FRANKFURT
UNIVERSITY
OF APPLIED SCIENCES

COMPUTER NETWORKS

Basics

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2024-10-21

AGENDA

- Historical background
- Components and Terms
- Reference Models
- Topologies

HISTORICAL BACKGROUND

SUCCESS FACTORS

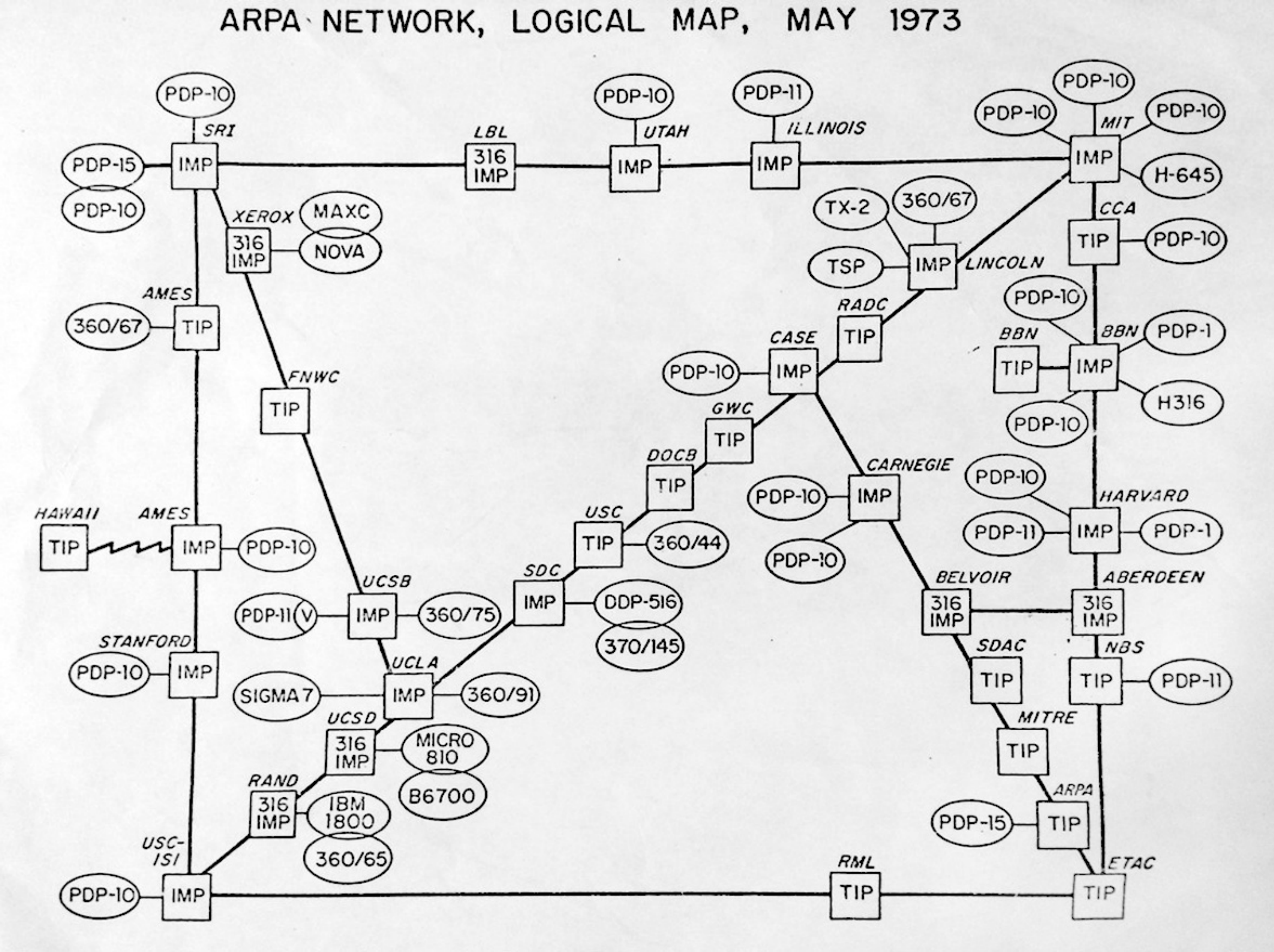
The concept of **Freedom** and **Openness**

- **Free** and **Open Systems**
- **Free** and **Open Standards**
- **Free** and **Open Source**

WHY FREEDOM AND OPENNESS ARE IMPORTANT?

- Diversity
- Security
- Sustainability
- (Digital) Sovereignty
- Privacy
- Freedom

THE ARPANET



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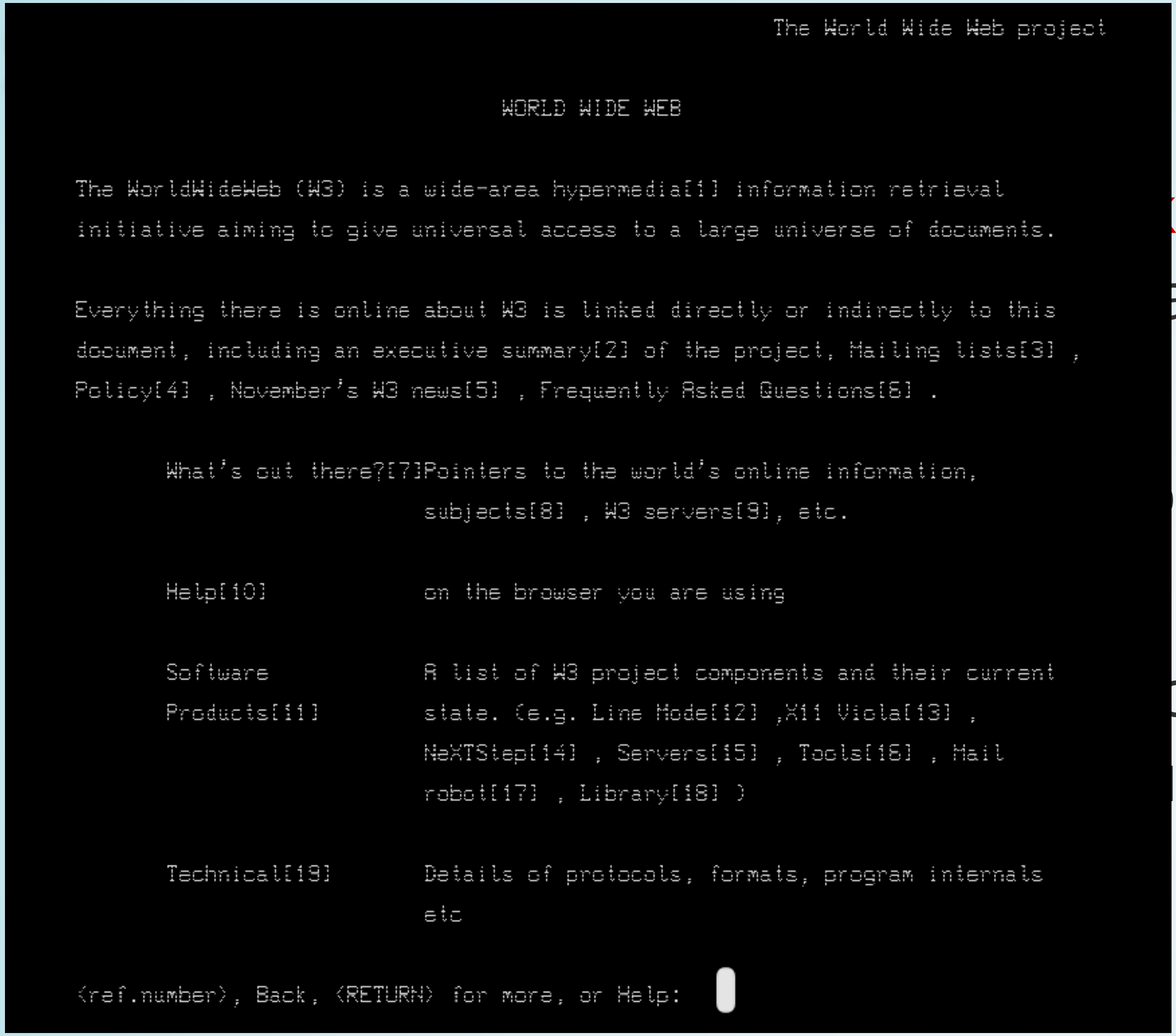
FIRST INTERNET PROTOCOLS

- **1972**: First public demo (remote login) using the Network Control Protocol (NCP) main use: terminal sessions, file transfer, Electronic Mail
- **1974**: Basics of TCP/IP written on paper by Cerf/Kahn (IP=Internet Protocol, TCP=Transmission Control Protocol), standardization in the following years
- **1982**: Transition towards IP version 4 (IPv4)
- **from 1983:**: Dissemination of TCP/IP due to Berkeley UNIX 4.2 BSD, source code publicly available



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                                              The World Wide Web project

                              WORLD WIDE WEB

   The WorldWideWeb (W3) is a wide-area hypermedia[1] information retrieval
   initiative aiming to give universal access to a large universe of documents.

   Everything there is online about W3 is linked directly or indirectly to this
   document, including an executive summary[2] of the project, Mailing lists[3] ,
   Policy[4] , November's W3 news[5] , Frequently Asked Questions[6] .

       What's out there?[7]Pointers to the world's online information,
                          subjects[8] , W3 servers[9], etc.

       Help[10]           on the browser you are using

       Software           A list of W3 project components and their current
       Products[11]       state. (e.g. Line Mode[12] ,X11 Viola[13] ,
                          NeXTStep[14] , Servers[15] , Tools[16] , Mail
                          robot[17] , Library[18] )

       Technical[19]      Details of protocols, formats, program internals
                          etc

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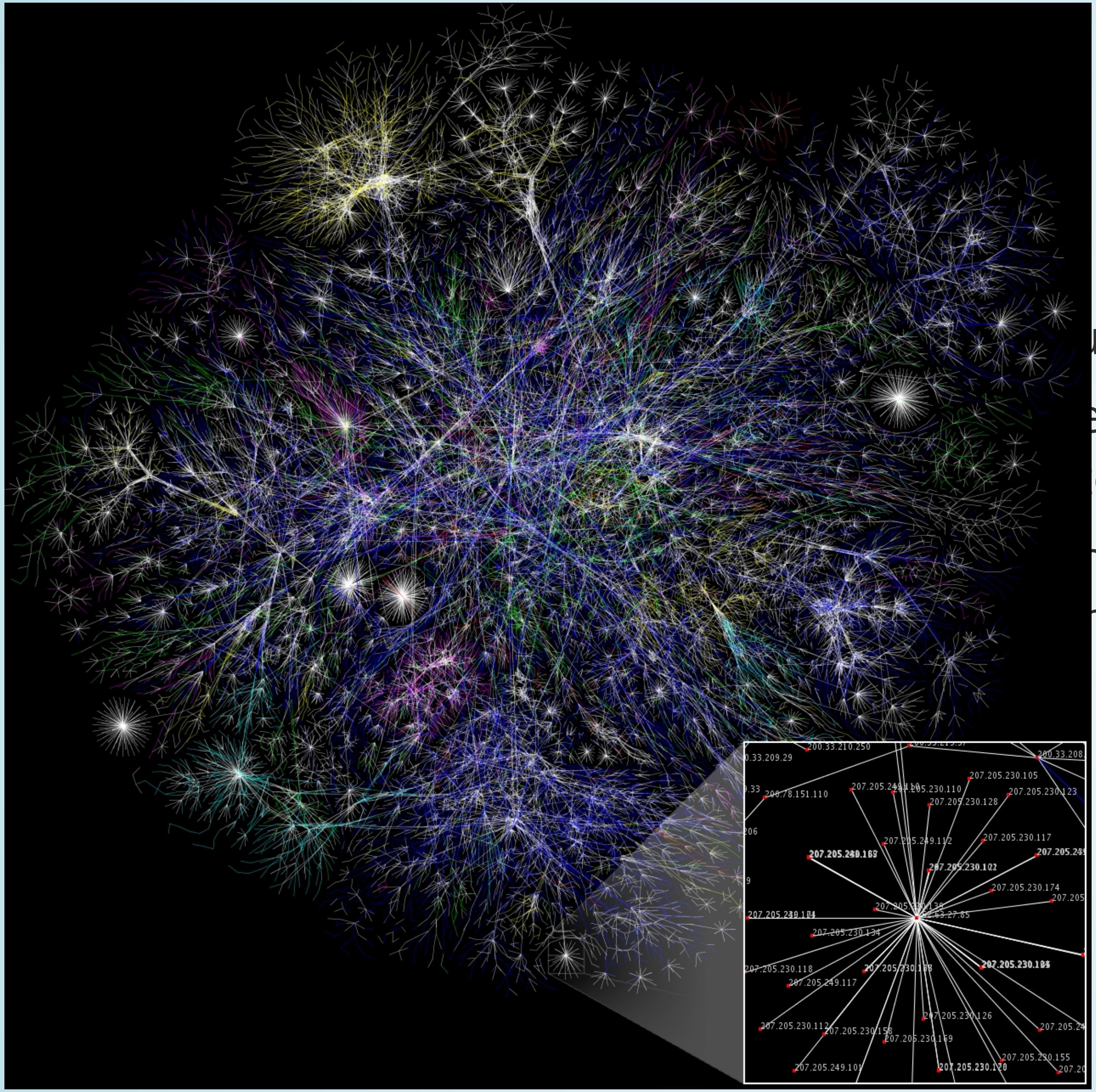
1. https://line-mode.cern.ch/www/hypertext/WWW/TheProject.html

GLOBAL SUCCESS

- **1996**: First search engines with a site-scoring algorithm, e.g., Google search
- **1998**: Start of the dot-com boom
- **2004**: Start of Web 2.0 brought up blogs and RSS as well as services like Facebook or Twitter
- **2007**: Apple’s iPhone and Android started the “Mobile Revolution”
- **2008**: Rise of the Internet of Things (IoT)



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COMPONENTS AND TERMS

WHY DO WE NEED COMPUTER NETWORKS?

Please go to the survey at
https://fra-uas.particifyapp.net/p/36002022

- Which network services or applications do you know?
- What are the main tasks of the network?

PURPOSE OF COMPUTER NETWORKS

The general task of a computer network is to enable communication among the participants.

- Resource sharing
  ⇒ assign different tasks to different computers
  ⇒ avoid bottlenecks
- Resource pooling
  ⇒ combine the resources and functionalities of multiple machines
- Resource balancing
  ⇒ increase the availability of the services by redundancy

REQUIRED COMPONENTS TO SET UP A COMPUTER NETWORK

- For setting up and running a computer network, these three components are required:

1. ≥ 2 computers with network services running
2. Transmission medium to send and receive data
3. Network protocols

- Rules that specify, how computers can communicate

NETWORK SERVICES

- A network service provides resources to other devices in the network
- Distinguished by their role:

  Server

- The terms *server*, *client*, and *peer* typically refer only to network services and not to hardware
- Almost any computer that acts as a server will also run client applications

- If each communication partner is server and client both,
  the participants are called peers
  (⟹ *Peer-to-Peer networks*)

TRANSMISSION MEDIA

Different transmission media exists to setup a computer network.

1. Guided transmission media
2. Wireless transmission

- Wireless transmission can be realized **directed** and **undirected**
- Directed transmission can base on the following technologies:
  - **Radio technology**: Electromagnetic waves in the radio frequency spectrum (radio waves) (e.g., directed WLAN and satellite Internet access)
  - **Infrared**: Electromagnetic waves in the spectral range (e.g., IrDA)
  - **Laser**: Data is transferred as light impulses via Laser Bridge
- Undirected wireless transmission is mostly based on radio technology (e.g., WLAN, cellular networks, terrestrial broadcasting and satellite broadcasting) or sonar

tion

DIFFERENT TYPES OF NETWORKS

Can you think of different examples for computer networks?

COMPUTER NETWORKS DISTINGUISHED BY THEIR DIMENSION (1/2)

- Depending on the dimension, different groups of computer networks are distinguished
- **Personal Area Network (PAN)** or **Body Area Network (BAN)**
  - Network of small mobile devices, such as smart phones
  - Dimension: Few meters
  - Technologies: USB, FireWire, WLAN, Bluetooth, IrDA
- **Local Area Network (LAN)**
  - Local network
  - Range covers an apartment, building, company site or university campus
  - Dimension: 500-1000 m
  - Technologies: Ethernet, Wireless LAN (WLAN)

COMPUTER NETWORKS DISTINGUISHED BY THEIR DIMENSION (2/2)

- **Metropolitan Area Network (MAN)**
    - Connects LANs
    - Range covers a city or agglomeration area
    - Dimension: 100 km
    - Technologies: Fiber-optic cables, WiMAX (IEEE 802.16)
        - Fiber-optic cables are used because of lesser attenuation (signal weakening) and higher data transmission rates
- **Wide Area Network (WAN)**
    - Connects several networks
    - Range covers a large geographic area inside a country or continent
    - Dimension: 1000 km
    - Technologies: Ethernet (10 Gbit/s), Asynchronous Transfer Mode (ATM)

COMMUNICATION MODES

- Synchronous (“Rendez-Vous”)
  - Sender and receiver needs to be present at the same time
  - May require to wait for the other side to become ready
  - For example, phone calls or video conference
- Asynchronous
  - Sender and receiver may act independently from each other
  - Requires buffering
  - For example, instant messaging or E-Mail

UNICAST AND BROADCAST

Unicast

One-to-one communication, i.e., one host sends information to *exactly one* other host

Broadcast

One-to-all communication, i.e., one host sends information to *all* other hosts in the network

GROUP COMMUNICATION: MULTICAST AND ANYCAST

Multicast

Group c ds
informa

- What are the use cases?
- What are the pros and cons?

Anycast

One-to-any communication, i.e., one hosts sends information to *one host in a given group*

CONNECTION-ORIENTATION

Network services may operate *connection-oriented* or *connectionless*.

connection-oriented

the service operates **stateful**

- comprises three phases: connection establishment, data transfer, and connection termination
- a virtual path between the involved hosts is established
- sequent data is exchanged between the same hosts
- typically used for reliable services

connectionless

the service operates **stateless**

- no path between the involved hosts is established
- typically used for low latency services

DIRECTIONAL DEPENDENCE (ANISOTROPY) OF DATA TRANSMISSION

Given a communication channel with two (or more) endpoints:

- Simplex
  - Only one side of the channel can send data → the channel can be used in only one direction
  - Examples: Radio, TV, Pager
- Duplex (Full-duplex)
  - Both sides of the channel are allowed to send → the channel can be used in both directions simultaneously
  - Examples: Phone, Networks with twisted pair cables because they provide separate wires for send and receive
- Half-duplex
  - Both sides of the channel can send, but not simultaneously → the channel can only be used in one direction at a time
  - Examples:
    - Networks with fiber-optic cables or coaxial cables, because there exists just a single line to sending and receiving
    - Wireless networks with just a single channel

BANDWIDTH, THROUGHPUT AND GOODPUT

Main factors, influencing the performance of a computer network:

- Bandwidth ($\rightarrow$ throughput)
- Latency (**delay**)

- The bandwidth specifies how many bits can be transmitted within a period via the network
  - If a network has a bandwidth of 1 Mbit/s, one million bits can be transmitted per second **in the ideal case**
    - Thus, a bit has a *width* of 1 μs
- Throughput is the actual achieved data rate ($\Rightarrow$ the bandwidth defines its upper bound)
- Goodput is the actual rate of data the user benefits from

LATENCY

The latency of a network is the time, a message needs to travel from one end of the network to the most distant end

Latency = Propagation delay + Transmission delay + Waiting time

- Waiting times are caused by network devices (e.g., Switches)
  - They need to cache received data first before forwarding it
  - Waiting time = 0, if the network connection between sender and destination is just a single line or a single channel

Source: Larry L. Peterson, Bruce S. Davie. Computernetzwerke. dpunkt (2008)

BANDWIDTH-DELAY PRODUCT

- Calculates the **volume of a network connection**
  - Signals cannot be transmitted with infinite speed via the transmission media
    - The propagation speed is in any event limited by the speed of light and it depends on the velocity factor of the transmission medium
  - The product of bandwidth and delay (latency) corresponds to the maximum number of bits that can reside inside the line between sender and receiver
- Example: A network with 100 Mbit/s bandwidth, and 10 ms latency

$$100,000,000\,\text{Bits/s} \times 0.01\,\text{s} = 1,000,000\,\text{Bits}$$

- There are a maximum number of $1,000,000$ Bits inside the network line
  - This is equivalent to $125,000$ Bytes (= 125 kB)

HOW DOES A COMPUTER NETWORK WORK?

You need information about someone/something:

- What do you do?
- Which problems are to solve?

THE BIG PICTURE

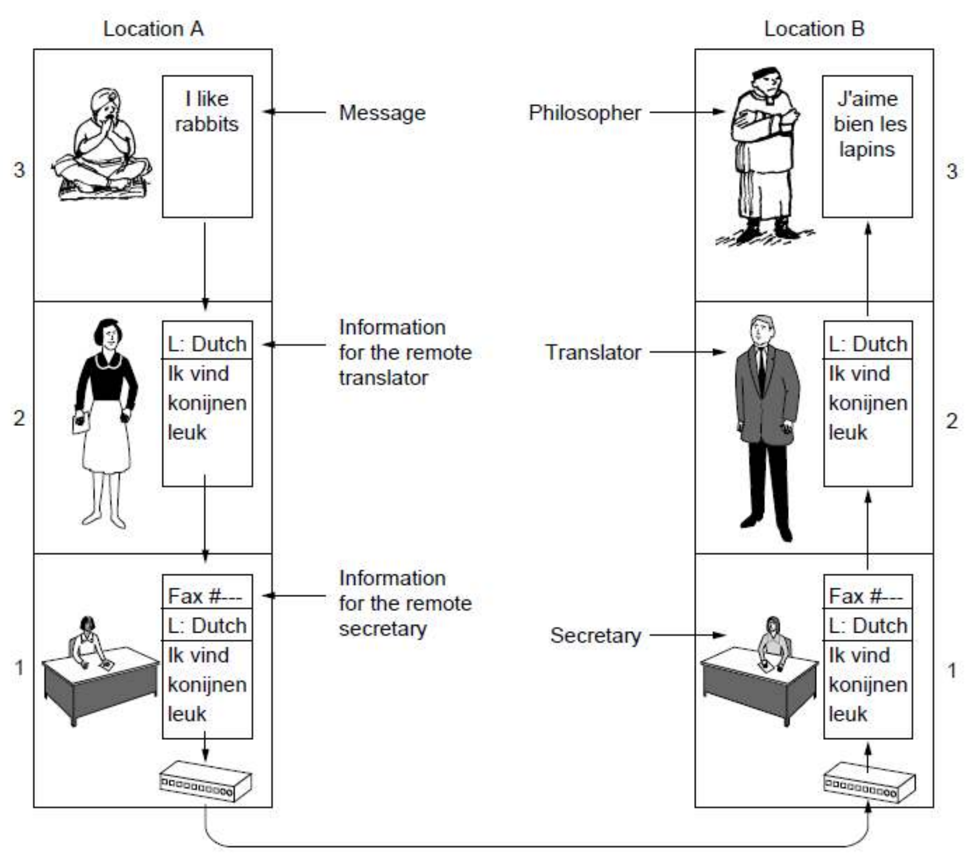
Let’s create it together

REFERENCE MODELS

REFERENCE MODELS

- Reference models are used to describe computer networks independently of concrete technologies
- Such a reference model consists of several layers
- Each layer addresses a particular aspect of communication and offers interfaces to the neighboring layer
- Each layer defines their own protocols that define syntax and semantics of parts of a transmitted message (e.g., header and trailer)
- These message parts are encapsulated
- Because each layer is complete in itself, single protocols can be modified or replaced without affecting all aspects of communication
- The most popular reference models are...
  - the **TCP/IP reference model**,
  - the **ISO/OSI reference model**, and
  - the **hybrid reference model**

“PHILOSOPHER-TRANSLATOR-SECRETARY”-ARCHITECTURE



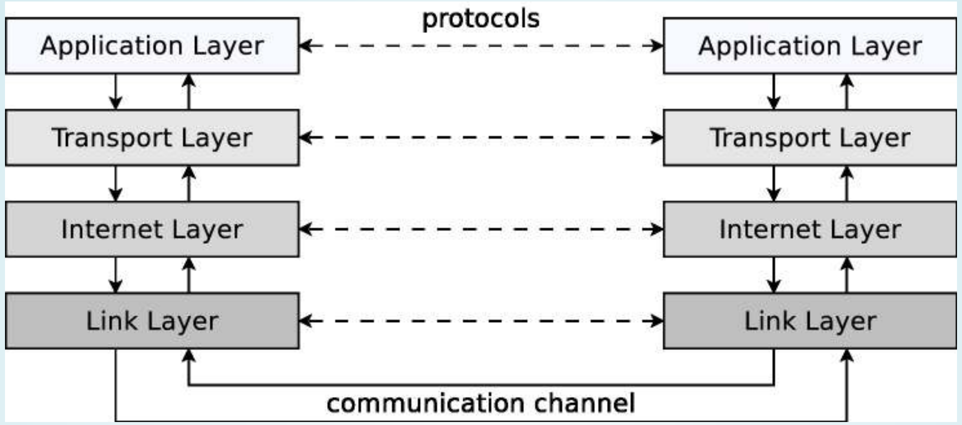
Source: Tanenbaum & Wetherall, © Pearson Education-Prentice Hall and D. Wetherall, 2011

TCP/IP REFERENCE MODEL OR DOD MODEL

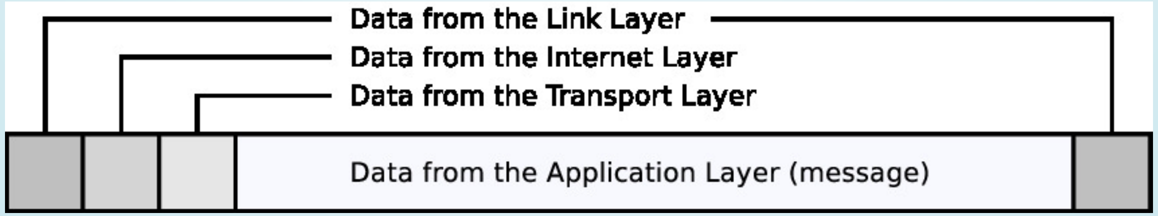
Number	Layer	Protocols (Examples)
4	Application Layer	HTTP, FTP, SMTP, POP3, DNS, SSH, Telnet
3	Transport Layer	TCP, UDP
2	Internet Layer	IPv4, IPv6, IPX
1	Link Layer	Ethernet, WLAN, ATM, FDDI, PPP, Token Ring

Described in **RFC 1122 (TCP/IP)**

TCP/IP REFERENCE MODEL – MESSAGE STRUCTURE

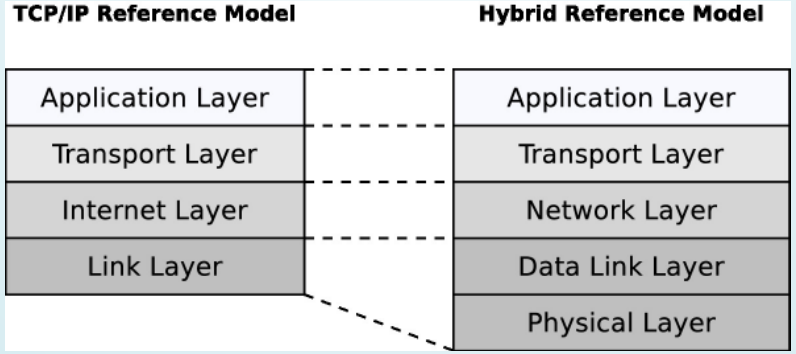


- Each layer adds additional information as header to the message
  - Some protocols (e.g., Ethernet) add in the link layer not only a header but also a trailer at the end of the message
  - The receiver analyzes the header (and trailer) on the same layer



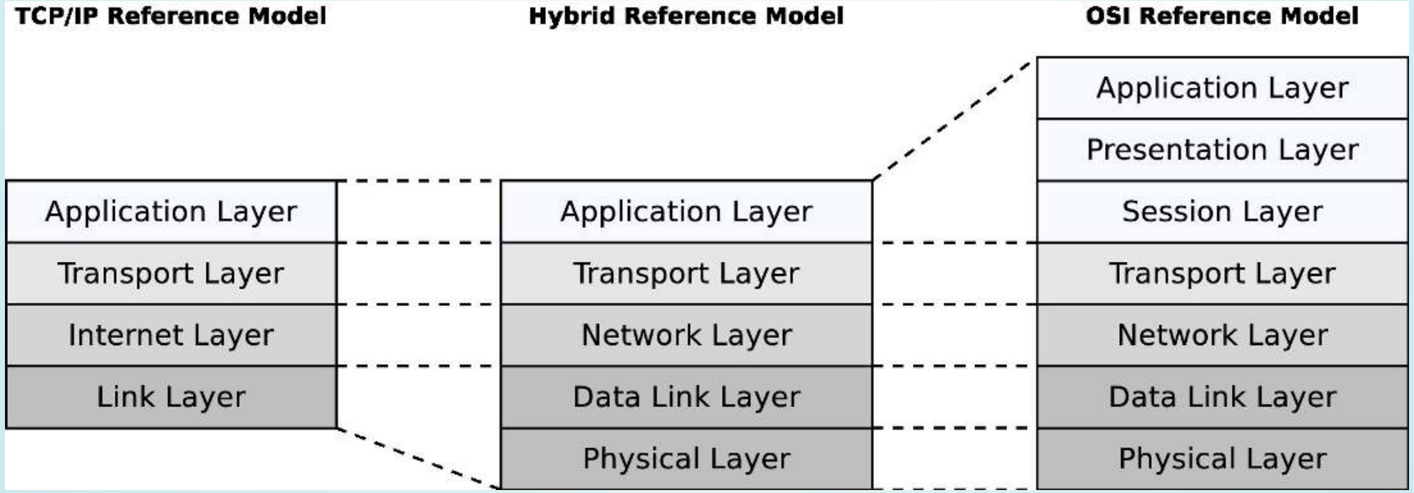
HYBRID REFERENCE MODEL

- The TCP/IP reference model is often presented in the literature (e.g., by Andrew S. Tanenbaum) as a 5-layer model
  - Reason: It makes sense to split the **Link Layer** into 2 layers, because they have different tasks
- This model is an extension of the TCP/IP model and is called hybrid reference model



OSI REFERENCE MODEL

- Some years after the TCP/IP reference model (1970s), the OSI (Open Systems Interconnection) reference model was developed from 1979 onwards
- 1983: Standardized by the Intern. Organization for Standardization (ISO)
- In contrast to the hybrid reference model, two additional layers are placed below the Application and above the Transport Layer



TCP/IP Reference Model	Hybrid Reference Model	OSI Reference Model
		Application Layer
		Presentation Layer
Application Layer	Application Layer	Session Layer
Transport Layer	Transport Layer	Transport Layer
Internet Layer	Network Layer	Network Layer
Link Layer	Data Link Layer	Data Link Layer
	Physical Layer	Physical Layer

OSI MODEL CONCEPTS

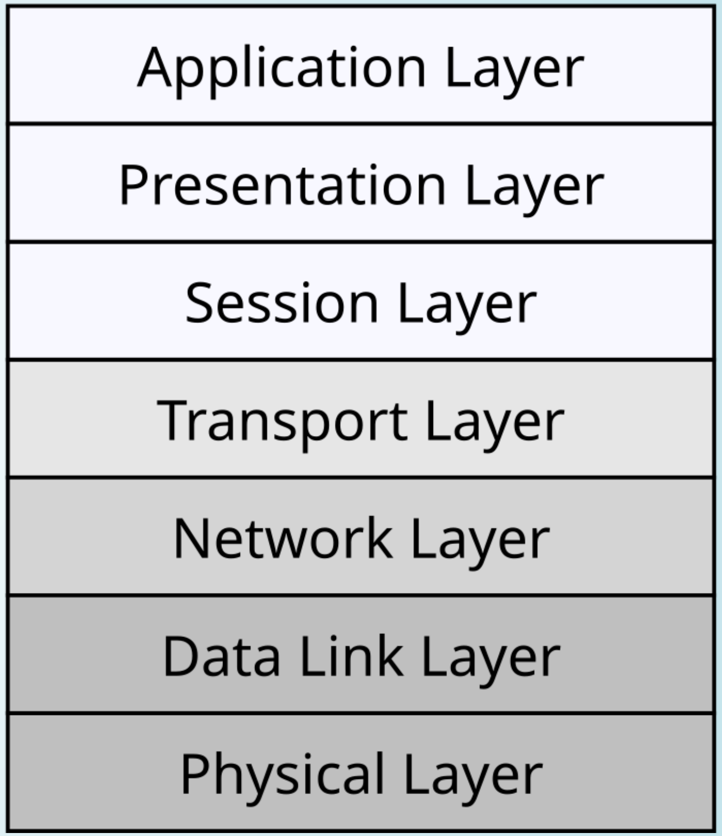
Central concepts of the OSI model are:

- **Services**
  - Define what the layer does, i.e., its semantics
- **Interfaces**
  - Define how to access it
- **Protocols**
  - Describe how the layer is implemented

PHYSICAL LAYER I

- **Transmits the ones and zeros**
  - Physical connection to the network
  - Conversion of data into signals
- Protocol and transmission medium specify among others:
  - How is the information encoded on the transmission medium?
  - Can transmission take place simultaneously in both directions?

OSI Reference Model



Application Layer

Presentation Layer

Session Layer

Transport Layer

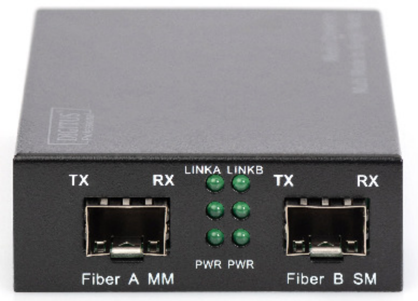
Network Layer

Data Link Layer

Physical Layer

PHYSICAL LAYER II

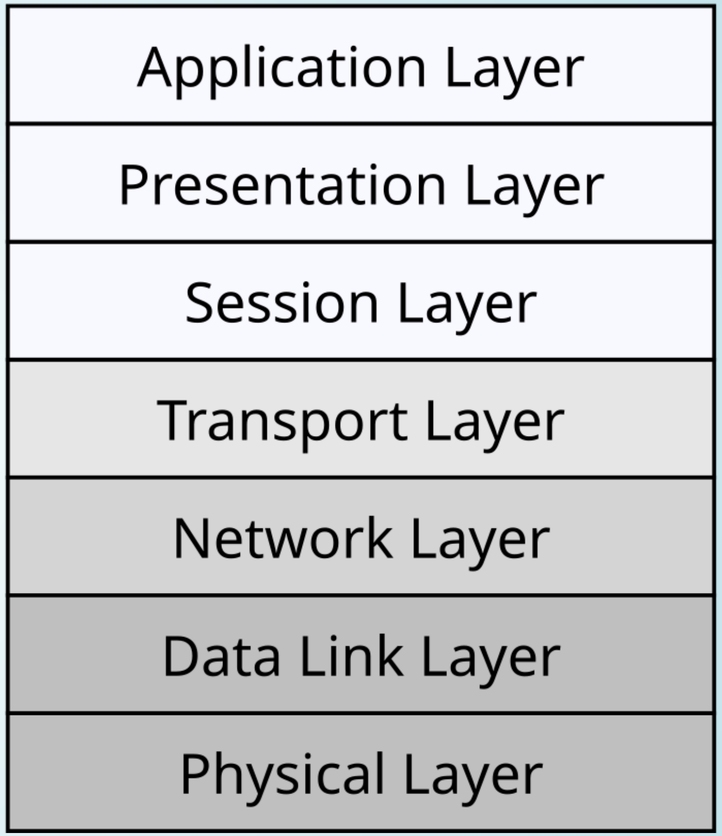
- **At sender site:** Signals are modulated onto the medium
- **At receiver site:** Signals are demodulated from the medium
- Devices: **Repeater**, **Hub** (Multiport Repeater)



DATA LINK LAYER I

- Ensures error-free data exchange of frames between devices in physical networks
  - Handles transmission errors with **checksums**
  - Controls the access to the transmission medium (e.g., via CSMA/CD or CSMA/CA)
- Specifies physical network addresses (MAC addresses)

OSI Reference Model



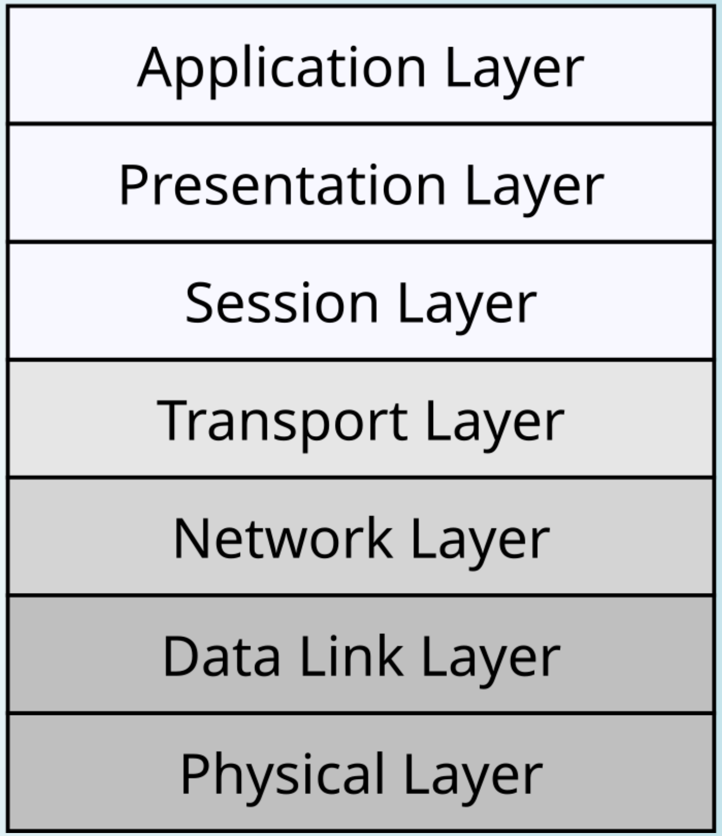
DATA LINK LAYER II

- **At sender site:** Packs the Network Layer packets into frames and transmits them (in a reliable way) via a physical network from one device to another
- **At receiver site:** Identifies frames in the bit stream from the Physical Layer
- Devices: **Bridges**, **Layer-2-Switches** (Multiport Bridges), **WIFI APs**, and **Modems** connect physical networks

NETWORK LAYER I

- Forwards packets between logical networks (over physical networks)
  - For this *internetworking*, the network layer defines logical addresses (most commonly IP addresses)
  - Each IP packet is routed independently to its destination (→ connectionless)

OSI Reference Model



Application Layer

Presentation Layer

Session Layer

Transport Layer

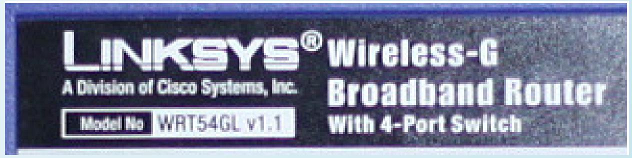
Network Layer

Data Link Layer

Physical Layer

NETWORK LAYER II

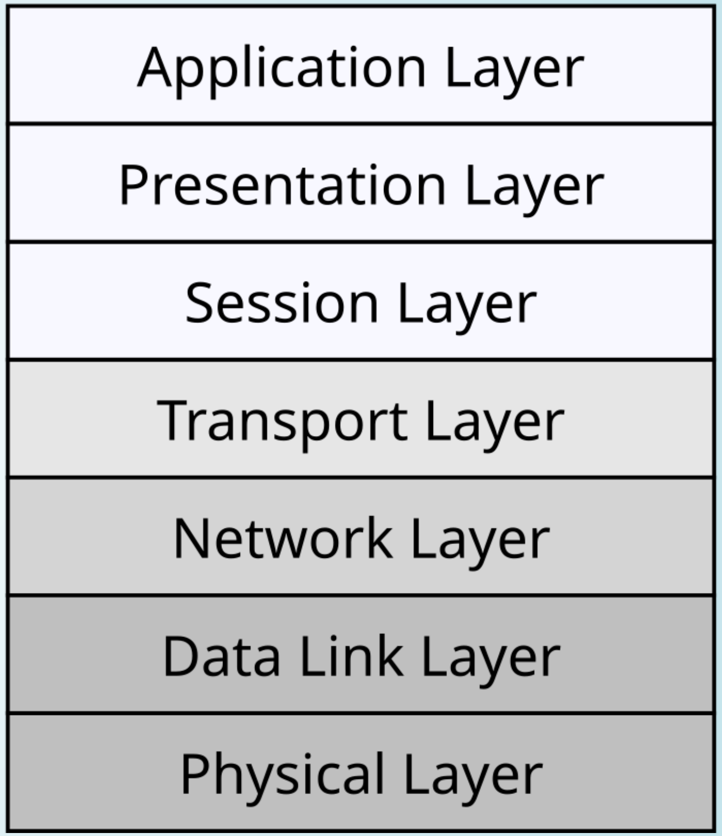
- **At sender site:** Packs the segments of the Transport Layer in packets
- **At receiver site:** Unpacks the packets in the frames from the Data Link Layer
- **Routers** and **Layer-3-Switches** connect logical networks
- Usually the connectionless Internet Protocol (IP) is used
  - Other protocols (e.g., IPX) have been replaced by IP



TRANSPORT LAYER I

- Transports segments between processes on different devices via so-called end-to-end protocols
- Transport protocols implement different forms of communication
  - Connectionless communication, typically UDP (User Datagram Protocol) in TCP/IP networks
  - Connection-oriented communication, typically TCP (Transport Control Protocol) in TCP/IP networks

OSI Reference Model


Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer

TRANSPORT LAYER II

- **At sender site:** Packs the data of the Application Layer into segments
- **At receiver site:** Unpacks the segments inside the packets from the network layer
- Addresses processes with **port numbers**

Combination of TCP/IP = de facto standard for computer networks

SESSION LAYER

- **Controls the dialogues** (connections) between processes
- Provides the following services
  - checkpointing (and recovery)
  - authentication
  - authorization
- Relevant protocols of the Session Layer are H.245, L2TP, PAP, and SOCKS
- Session Layer services are commonly used for RPCs (cf. lecture *Distributed Systems*)

Many network applications do not require a dedicated **session layer** protocol.

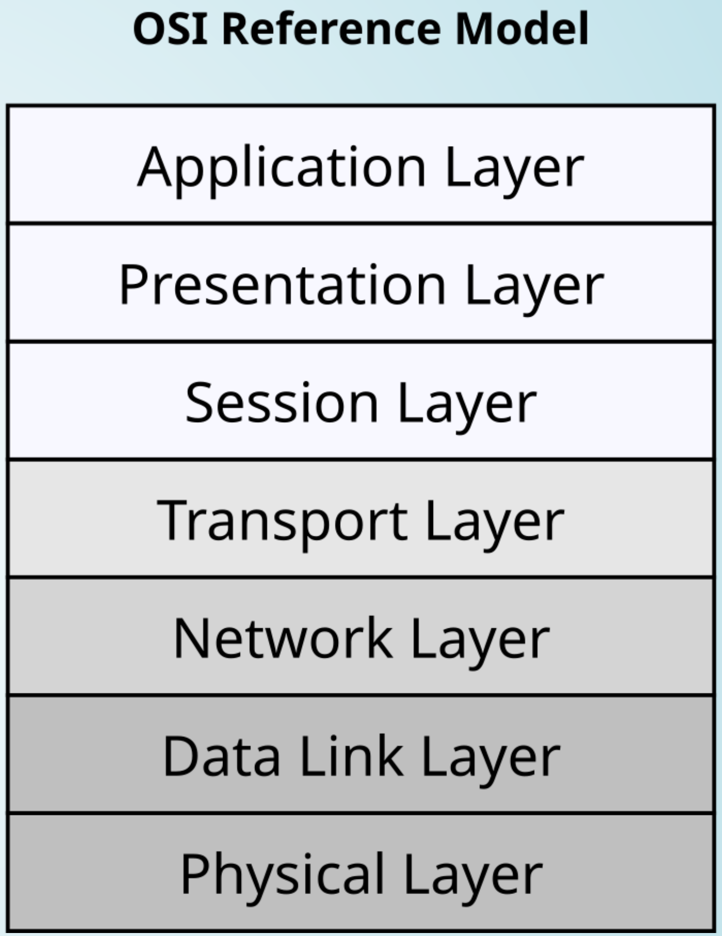
PRESENTATION LAYER

- Contains rules for setting the **format (presentation) of messages**
  - The sender can notify the receiver that a message has a specific **format** (e.g., ASCII) to make conversion happen, which is perhaps necessary
  - Data records can be specified here with fields (e.g., name, student ID number...)
  - **Data types and their length** can be defined here
  - **Compression and encryption** could be implemented by this layer

The functionality of the **presentation layer** is often implemented as part of the **application layer**.

APPLICATION LAYER

- Contains all protocols, that interact with the application programs (e.g., browser or email program)
- Here is the actual payload (e.g., HTML pages or emails), formatted according to the used application protocol
- Some Application Layer protocols: HTTP, FTP, SMTP, POP3, DNS, SSH, Telnet



OSI Reference Model

Application Layer

Presentation Layer

Session Layer

Transport Layer

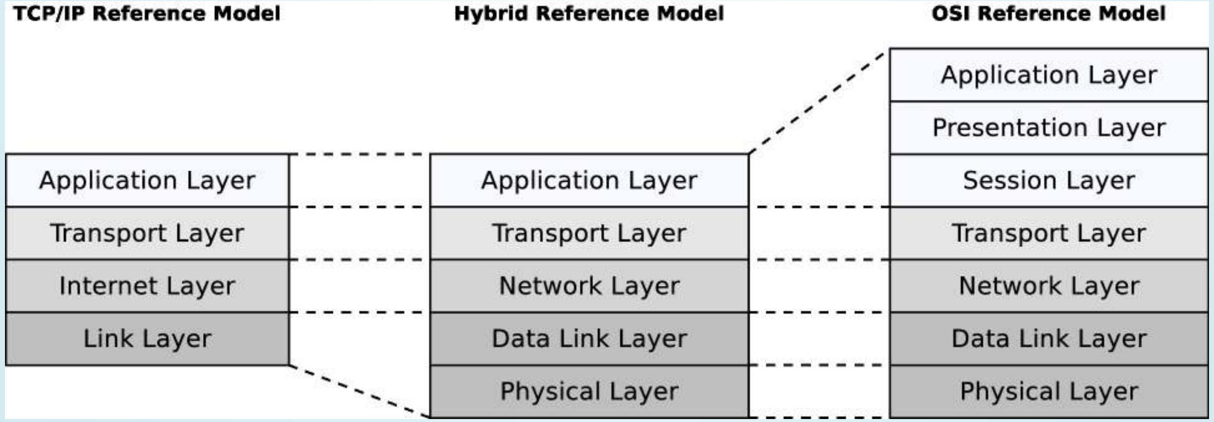
Network Layer

Data Link Layer

Physical Layer

REFERENCE MODELS – SUMMARY

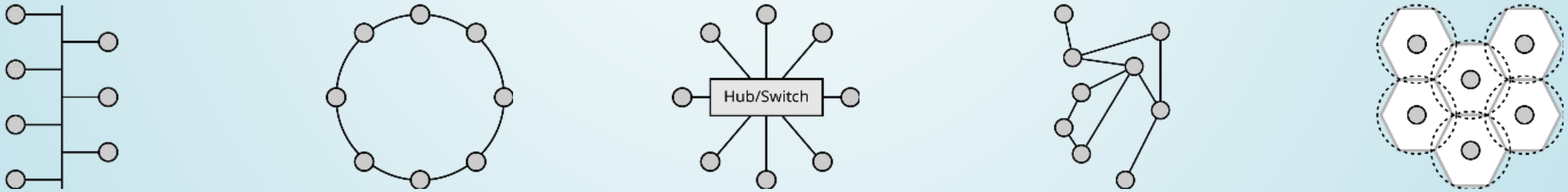
- The OSI reference model is the most fine granular and is most widely used
- Protocols of the **physical** and the **data link layer** are often highly entangled in practice
- Many network applications do not require dedicated protocols on the **session** and **presentation layer**
  - Their functionality is often implemented as part of the **transport** or **application layer**



TOPOLOGIES

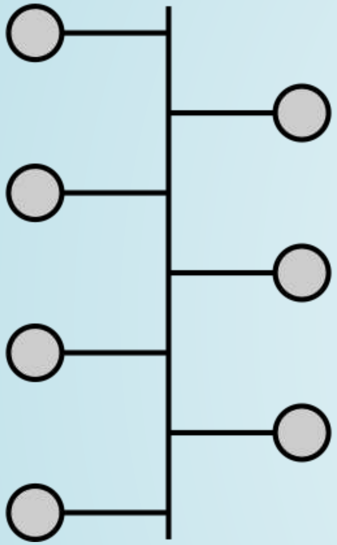
TOPOLOGIES OF COMPUTER NETWORKS

- The topology of a computer network...
  - determines how the communication partners are connected with each other
  - affects its reliability a lot
- The structure of large-scale networks is often a combination of different topologies
- Physical and logical topology may differ
  - Physical topology: Describes the wiring
  - Logical topology: Describes the flow of data between the terminal devices
- Topologies are graphically represented with nodes and edges



BUS NETWORK

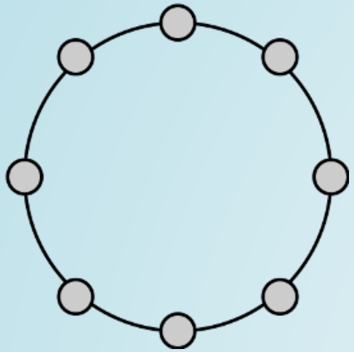
- All terminal devices are connected via a **shared communication medium** – the bus



- No active components between the terminal devices and the shared communication cable
  - If a node fails, it does not affect the network itself
- **Advantage**: Cheap to implement
  - In the past, Hubs and Switches have been expensive
- **Drawback**: Shared communication cable fails
  $\Longrightarrow$ Complete network fails
- Only a single node can send data at each point in time
  $\Longrightarrow$ otherwise, collisions will occur
  - A media access control method like CSMA/CD is required

Examples: (original) Ethernet, CAN, I²C, SPI

RING NETWORK

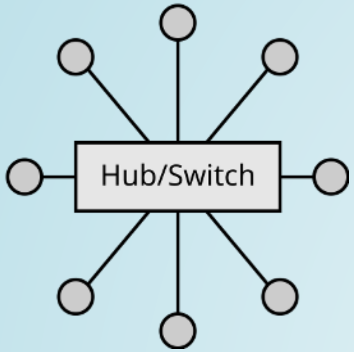


- Connects node to node
- All data is transferred from nodes to nodes until the destination is reached
- Disruption of a single link $\Longrightarrow$ network failure
- Each node is also a repeater, which amplifies the signal
  - For that reason, large-sized rings (transmission medium dependent) are possible
  - Maximum ring length for Token Ring: 800 m

Examples:

- Token Ring (**logical**): 4-16 Mbps
- Fiber Distributed Data Interface (FDDI): 100-1000 Mbps

STAR NETWORK

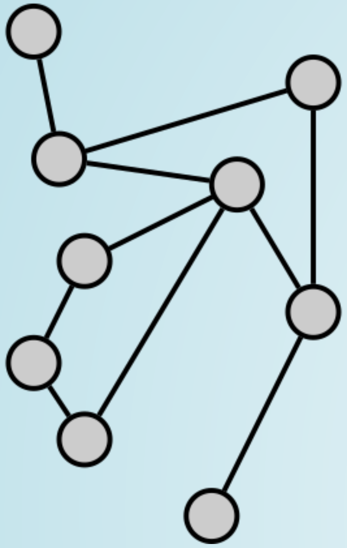


- All nodes are connected directly with a central component (Hub or Switch)
- Failure of the central component leads to a failure of the network itself
    - The central component can be implemented in a redundant way
- Failure of a node do not cause a failure of the network itself
- **Advantages**: Expandability and stability

Examples:

- (modern) Ethernet
- Token Ring (**physical**): 4-16 Mbps
- Fibre Channel (storage networks): 2-16 Gbps
- InfiniBand (cluster): 10-40 Gbps

MESH NETWORK

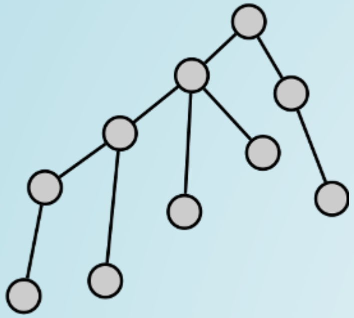


- Each node is connected with one or more other nodes
    - In a **fully connected mesh network**, the nodes are all connected to each other
- If nodes or connections fail, communication inside the network is typically still possible because the frames are redirected
- **Advantages**: Failure safe (depends on the degree)
- **Drawbacks**: Cabling effort and energy consumption
- Additional challenge: complexity to find the best way from sender to receiver (cf. *Travelling salesman problem*)

Examples:

- Logical topology between Routers
- Ad-hoc (wireless) networks

TREE NETWORK

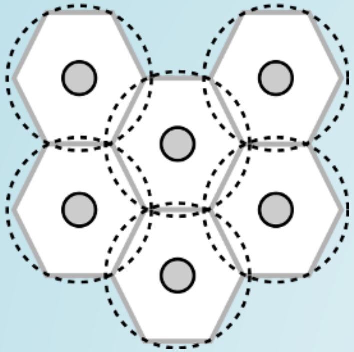


- A dedicated root node exist with one or more edges
  - Every edge leads to a leaf node or to the root of another tree
- Several star topology networks are hierarchically connected
- **Advantages**:
  - Failure of a terminal device (leaf node) has no consequences
  - Good expandability and long distances are possible
  - Well suited for searching and sorting algorithms
- **Drawbacks**:
  - When a node fails, the complete (sub-)tree behind is no longer accessible
  - In a large tree, the root may become a bottleneck because the communication from one half of the tree to the other half always needs to pass the root

Examples:

- Connecting Hubs or Switches via an uplink port

CELLULAR NETWORK



- Implemented by wireless networks
- Cell: Area where the nodes can communicate with the base station
- **Advantage**: Failure of nodes do not affect the network itself
- **Drawback**: Maximum dimension is limited by the number of base stations and their positions
- Only one nodes can send data at each point in time $\Longrightarrow$ otherwise, collisions will occur
    - A media access control method like CSMA/CA is required

Examples:

- Wireless LAN = WiFi (*IEEE 802.11*)
- Global System for Mobile Communications (*GSM*)

CURRENT SITUATION

- Today, Ethernet (1-10 Gbit/s) with Switches ($\Longrightarrow$ **star topology**) is the standard for wired LAN
- Connecting Hubs and Switches implements a **tree topology**, if there are no loops in the cabling
- **Cell topology** is the standard for wireless networks
- **Mesh topology** is one possible use case of wireless networks and it is the logical topology between routers
- **Bus** and **ring topologies** are no longer used for new computer network infrastructures
    - 10BASE2 (Thin Ethernet) and 10BASE5 (Thick Ethernet) are outdated since the mid/end-1990s
    - May 2004: IBM sells his complete Token Ring product lineup

RECAP

Let's go again to the survey at https://fra-uas.particifyapp.net/p/36002022

- Which components do we require for a computer network?
- Name some properties to characterize a computer network
- Which characteristics do apply for a phone call?

SUMMARY

You should now be able to answer the following questions:

- What is a Computer Network and what are its objectives?
- What is the difference between bandwidth, throughput, and latency?
- What is a reference model and what do their difference layers represent?