Modul - IT Systems (IT)

Bachelor Programme AAI

07 - Lecture: Networks

Prof. Dr. Marcel Tilly

Faculty of Computer Science, Cloud Computing

Agenda

- Computer networks
- Data transmission
- OSI Layer Model
  - Physical Layer
  - Link Layer

Learning objectives

Students will be able to ...

- ... explain computer networks
- ... explain basic concepts of data transmission
- ... explain the OSI model
- ... explain basic concepts of physical and link layer

Computer Networks

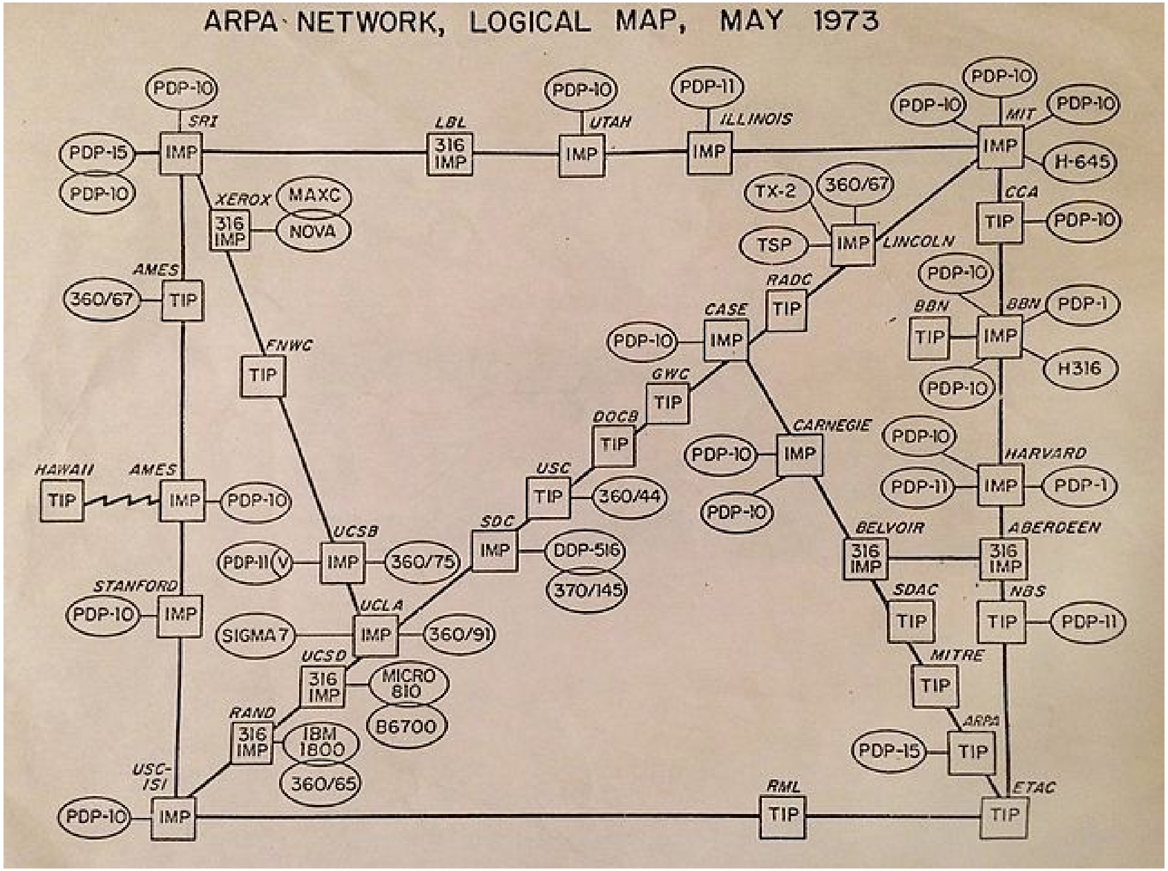
- **Computer networks** are used to exchange data between computers.
- The data can be transmitted via cable, optical fiber, electromagnetic radiation, ... (there are also somewhat more unusual transmission media - see RFC 1149).
- One of the first large networks was ARPANET, the forerunner of today's Internet. The US government (more precisely, DARPA) wanted to create a decentralized and fault-tolerant network for military research.
- In the early 1970s, Vint Cerf and Robert Kahn finally created the basis for today's Internet, and then in the early 1980s the new Internet replaced the old ARPANET.
- A major component of the ARPANET was the **Interface Message Processor (IMP)**.
  - This is a packet switching node for the ARPANET and immediate predecessor of modern routers.
  - IMPs were the subject of the first Request for Comments in April 1969.

The IMP

Technische Hochschule Rosenheim

- IMPs used special serial interfaces to communicate with the hosts they connected to the ARPANET.
- The IMP was conceived by Wesley A. Clark:
  - Clark proposed to define an interface that could be implemented as easily as possible for all systems, and to implement the interface to the external network separately for those systems that could mediate between the others - Until then, it had been envisaged to develop software for each operating system to be networked, which would establish the interoperability of all of them.
  - This concept became an essential foundation of the later Internet.
- The first IMP was located at the University of California, Los Angeles. The second IMP was located at the Stanford Research Institute(SRI).
- The first communication was made on October 29, 1969, under the direction of Leonard Kleinrock.
  - It was the first two letters of the word "login". The system crashed when the third letter was sent.

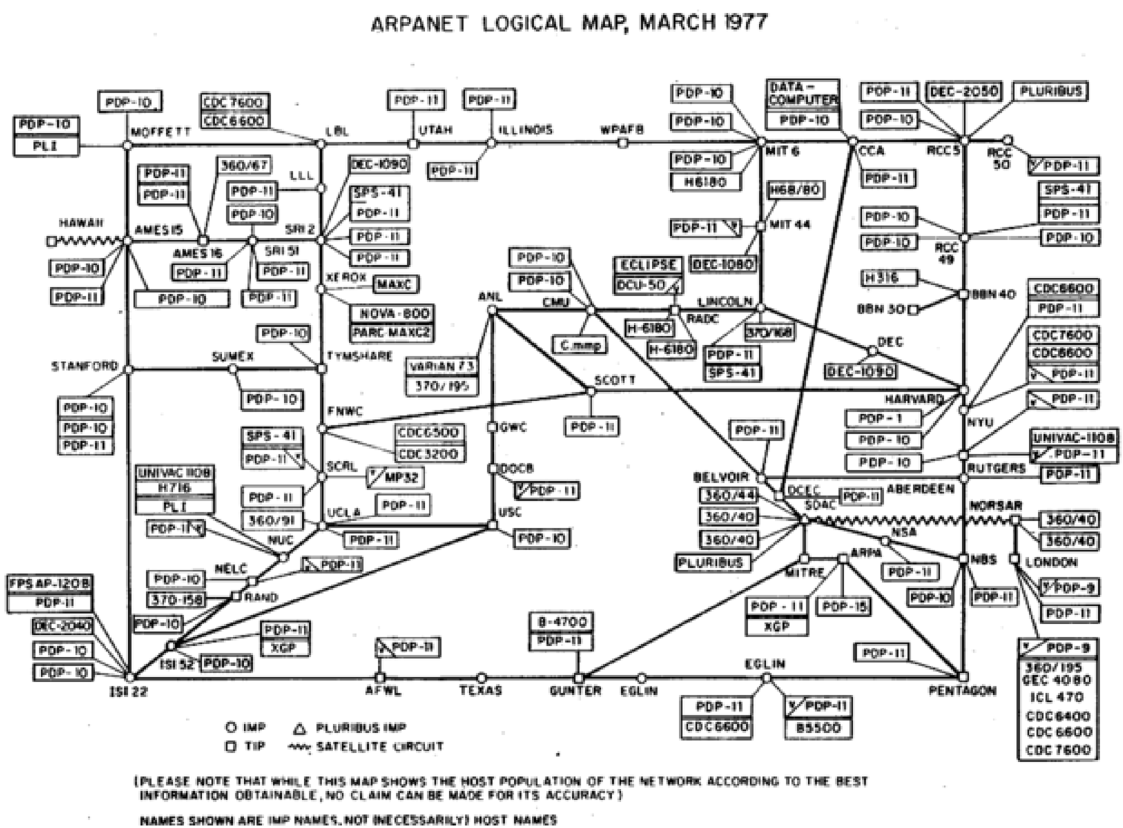
Logical map ARPANET 1973



taken from https://de.wikipedia.org/wiki/Arpanet#/media/Datei:Arpanet_map_1973.jpg

Logical map ARPANET 1977

Technische Hochschule Rosenheim



taken from https://de.wikipedia.org/wiki/Arpanet#/media/Datei:Arpanet_logical_map,_march_1977.png

Motivation: Layer model

- How to get *complexity* under control?
  - Heterogeneous networks of different autonomous organizations
  - Infinite number of hosts with different features.
- How to add new *features* without developing/programming everything from scratch?
- How to develop and program the hardware, drivers, and applications needed for data communications in a modular fashion?

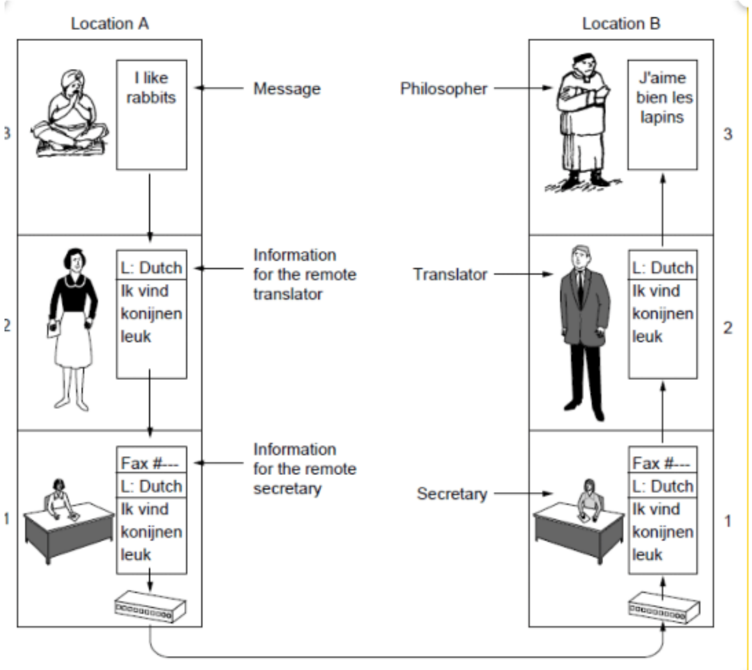
Motivation: Layer model

- How to get *complexity* under control?
  - Heterogeneous networks of different autonomous organizations
  - Infinite number of hosts with different features.
- How to add new *features* without developing/programming everything from scratch?
- How to develop and program the hardware, drivers, and applications needed for data communications in a modular fashion?
- **Solution**: Layer model
  - Examples from everyday life:
    - Sending mail (philosopher, translator, secretary).

Philosopher, Translator, Secretary

2 philosophers ...

- 2 philosophers want to discuss with each other
    - 1 philosopher speaks only English
    - 1 philosopher speaks only French
- Both secretaries speak Dutch
- Protocols on the 3 layers serve different purposes



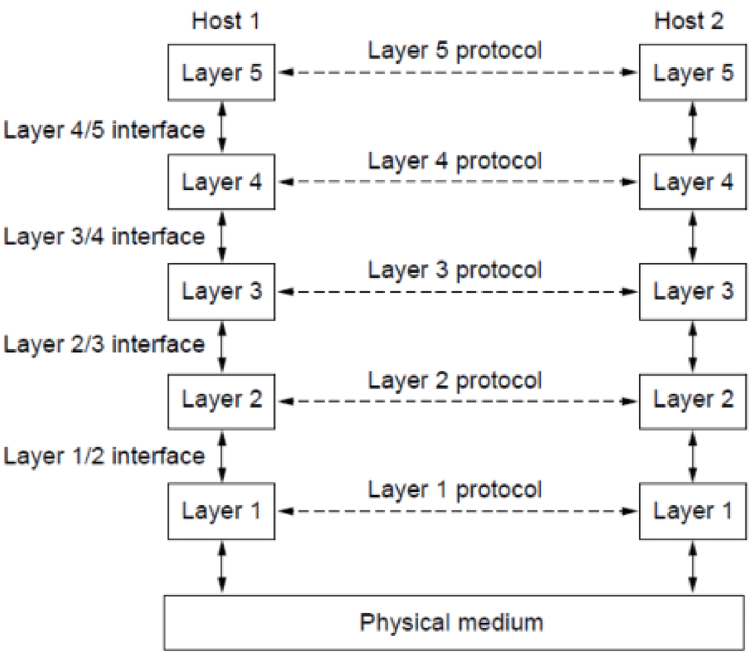
The OSI model

Technische Hochschule Rosenheim

- The **OSI model** (Open Systems Interconnection Model) is a reference model for network protocols.
  - It includes **seven** layers and describes how devices can communicate with each other.
  - Each of these layers performs a different task.
  - In the **OSI** model, instances of the same layer always communicate with each other via a protocol, e.g. layer 3 on the first device with layer 3 on the second device.
  - The data is passed from the top layer to the bottom layer on the sending device.
    - possibly provided with meta information
    - transmitted
    - and on the receiving side from the lowest layer to the highest layer (where the meta information is read out and removed).
  - The OSI model does not define a network architecture. It only says what the individual layers should do.

Horizontal and vertical communication

- Horizontal:
    - Each protocol instance talks virtually to the protocol instance on the same layer opposite.
- Vertical: Each layer ...
    - ...uses the services of the layer below
    - ...provides a "new" service upwards (Service Access Point = SAP)



Technische Hochschule Rosenheim

The 3 concepts of the OSI model

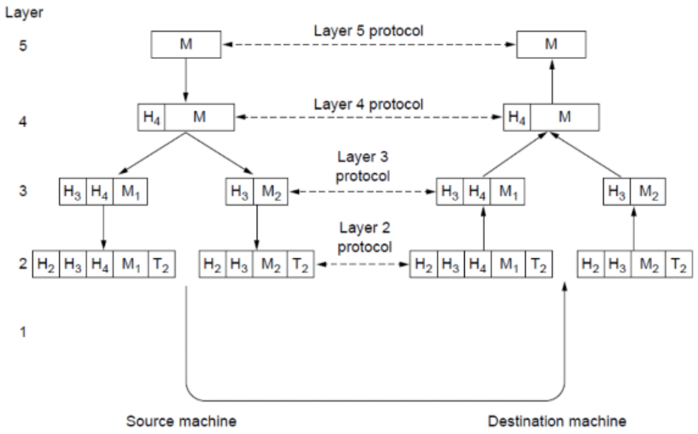
These are: *services*, *interfaces*, *protocols*.

- **Service** defines what the layer does.
  - Each layer provides services to the layer above it.
- **Protocols** regulate how the process is performed within a layer (except in the physical layer).
  - Because they are arranged in layers on top of each other, the resulting structure is also called a protocol stack.
  - A protocol defines the sequence of certain processes
  - In the network area for data transmission, this includes, among many other things, the addressing of the network components.
- The **interface** of the lower layer tells the layer above how to access its services.

Layer model

Implementation through headers

- Each layer adds its own *header* to message to be transmitted.
- The receiver removes this header again.
  - *Header* = envelope or control information.
- Some layers split (too large) messages also. The message is then reassembled on the opposite side.



OSI layers

Layers and meaning

#	Layer	Meaning	Units
7	Application Layer	Application Layer	
6	Presentation Layer	Data	
5	Session Layer	Communication Layer	
4	Transport Layer	TCP, UDP	
3	Network Layer	Network Layer	Packets
2	Data Link Layer	Link Layer	Frame
1	Physical Layer	Physical Layer	Bits, Symbols, Packets

Reference model

In network technology, the OSI model developed by ISO represents the first step toward international standardization. (1983)

- OSI stands for *Open Systems Interconnection*.
- The model defines an open communication system.
- The OSI - reference model divides the functions required for data communication into individual sections: **These are called layers**.
- *An important principle*: There should be enough layers so that several functions do not have to be packed into one. But neither should there be more layers than are really necessary.
- In this case, seven layers has been agreed upon.
- A further distinction is that the lower layers 1 to 4 are transport oriented, the upper layers 5 to 7 are application oriented.

OSI- Discussion

- **Advantages**
  - Breaking down complexity.
  - Each layer has clearly defined tasks, data structures and control mechanisms.
  - Transparency: layer does not need to know what exactly happens in higher or lower layer.
  - A layer can be changed without influencing other layers.
- **Possible disadvantages**
  - Slight overhead.
  - Practice / historical reasons: Same task implemented in multiple layers.
    - Example: Error correction on layer 2 and layer 4
  - Higher layer needs information from lower layer
    - Example: WLAN routing protocols (layer 3) need information from layer 2

OSI layers

Technische Hochschule Rosenheim

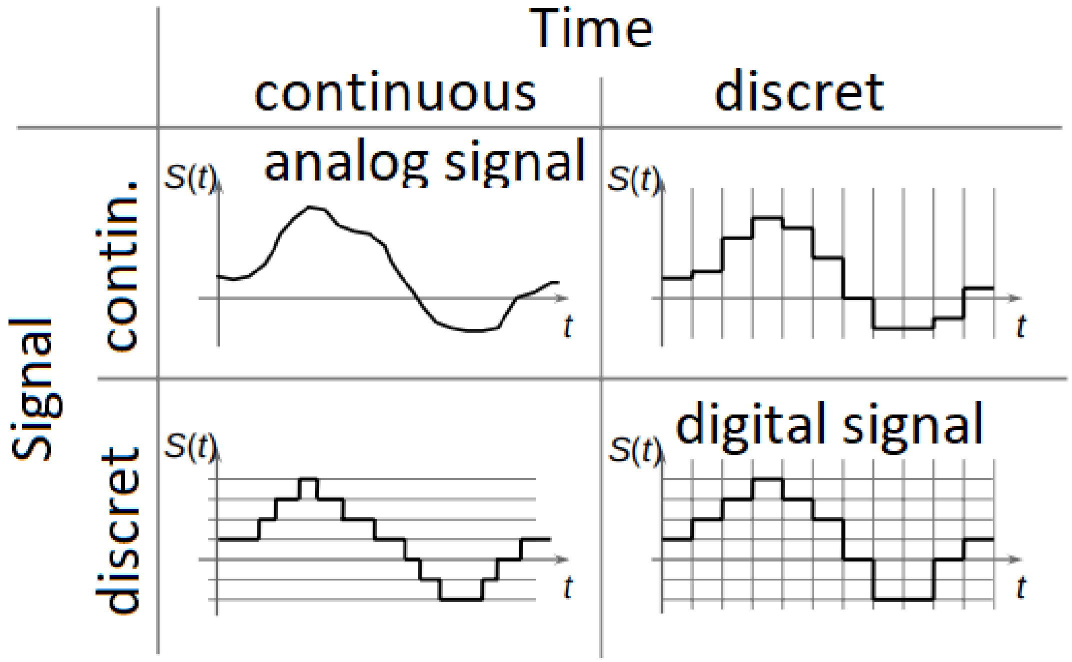
Layers and meaning

#	Layer	Meaning	Units
7	Application Layer	Application Layer	
6	Presentation Layer	Data	
5	Session Layer	Communication Layer	
4	Transport Layer	TCP, UDP	
3	Network Layer	Network Layer	Packets
2	Data Link Layer	Link Layer	Frame
1	Physical Layer	Physical Layer	Bits, Symbols, Packets

Physical Layer

Technische Hochschule Rosenheim

Signal classes

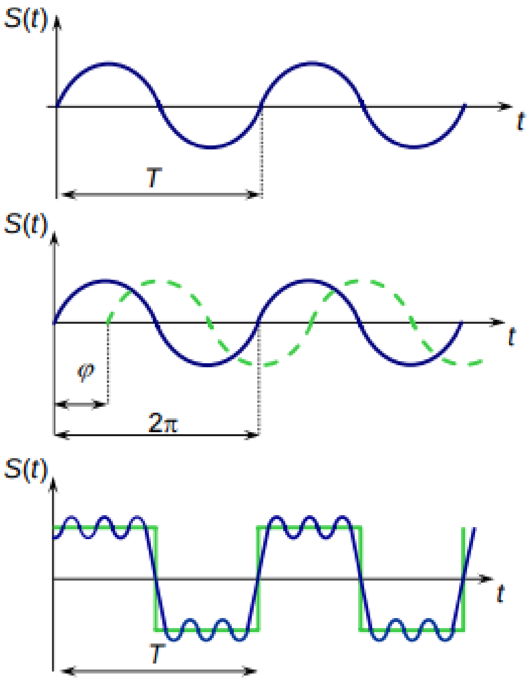


Physical Layer

Periodic signals

Phase, frequency

- Sinus wave
- Phase diff
- Square wave



Physical Layer

Signal transmission

- Each signal consists of many different frequencies.
- Attenuation
  - The longer the line, the more attenuation (reduction of power/amplitudes).
- Distortion
  - Transmission media attenuate frequencies to different degrees.
  - Usually only frequencies up to certain maximum value fc can be transmitted well.
- Bandwidth
  - Electrical engineering: Frequency range that can be transmitted "well".
  - Computer science: data rate that is possible under physical conditions.

Example: Transmission of the signal 01100010

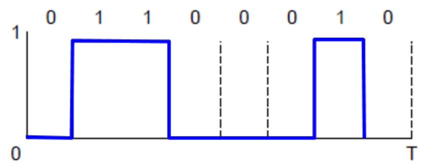
What could this look like?

Physical Layer

Signal transmission

- Each signal consists of many different frequencies.
- Attenuation
  - The longer the line, the more attenuation (reduction of power/amplitudes).
- Distortion
  - Transmission media attenuate frequencies to different degrees.
  - Usually only frequencies up to certain maximum value *fc* can be transmitted well.
- Bandwidth
  - Electrical engineering: Frequency range that can be transmitted "well".
  - Computer science: data rate that is possible under physical conditions.

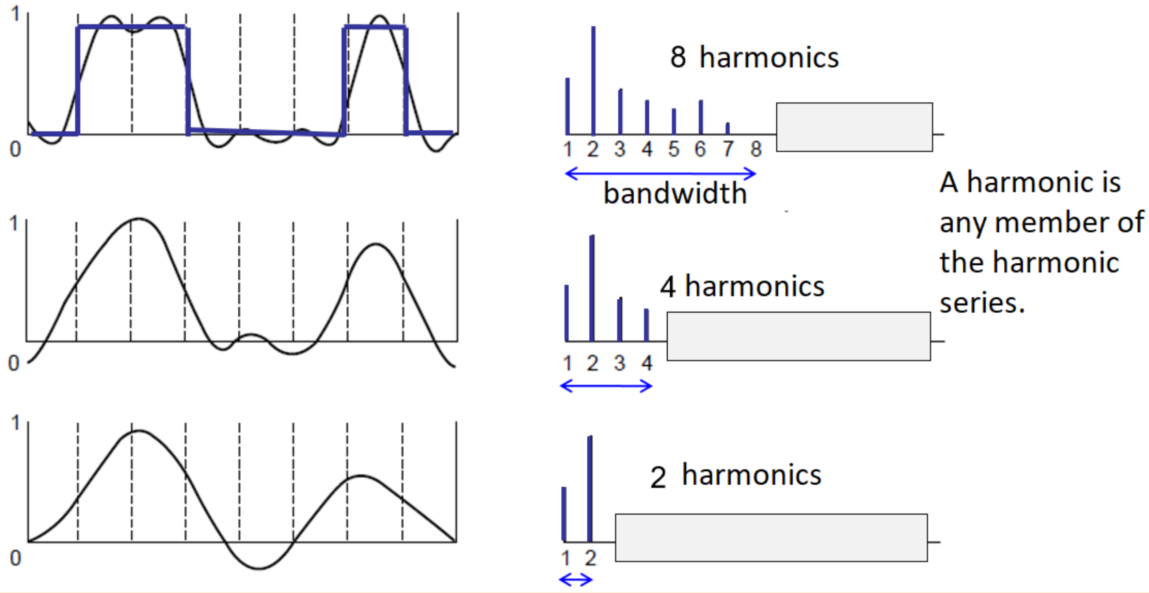
Example: Transmission of the signal 01100010



Physical Layer

Limited bandwidth

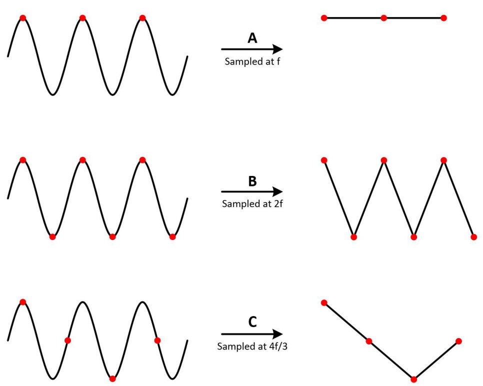
- Due to distortion, certain frequency components are not transmitted well.
- Loss of high frequency components → signal cannot be reconstructed.



Nyquist sampling rate

- The Nyquist sampling theorem is used to explain the relationship between the sample rate and the frequency of the measured signal.
- The theorem states that the sample rate f_s must be at least twice greater than the highest frequency component to be examined in the measured signal.
- Consequently, this frequency is often referred to as the "Nyquist frequency", f_N.

$$f_s > 2 * f_N$$



Nyquist Theorem

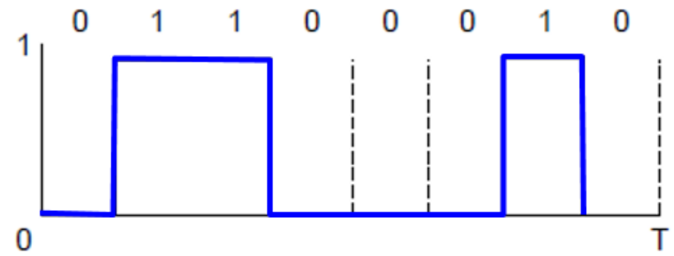
Data rate *D* at unnoised channel

- Data rate D for **unnoisy** channel depends on:
  - Bandwidth B (size of the transmittable frequency range)
  - Number of signal stages used V

Nyquist theorem : $D = 2Blog_2V$

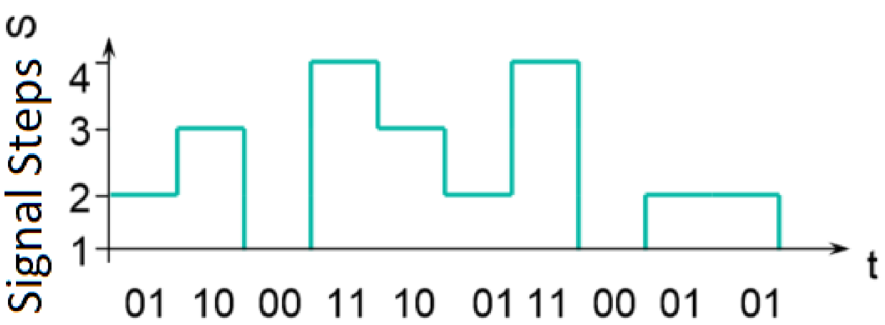
High bandwidth → high data rate

- **Question: What is V for the mapped signal?**.
  - B=4 kHZ, (channel unnoised!)
  - How many signal levels *V* are there?
  - What is the maximum data rate?



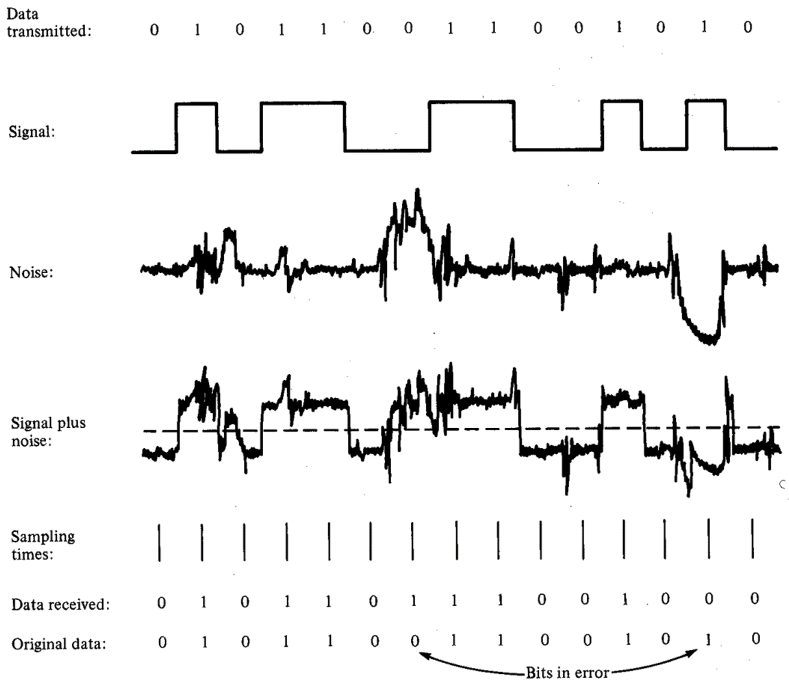
Baud rate vs. bit rate

- **Bitrate = Data rate**
  - Number of transmitted bits per time unit.
  - Unit: bit/s, kbit/s, KB/s, etc.
- **Baudrate = Step rate**
  - Number of signal steps per second (symbols).
  - Unit: [baud] or [Bd].
    - Ex: Each signal step / each symbol / each step represents 2 bits!
  - If there are many possible symbols, the hardware complexity increases.



Example

Example: Bit error in noisy channel



from tanenbaum

Shannon theorem

Maximum data rate D for noisy channel

Shannon Theorem: $D = B * log_2(1 + S/N)$

- Delimitation
  - Applies in addition (!) to Nyquist.
  - Limit for data rate when noise is present.
- S/N: Signal-to-noise ratio (S/N)
  - Power of the useful signal S / power of the noise N
- S/N usually expressed in decibels (dB).
  - dB value: $10 * log(S/N)$
  - Example: S = 100mW, N = 1 mW, S/N = 100 → ?? dB!
- Noise sources
  - Intermodulation, crosstalk, thermal noise.

Physical Layer

Physical transmission media

Which ones come to your mind?

Go to https://zumpad.zum.de/p/it-systeme and collect!

Physical Layer

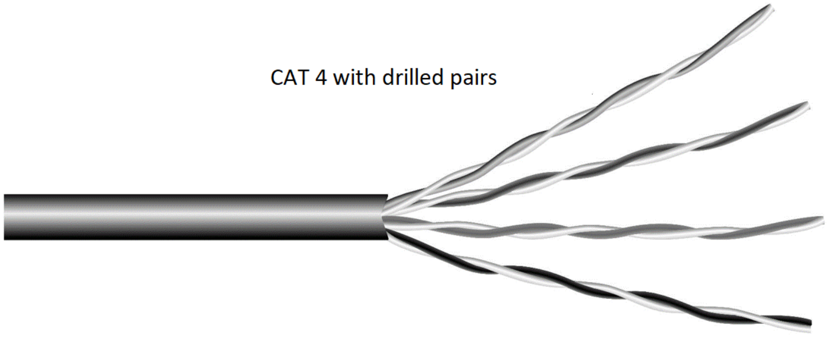
Transmission media

- Wired / Cable
  - twisted pair
  - Coaxial cable
  - Fiber optic cable
  - Power Grid
- Wireless / Air
  - Radio links
  - Satellite
  - mobile radio
  - WLAN
- Different transmission media → different properties and bandwidths

Physical layer

Transmission media

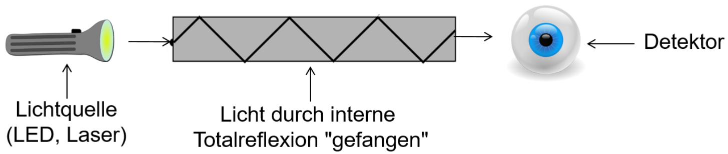
- Often used in
  - Local Area Networks (LANs)
  - telephone lines
- Twisting reduces attenuation
  - Cable otherwise radiates like an antenna.
- Different specifications (Categories)
  - CAT5: Operating frequency 100 MHz
  - CAT6: Operating frequency up to 250 MHz 100m
  - CAT6/7: Up to 600 Mbps at 100m



Physical Layer

Technische Hochschule Rosenheim

Fiberglass



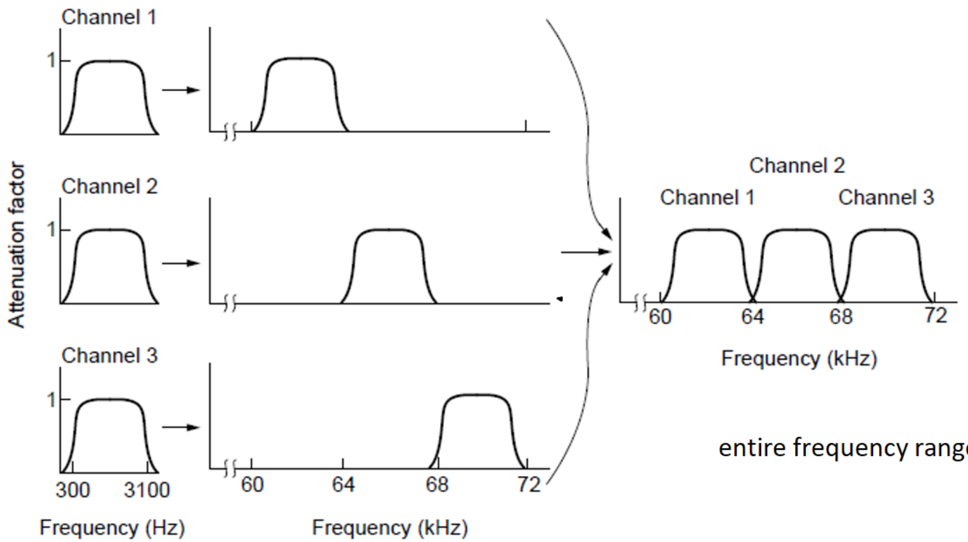
- Deployment
  - Backbone links
  - Fiber-to-the-Home (FTTH)

- Multi-mode
  - Core with "larger" average (>10 µm)
  - Light is reflected as shown in figure
  - Multiple simultaneous light beams possible.

- Single-mode
  - Very narrow core (<10 µm)
  - Light beam has no clearance at all
  - More expensive → for longer distances!

Frequency Division Multiplexing

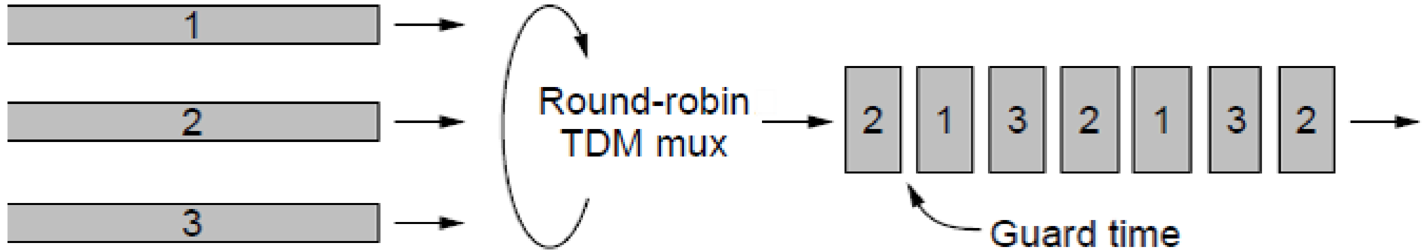
- Frequency Division Multiplexing = **FDM**
- Frequency ranges are allocated to users.
- Each user uses his frequency range.



entire frequency range

Time Division Multiplexing

- Time Division Multiplexing = **TDM**
- Frequency range (channel) is divided over time.
- Users alternate in time.
- Commonly used in telephone and cellular networks.



Physical Layer

Duplex vs Simplex

- Full-duplex (engl. Full duplex)
  - Both transmission directions possible at the same time
  - Mostly for cable transmission
- Half-duplex (German: Halbduplex)
  - Both transmission directions, but not simultaneously
  - Example: WLAN
- Simplex
  - Only one transmission direction possible
  - Unusual.

Question

Full-duplex, half-duplex, or simplex?

```
- Lecture?
- Soccer stadium?
- One-way street?
```

PINGO Survey: ID 328791

https://pingo.coactum.de/328791

OSI layers

Technische Hochschule Rosenheim

Layers and meaning

#	Layer	Meaning	Units
7	Application Layer	Application Layer	
6	Presentation Layer	Data	
5	Session Layer	Communication Layer	
4	Transport Layer	TCP, UDP	
3	Network Layer	Switching Layer	Packets
2	Data Link Layer	Link Layer	Frame
1	Physical Layer	Physical Layer	Bits, Symbols, Packets

Link Layer

Services of the Link Layer

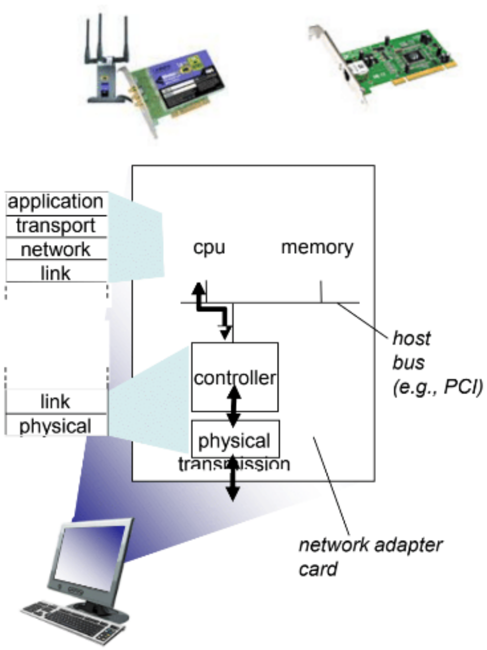
- Transmission of frames between neighboring *nodes*.
- Framing
  - Positional recognition of characters, recognition of block boundaries.
  - *Frame = Header + Payload*
  - also *payload = IP packet*
- Multiple access: Who may use the medium and when?
  - Necessary if multipoint medium.
  - Examples: WLAN, satellite networks, access network for cable connection
  - Error detection and correction
- Dealing with bit errors on the physical layer.
- Add redundancy to detect or correct errors.
- Reliable data delivery.
- Correction of packet losses, correct sequence, avoidance of duplicates.
- Partially for WLAN, not at all for Ethernet

Link Layer

Technische Hochschule Rosenheim

Services of the link layer

- In all nodes
    - Also routers and switches!
    - Not in hubs!
- Implementation of most functionality in hardware
    - Error detection
    - Framing
- Network Interface Card (NIC)
    - Implements large parts of the link layer and physical layer (line codes, etc.).
    - Connected to CPU via bus



Link Layer

Technische Hochschule Rosenheim

Ethernet 802.3 frames

- Preamble
  - At the beginning: 7 times 10101010, then 1 time 10101011
  - Synchronization of sender and receiver, start of frame.
- Addresses
  - Each 6 byte sender and receiver MAC address.
  - Exceptions:
    - Dest. MAC is FF:FF:FF:FF:FF:FF
    - Promiscuous Mode
- Type
  - 2 bytes -> specifies type of network protocol (IPv4, IPv6)
- CRC

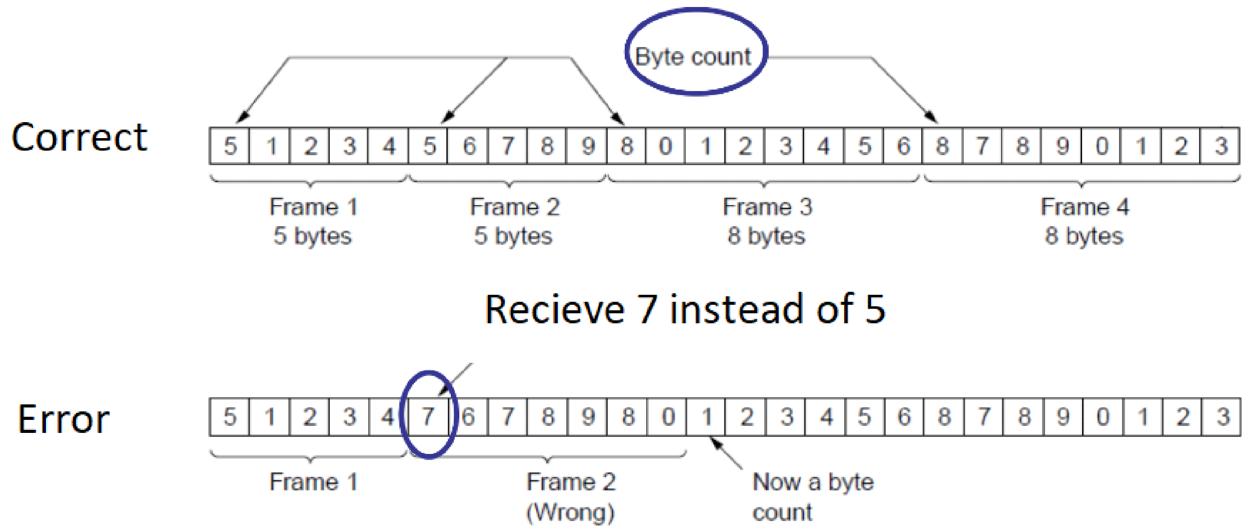
Link Layer

Framing

- Physical Layer receives and transmits **bit stream**.
- Error handling by link layer only possible
  - if bits are split into finite sequences (=frame).
  - Frame has redundancy (e.g. checksum), see next section.
- Problems
  - How does receiver recognize *frame start and end* from bit stream?
  - How to transmit arbitrary bit and character combinations?
- **Solutions**
  - Byte Count
  - Byte Stuffing
  - Bit Stuffing

Byte Count: Length specification of the user data

- Each frame starts with a field that specifies the number of bytes it contains.
- Disadvantage: Re-synchronization after error difficult or impossible!

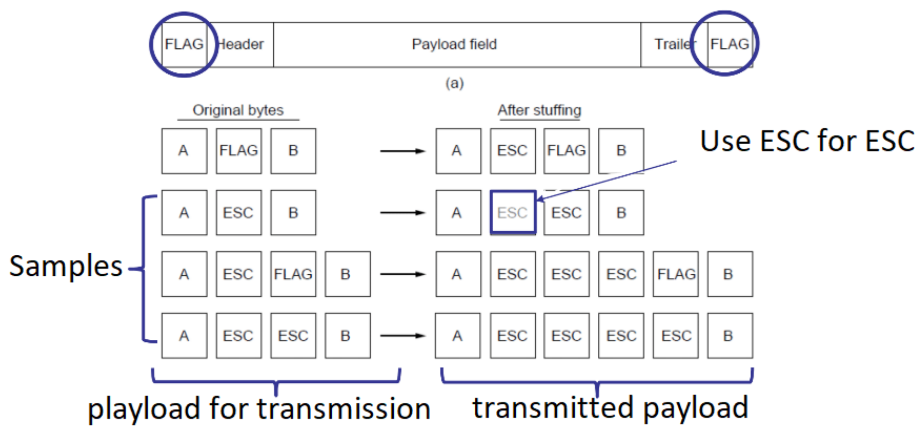


Link Layer

Technische Hochschule Rosenheim

Byte stuffing: control characters and character stuffing

- Reserved byte **FLAG** marks **frame start and end**.
- Possible problem: **FLAG** occurs in user data
  - Way out: Use another reserved byte ESC (=escape)
  - Simple synchronization after error, but overhead!



Link Layer

Technische Hochschule Rosenheim

Bit stuffing: bounding box and bit stuffing.

- **Advantage**: Frame length does not have to be a multiple of 8 bits!
- Each frame starts with special reserved bit pattern:
  - Here in the example: 01111110
- Rules
  - When **transmitting**: A 0 bit is always inserted after 5 1 bits.
  - On **Receive**: After 5 bits of 1, a 0 bit is always deleted.

Data bits 0 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 0

Tranmitted bits (after stuffing) 0 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 0 0 1 0

Stuffed bits

Link Layer

Technische Hochschule Rosenheim

Handling bit errors

- Causes of bit errors: noise, attenuation, distortion, etc.
- Basic idea
  - Framing (e.g., check sum over frames)
  - Redundancy (e.g. checksum over frames)
- Error correction through redundancy
  - Requires a lot of redundancy
  - Common with non-repeatable media (CD, RAM, etc.), not with TCP/IP
- Error detection by redundancy
  - Error is only detected, but not corrected.
  - Measures:
    - *Ethernet 802.3*: No retransmission. Retransmission of the faulty block possibly only by TCP if timeout occurs.
    - *WLAN 802.11*: Active re-request of the faulty block by Link Layer (=Active Repeat Request).

Link Layer

Technische Hochschule Rosenheim

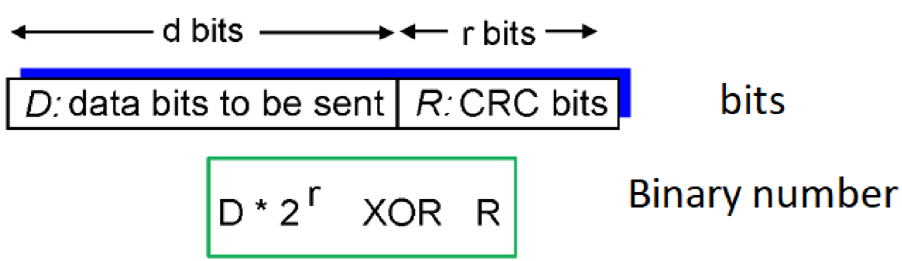
Checksum (in IP and TCP headers)

- Idea: **Addition**.
  - Consider bits in groups of 16-bit words
  - Sum all 16-bit words considering the carry
  - 1's complement of the result is the checksum
- Check at receiver relatively simple
  - Add all transmitted words AND checksum
  - Result must consist of 1s bits, otherwise error

Word 1		1	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
Word 2		1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Carry	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1
Sum		1	0	1	1	1	0	1	1	1	0	1	1	1	1	0	0
Checksum		0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	1

Cyclic Redundancy Check (CRC)

- Consider data bits *D* to be transmitted as an unstructured bit sequence (binary number).
- Approach
  - **Generator G**: Sender and receiver know common bit pattern of $r+1$ bits.
  - **R**: Sender determines r additional bits and appends them to data *D*.
    - The resulting bit pattern of length *d+r* is then transmitted.
    - Important: The bits *d+r* must be divisible by *G*.
  - Receiver makes sample and checks if divisible by G $(D * 2^r XOR\ R) = nG$
- Ethernet and WLAN: Implementation of CRC in hardware possible



Link Layer

Technische Hochschule Rosenheim

Example: Cyclic Redundancy Check (CRC)

- Calculation in XOR arithmetic, without carry.
- **Given**: Generator G with r+1 bits
- **Sought is R**:
  - r bits to be appended to D.
  - $(D * 2^r) XOR\ R$
- Calculation of R:
  - First append r 0s bits, then divide by G.

$$R = remainder(D * 2^r / G)$$

  - Complete R with leading zeros to r digits, if necessary.

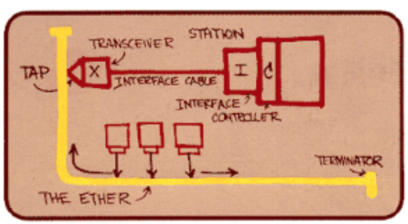
Example: D = 101110, d= 6, G= 1001, r= 3

Link Layer

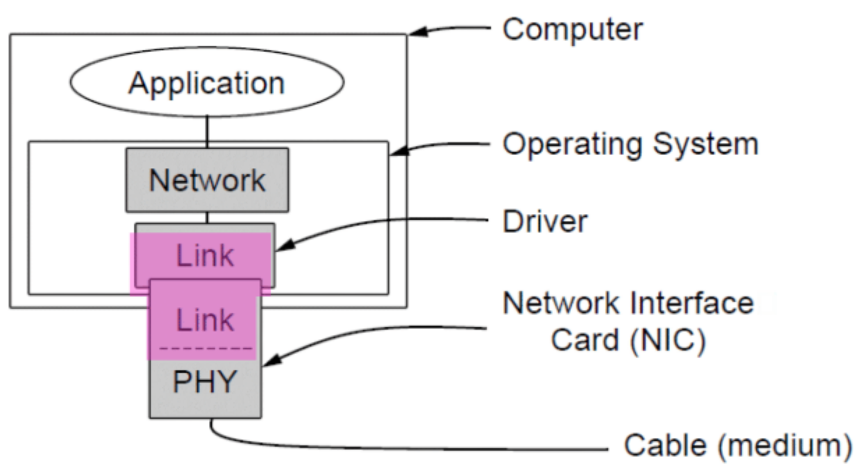
Technische Hochschule Rosenheim

Ethernet

- Dominant LAN technology
- Network cards are inexpensive (< 3 Euro)
- Speeds increased constantly: 10 Mbps -10 Gbps



Ethernet Schema von Metcalf



Link Layer

Technische Hochschule Rosenheim

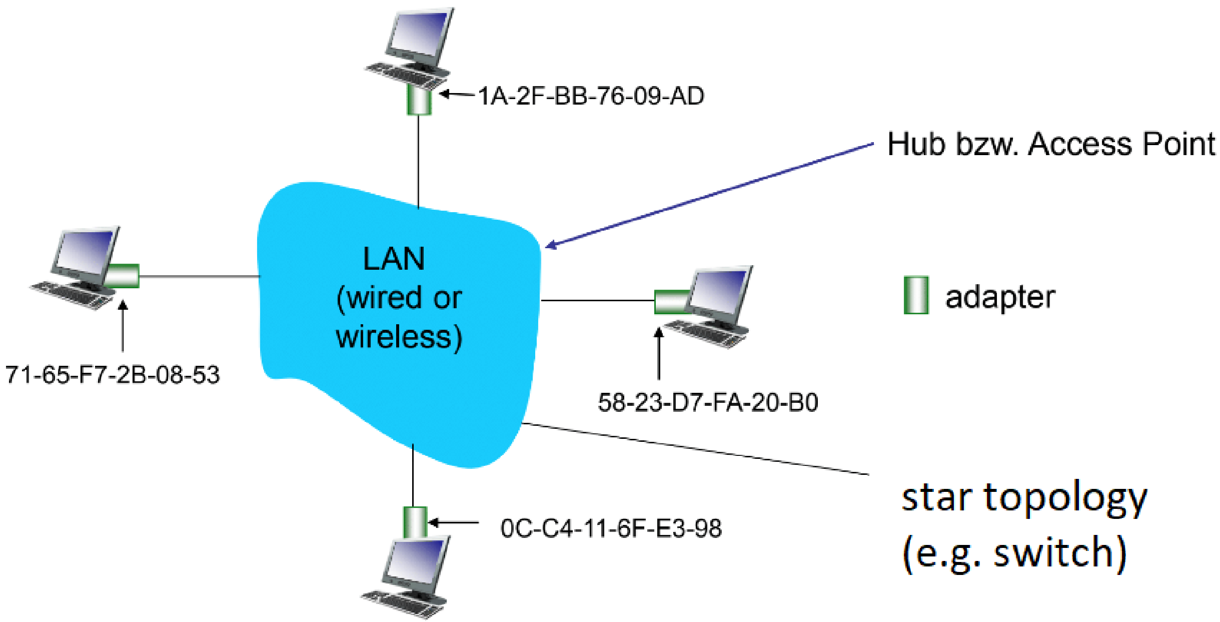
Mac address

- Address of the link layer
    - Identifies neighbors, important especially for multipoint connections.
    - Only valid locally (LAN, WLAN).
- Each interface of a host / router has its own MAC address.
    - A device can have several MAC addresses.
- Ethernet and WLAN: 48 bit
    - Partly fixed to network card
    - Sometimes changeable by SW
    - Example: *1A-2F-BB-76-09-AD*
    - Broadcast address: FF-FF-FF-FF-FF
- Addresses are assigned by IEEEoVendor buy address space

Link Layer

Technische Hochschule Rosenheim

LAN addresses



Each network card must have **unique** MAC address!

Summary

Lessons Learned …

- … OSI layer model
- … Physical Layer
- … Nyquist and Shannon theorem
- … Transmission media
- … Multiplexing
- … Link Layer
- … Framing