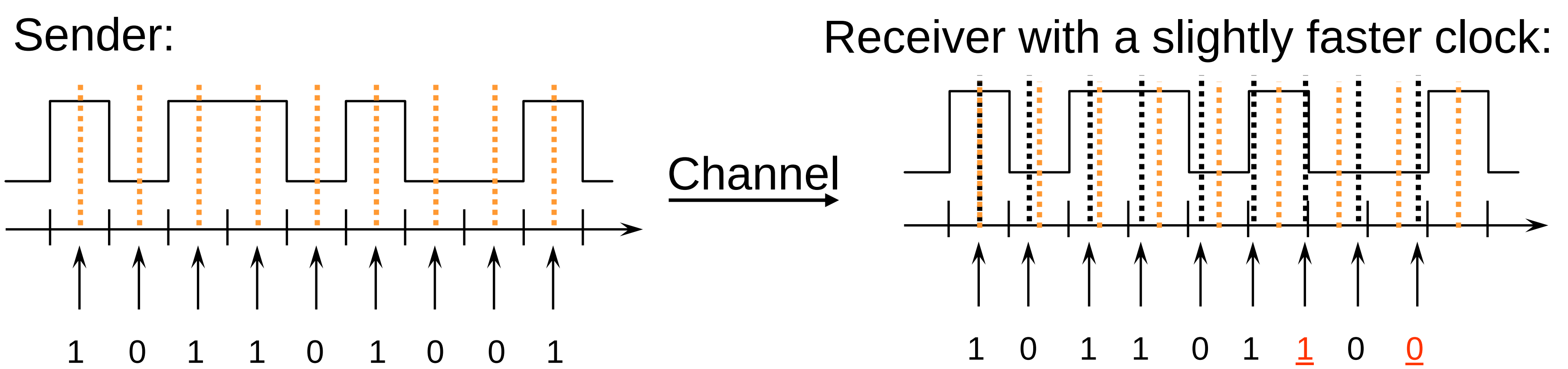
When to Sample Received Signal?

- How does the receiver know *when* to check the received signal for its value?
  - One typical convention: In the middle of each symbol
  - But when does a symbol start?
    - The length of a symbol is usually known by convention via the symbol rate

- The receiver has to be *synchronized* with the sender at bit level
  - Link layer will have to deal with *frame synchronization*
  - There is also *character synchronization* – omitted here

Overly Simplistic Bit Synchronization

- One simple option, assume
  - ... that sender and receiver are synchronized at some point in time
  - ... that both have an internal clock that tics at every symbol step
- Usually, this does not work due to *clock drift*
  - Two different clocks never stay in perfect synchrony
- Errors, if synchronization is lost:



Options to Tell Receiver When to Sample

- Relying on clock synchronization does not work

1. Provide an explicit clock signal
   - Needs parallel transmission over some additional channel
   - Must be in synch with actual data, otherwise pointless
   - ➢ Useful only for short-range communication

2. Synchronize receiver at crucial points, e.g. start of character or block
   - Otherwise, let receiver clock run freely
   - Relies on short-term stability of clock generators (do not diverge too quickly)

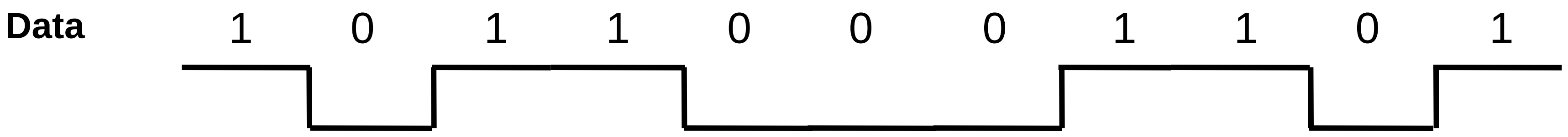
3. Extract clock information from the received signal itself

Extract Clock Information from Signal

- Put enough information into data signal itself so that receiver can know immediately when a bit starts/stops

➢ Would the simple 0/low, 1/high mapping of bit/symbol work?

- Receiver can use 0-1-0 transitions to detect length of a bit

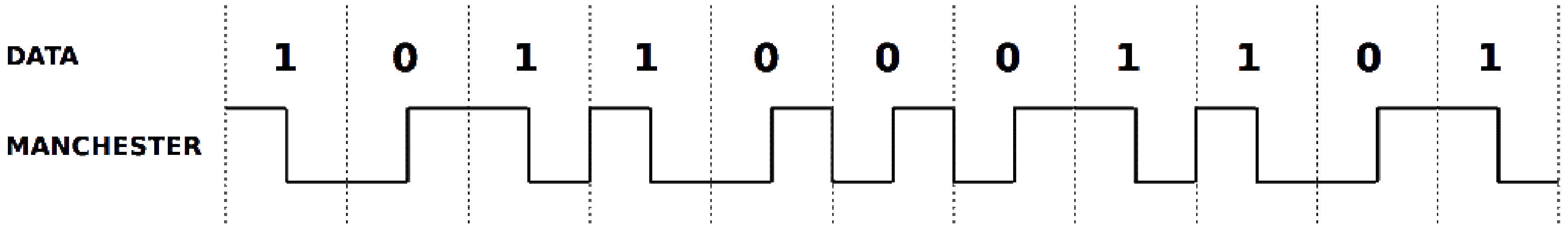


- Fails depending on bit sequences, e.g. long runs of 1s/0s
  - ➢ Receiver can loose synchronization

➢ Not nice not to be able to transmit arbitrary data

Manchester Encoding

- Idea: At each bit, provide indication to receiver that this is where a bit starts/stops/has its middle
  - For a 0 bit, have symbol change in middle of bit from low to high
  - For a 1 bit, have the symbol change in middle of bit from high to low



- The signal is self-clocking since one transition per period is guaranteed
- Disadvantage: bit rate is as half as high as baud rate

Baseband vs. Broadband Transmission

- Baseband transmission (all schemes described so far)
  - Put digital symbol sequences directly onto the wire
    - At different levels of current, voltage, …
  - Problems:
    - Limited bandwidth reshapes signal at receiver
    - Attenuation and distortion depend on frequency
      - Baseband transmissions have many different frequencies because of their wide Fourier spectrum
      - ➢ Rectangular signal causes “infinite” spectrum

- Possible alternative: broadband transmission
  - Needed for wireless transmission (antennas) and frequency division multiplex

Broadband Transmission

- Idea: Get rid of wide spectrum needed for baseband transmission
- Use carrier (sine wave) for the symbols to be transmitted
  - Typically, sine wave has high frequency
  - But only a *single* frequency
- Pure sine waves have no information, so its shape has to be influenced according to symbols to be transmitted
  - ➢ Carrier has to be *modulated* by symbols (widening the spectrum)

- Three parameters that can be influenced:
  - Amplitude a
  - Frequency f
  - Phase ϕ

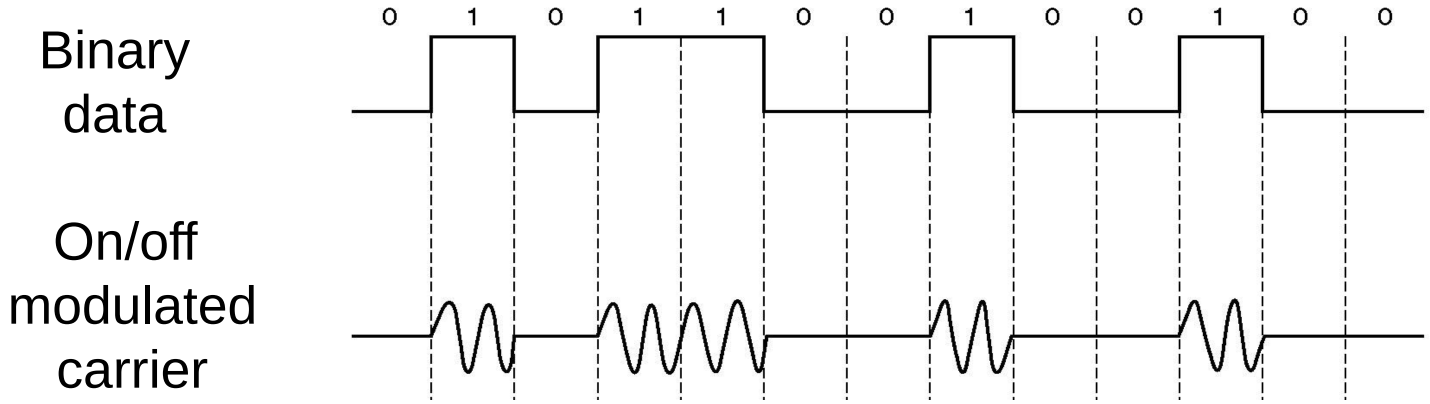
$$f(t) = a \sin(2\pi f t + \phi)$$

Amplitude Modulation (AM)

- Amplitude modulated sine wave $f_A(t)$ is given as

$$f_A(t) = s(t)\sin(2\pi f\, t + \phi)$$

  - Amplitude is given by the signal $s(t)$ to be transmitted
- Special cases:
  - s(t) is an *analog* signal – *amplitude modulation*
  - s(t) is a *digital* signal – *amplitude keying*
  - s(t) only takes 0 and *a* as values – *on/off keying*
- Examples:



- Used in: LF, MF, and HF radio

Frequency Modulation (FM)

- Frequency modulated sine wave $f_F(t)$ is given by

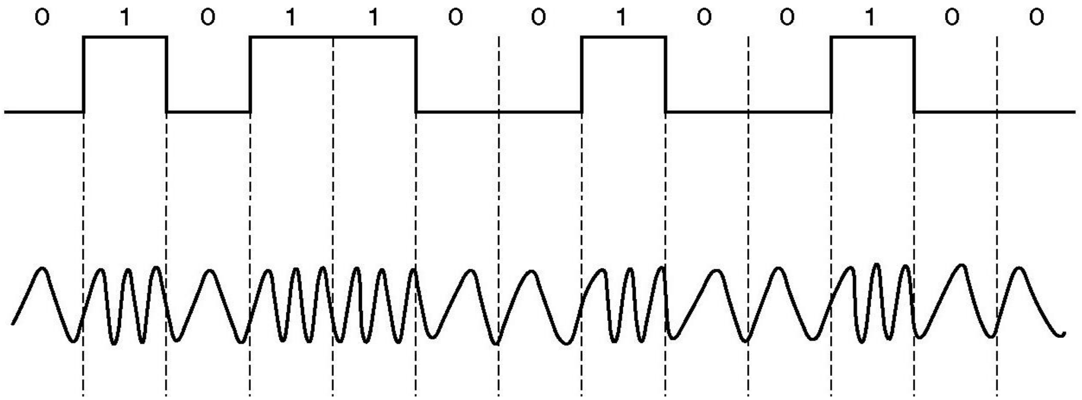
$$f_F(t) = a \sin(2\pi s(t)t + \phi)$$

  - Modulation/keying terminology like for AM

- Example:

Binary data

Frequency-modulated carrier



- Used in: VHF radio, TV, VHS, synthesizers

Note: s(t) has an additive constant in this example to avoid having frequency zero

Phase Modulation

- Similarly, phase modulated carrier is given by

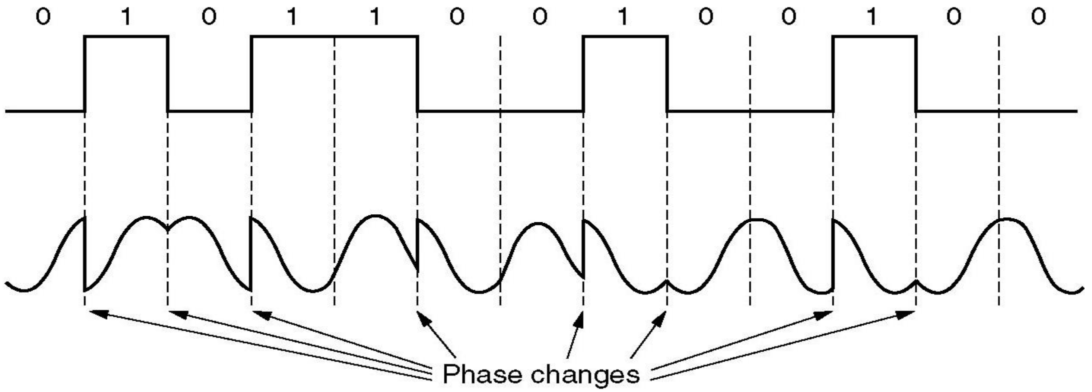
$$f_P(t) = a \sin(2\pi f t + s(t))$$

  - Modulation/keying terminology again similar

- Example:

Binary data

Phase-modulated carrier



- s(t) is chosen such that there are phase changes when the binary data changes
  - Typical example for *differential coding*

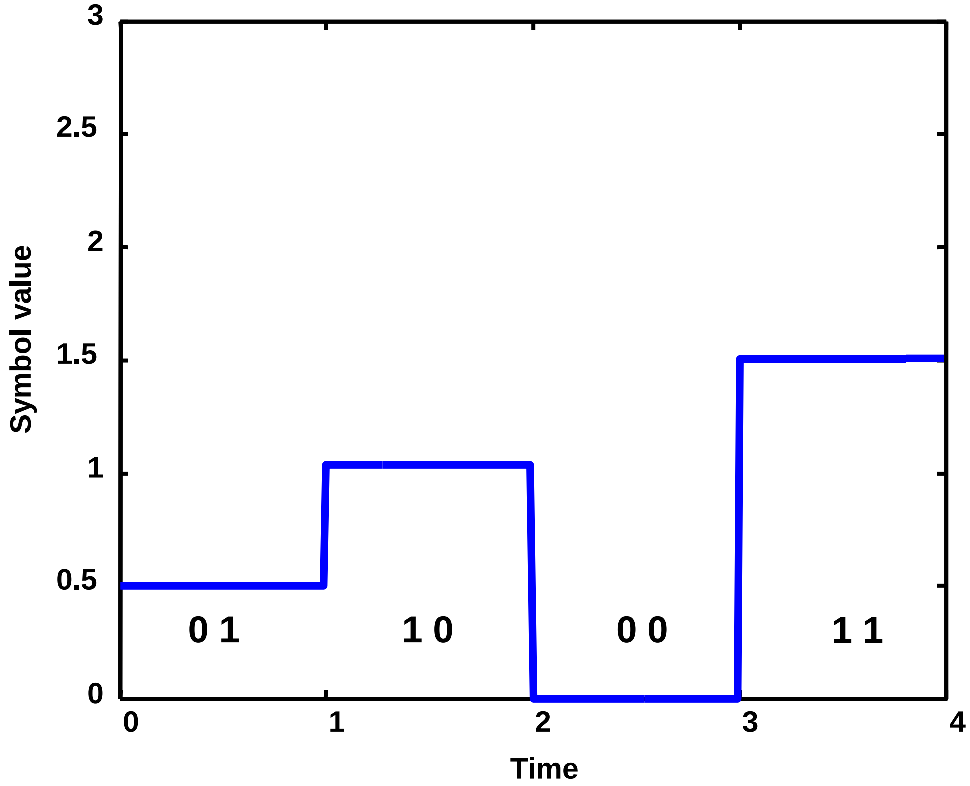
Use More Than 0 and 1 in Channel

- Who says we can only use 0 and 1 as possible levels for the transmitted signal?
- Suppose the transmitter can generate signals (current, voltage, …) at *four different levels*, instead of just two
  - To select one of four levels, *two bits* are required

- Terminology
  - *Bits* are 0 or 1, used in “higher” layers
  - *Symbols* (with multiple values) are transmitted over channel
  - *Symbol rate*: Rate with which symbols are transmitted
    - Measured in baud
  - *Data rate*: Rate with which physical layer processes incoming data bits
    - Measured in bit/s

Example: Bits and Symbols

- Use 4-level symbols to encode 2 bits:
  - Map
    00 ➔ 0
    01 ➔ 1
    10 ➔ 2
    11 ➔ 3

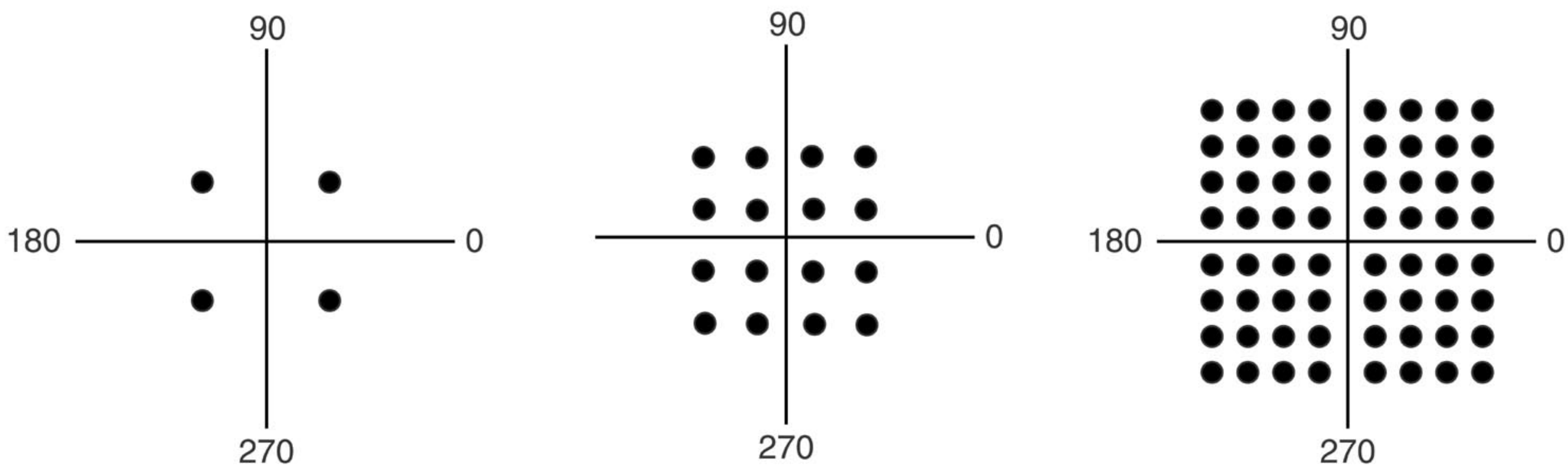


➢ Symbol rate is only half the data rate as each symbol encodes two bits

Example: Bits and Symbols

- Today's systems:
  - Many bits per symbol
  - Often Phase Shift Keying/Amplitude Shift Keying combined

- Constellation diagram encodes amplitude and phase of symbols



Data Rate with Multi-valued Symbols

- Using symbols with multiple values increases data rate
- *Nyquist's formula:*

$$\text{maximum data rate [bit/s]} = 2H \log_2(V)$$

V: number of symbol values

H: bandwidth in Hz

- Indicates that unlimited data rate can be achieved when enough symbol levels are used
- But: More and more symbol levels have to be spaced closer and closer together
  - Even small random noise would then result in one symbol being misinterpreted for another

Achievable Data Rate with Noise

- Achievable data rate is limited by noise
  - More precisely: by relationship of signal strength compared to noise, i.e., Signal-to-Noise Ratio (SNR, S/N)
- *Shannon's formula:*

$$\text{maximum data rate [bit/s]} = H \log_2 (1 + S/N)$$

S: signal strength

N: noise level

H: bandwidth in Hz

- S/N commonly expressed in dB:
  - S/N [dB] = $10 \times \log_{10}(S/N)$
- This theorem formed the basis for information theory

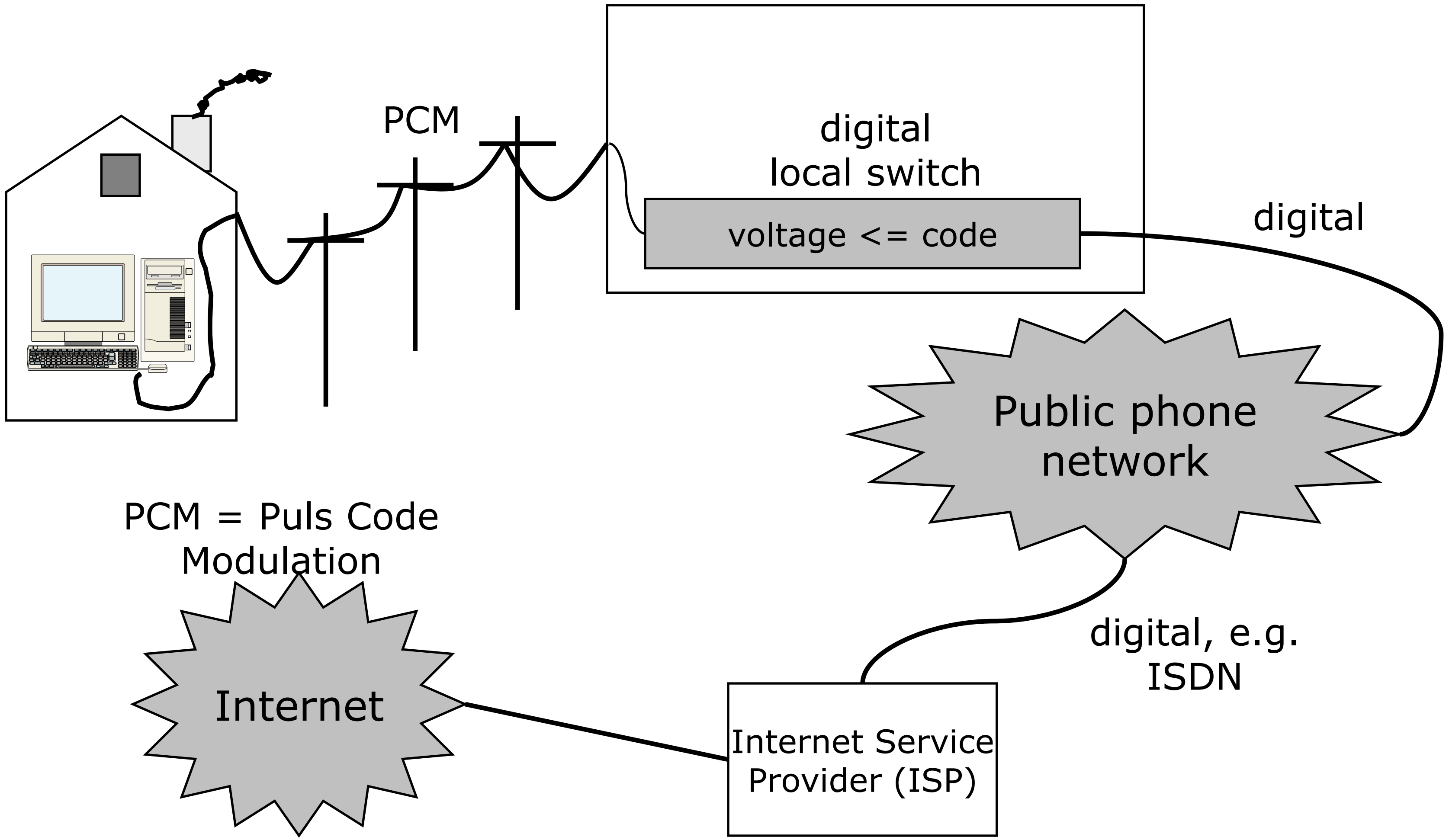
Classical Modems for Analog Subscriber Lines: V.90/V.92

- Idea
  - Modulation/Demodulation of signals depending on data
  - Dynamically adaptation to medium characteristics

- Key parameters
  - Data rates up to 56 kbit/s downstream (provider to user)
  - Upstream 33.6 kbit/s (based on V.34)
    - V.92: 48 kbit/s upstream plus data compression (V.44)

- Technology
  - Digital infrastructure required, only last mile analog
  - Digital transmission from provider to last switch
  - PCM signals from switch to modem
  - Data rates depend much on line quality
    - Line probing required plus adaptation

V.90 Basic Architecture



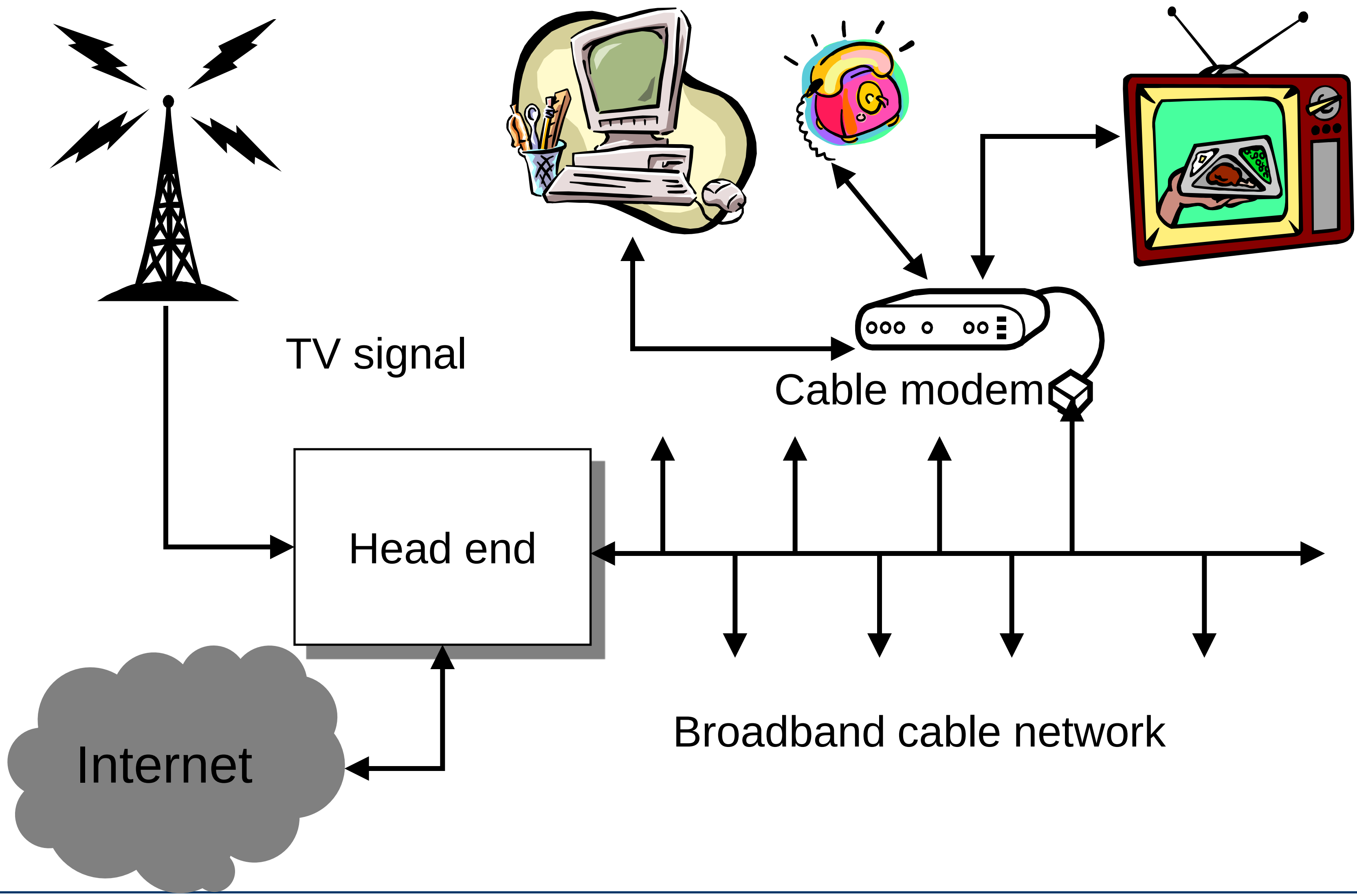
Newer Modem Technologies

- Cable modem
  - Data transmission via broadband cable (TV)
  - Infrastructure must be bi-directional
  - Data rates in the Gbit/s range but always shared medium

- Powerline communications
  - Data transmission via power lines
  - Couple high-frequency signals into standard power lines
  - Data rates up to several Mbit/s but shared medium

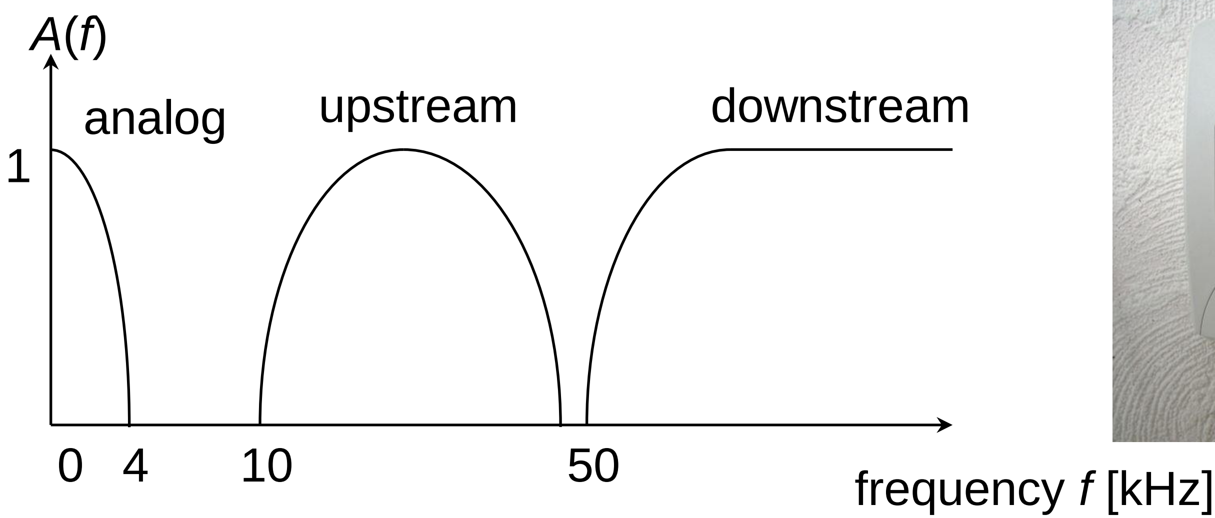
- xDSL modems
  - Higher data rates using conventional phone lines
  - Typical data rates up to 16 Mbit/s downstream, up to 1 Mbit/s upstream (ADSL)
  - Not everywhere, rates depend on location, interference …
  - Special technologies for faster response (“FastPath”)
  - Up to 50/100/200 Mbit/s at certain places (VDSL)
  - Symmetrical for companies/servers

Broadband Cable:
Digital TV Plus Internet

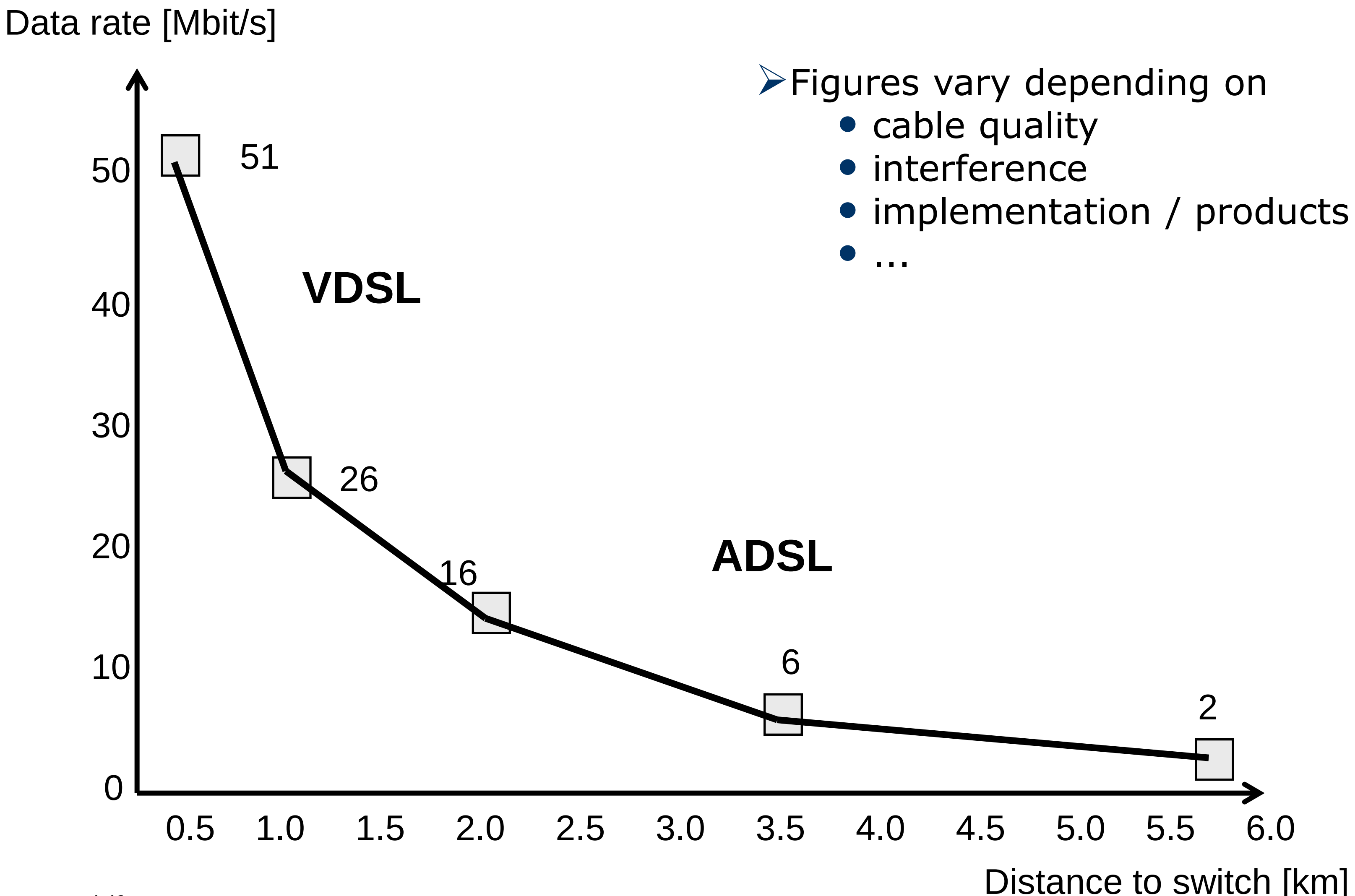


xDSL

- xDSL: Different DSL (Digital Subscriber Line) technologies
- Goal: Use already existing phone lines (simple twisted pair, unshielded) for higher data rates
  - Works around last mile problem
  - Similar to ISDN: Replacement of analog phone system by a fully digital system (offering *n* 64 kbit/s channels)
- Co-existence of classical analog (or digital ISDN) phone system plus high data rates



Typical Downstream Data Rates



- Figures vary depending on
  - cable quality
  - interference
  - implementation / products
  - ...

Source: www.dslforum.org

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