MVŠO

MORAVSKÁ VYSOKÁ ŠKOLA OLOMOUC

Computer Networks

Vít PÁSZTO

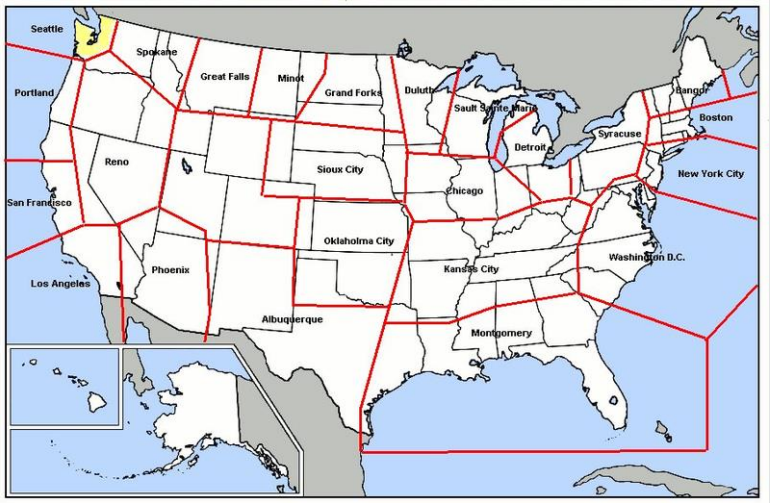
17.3.2022

Computer Networks

- Set of technologies allowing transfer and exchange of information among computers
- Allows users to communicate (following some rules) in order to share and exchange data (resources/information)
- History goes back to the second half of 20th century (US Air Force WAN for semi-automatic ground envi (radar))
- Internet (WWW), storage services, printers/faxes (peripherial devices), email, instant communication (messengers, VoIP and others)

Computer Networks

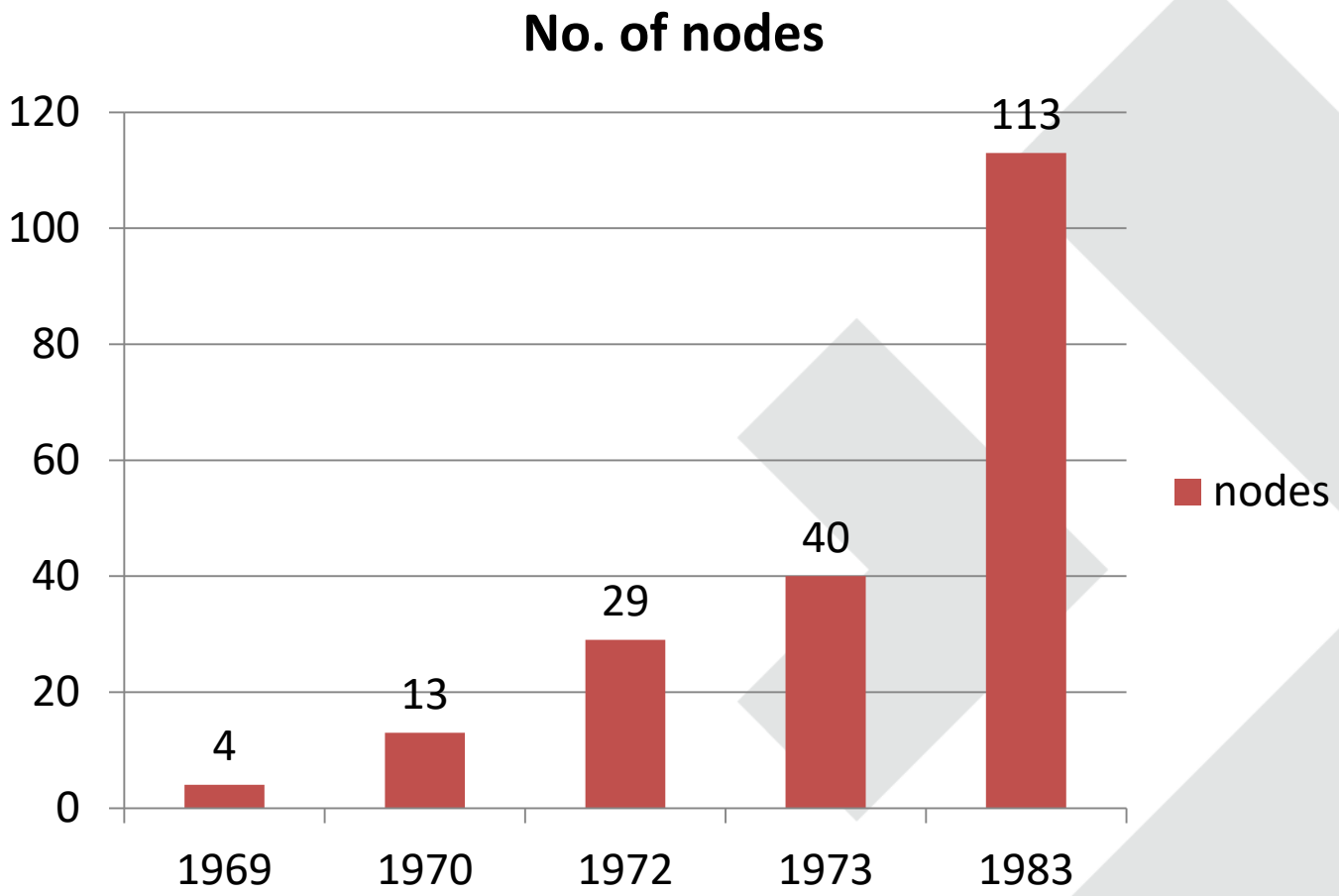
- History goes back to the second half of 20th century (US Air Force WAN for semi-automatic ground envi (radar))



ARPANET

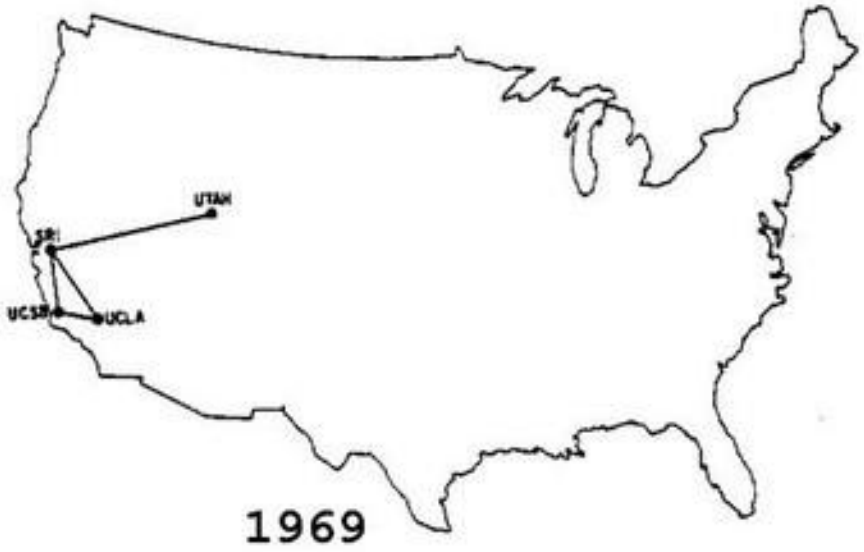
- The first „modern“ computer network (1969)
- U.S. Ministry of Defence (ARPA) – Larry Roberts
- Testing network for packet switching
- No central unit because of destruction of any part
- Four initial members:
  - UCLA, SCRI (Stanford Central Research Institute), UCSB (University of California Santa Barbara), University of Utah
- First packet sent on 29th Oct 1969
- Network Control Protocol (NCP)

ARPANET

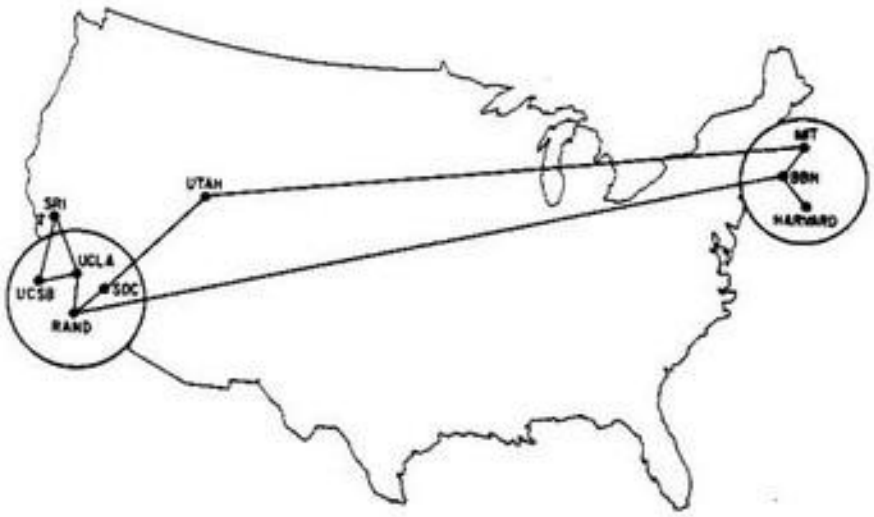

No. of nodes
120
100
80
60
40
20
0
4
13
29
40
113
1969
1970
1972
1973
1983
nodes

ARPANET

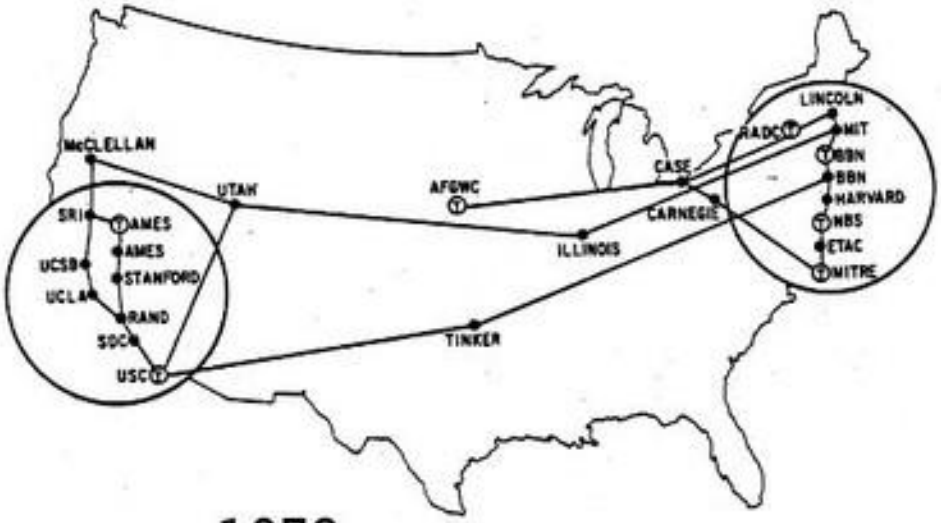
- 1973 – Europe joined the network
  - Norway and UK („emails“)
  - 1976 – Queen Elizabeth used the network
- 1983 – Separation of ARPANET → MILNET → 68 nodes lost from ARPANET
- 1983 – NCP replaced by TCP/IP
- Establishments of LANs (NSFNET) → ARPANET as backbone network
- Disconnected in 1990



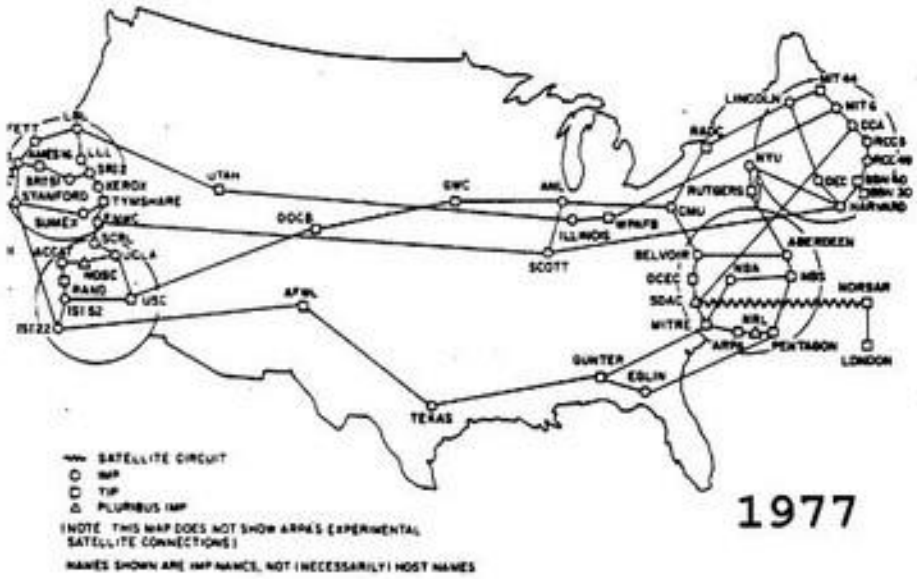
1969



1970

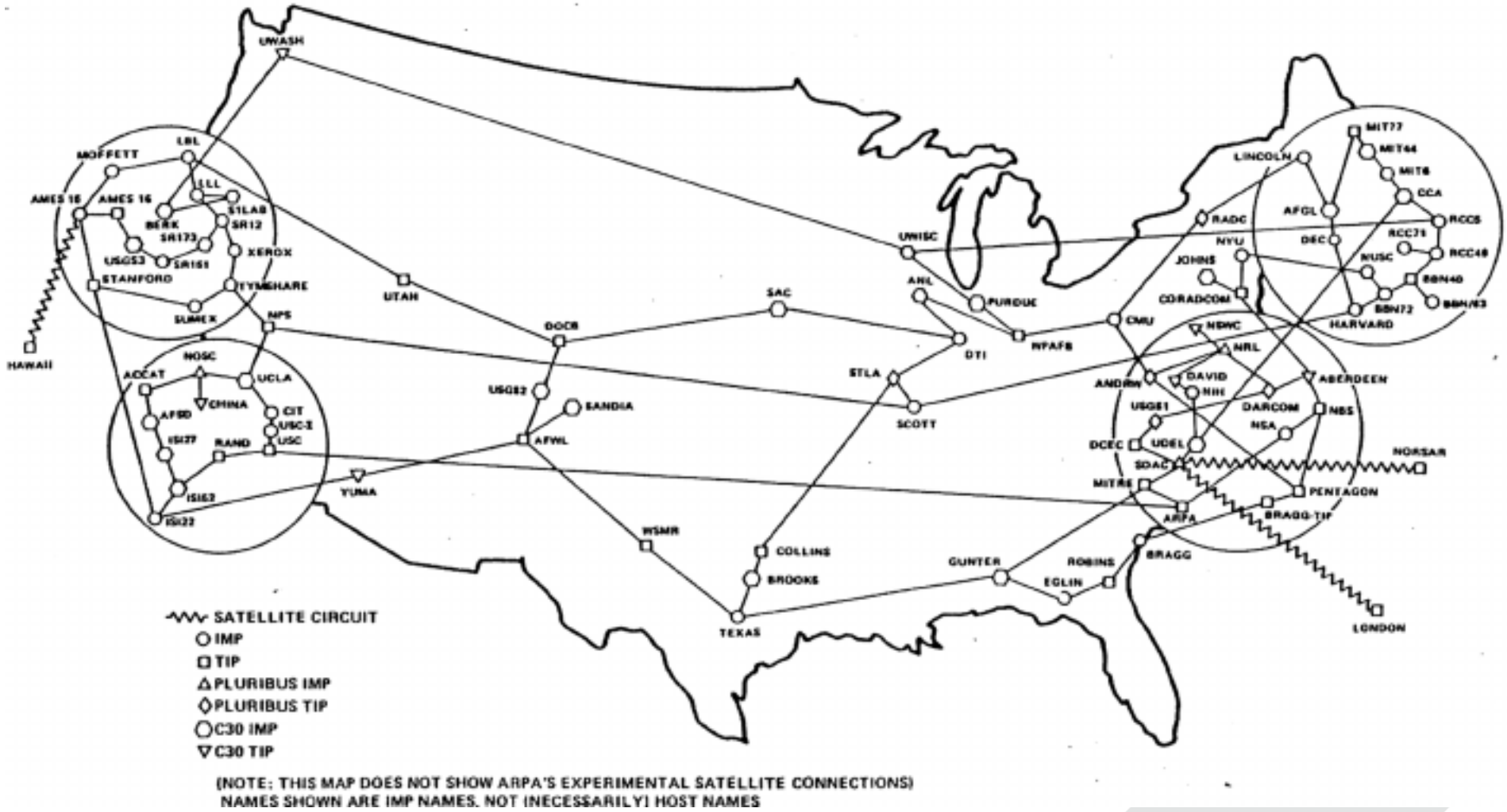


1972



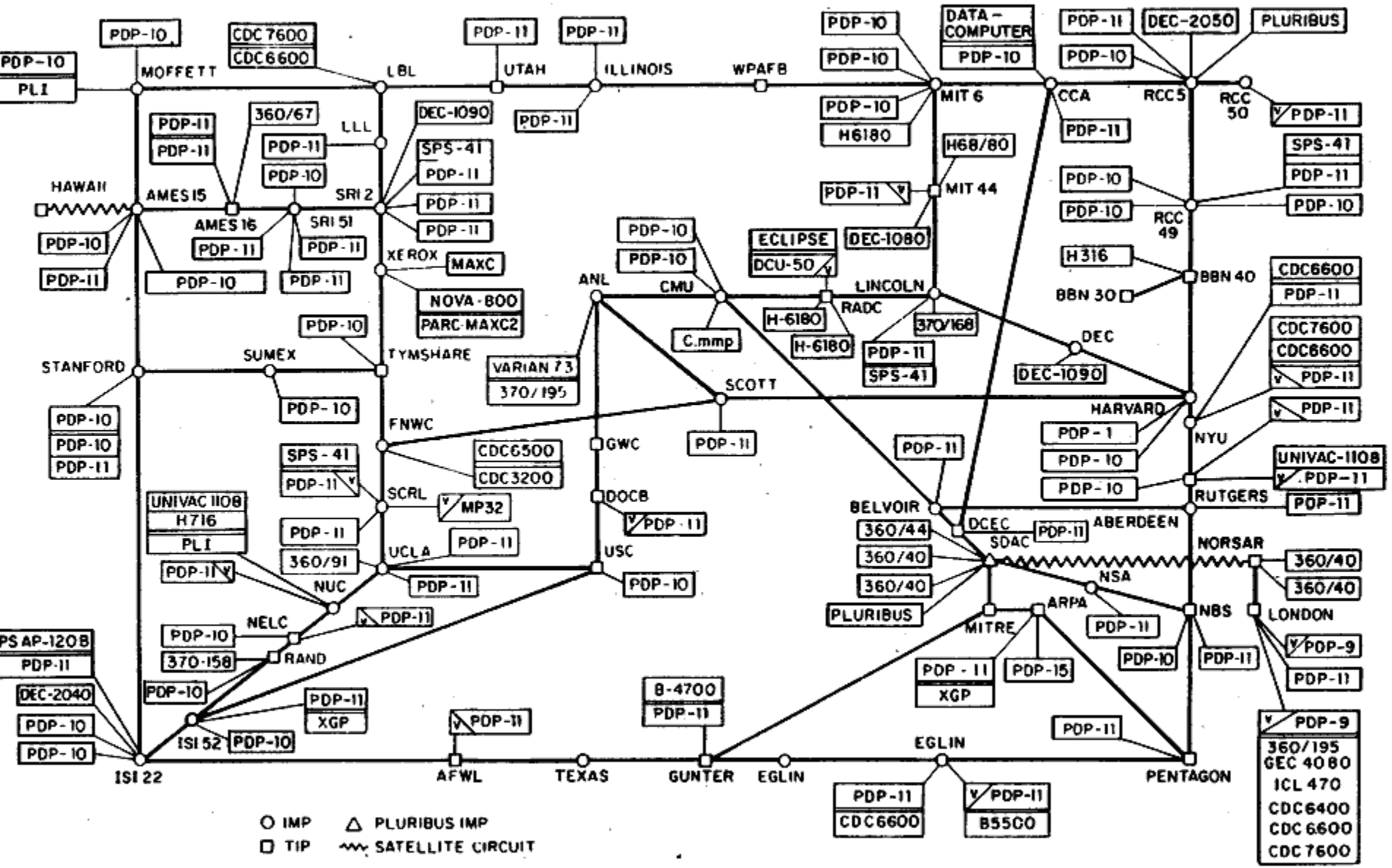
1977

ARPANET GEOGRAPHIC MAP, JANUARY 1982



(NOTE: THIS MAP DOES NOT SHOW ARPA'S EXPERIMENTAL SATELLITE CONNECTIONS)
NAMES SHOWN ARE IMP NAMES, NOT (NECESSARILY) HOST NAMES

ARPANET LOGICAL MAP, MARCH 1977



(PLEASE NOTE THAT WHILE THIS MAP SHOWS THE HOST POPULATION OF THE NETWORK ACCORDING TO THE BEST INFORMATION OBTAINABLE, NO CLAIM CAN BE MADE FOR ITS ACCURACY)

NAMES SHOWN ARE IMP NAMES, NOT (NECESSARILY) HOST NAMES

Computer Networks

- Computers
  - Multi-users with limited communication
- Computer network
  - Computers are connected and cooperating
  - They keep their identity
- Distributed operating system
  - Cluster of computers, which is compact unit
  - Inner structure is transparent to the user

Computer Networks

- Sharing resources
  - Data sets and files (programs, data)
  - Technical resources (peripheries, capacities)
- Communication
  - Between users – email, messaging, social networks
  - Between programs – distributed apps

Computer Networks

- Higher reliability
  - Back-ups
  - Redundant infrastructures
- Costs savings
  - Network of rather small computers is cheaper then one super-computer
  - Nowadays we have computer clusters and grids

Computer Networks - classification

- Switching
- Node connection
- Signal type
- Geographical scale
- Property/ownership

Computer Networks – classification (Switching)

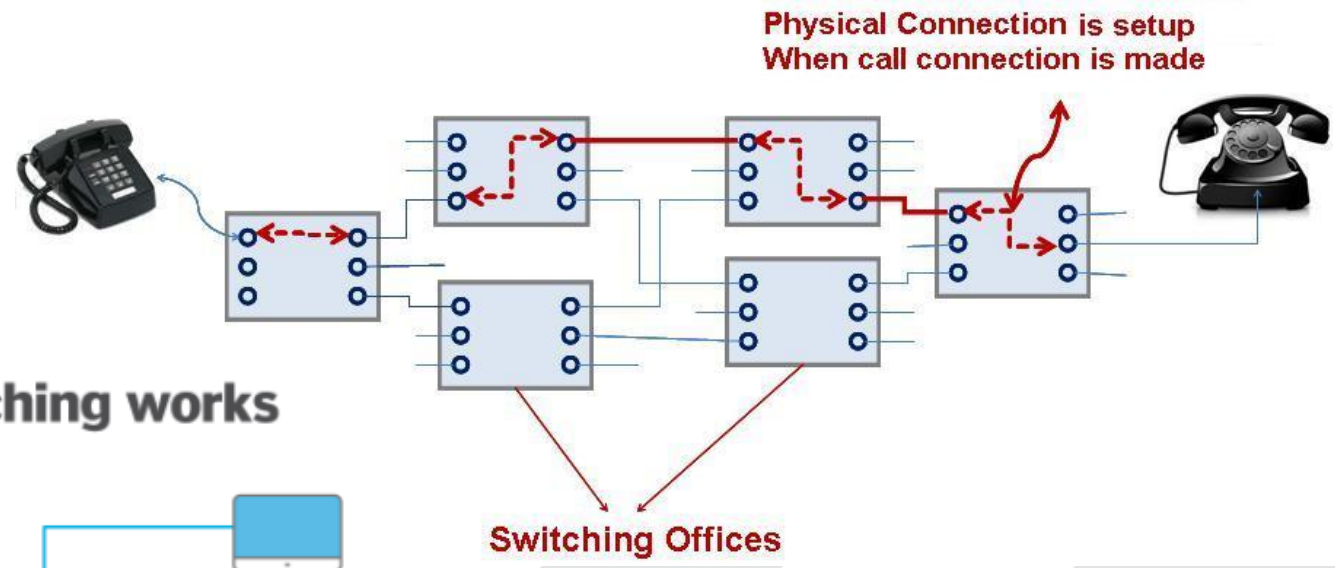
- Circuit switched network
  - Oldest technology (telegraphy, telephony, ISDN)
  - Connection established for two nodes
  - Communication channel open as long as the „call“ lasts (bit stream)
  - Connection via operator‘s exchange/switchboard
  - The link remains reserved even if no communication
  - Virtual circuit switched network

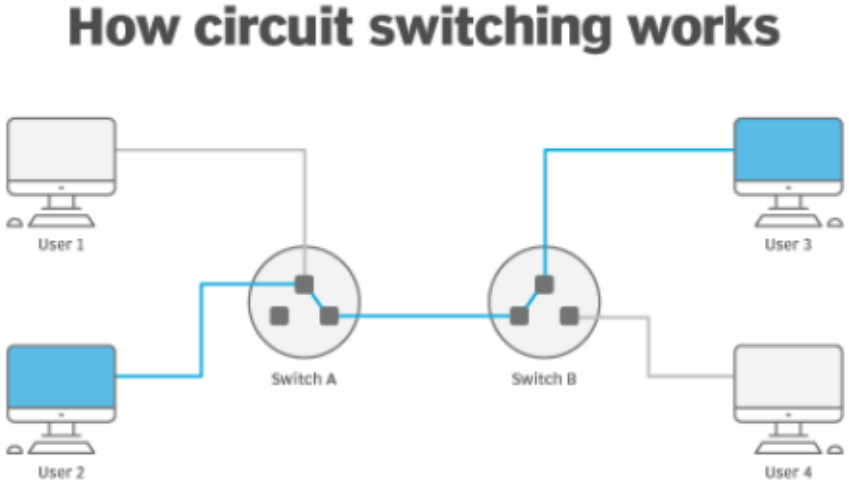
Computer Networks – classification (Switching)

- Circuit switched network
  - –cons & pros:
    - reduced communication speed, comm. between 2 nodes, set up
    + „low“ acquisition, running costs, reliability (fast, errorless)

Computer Networks – classification (Switching)

- Circuit switched network



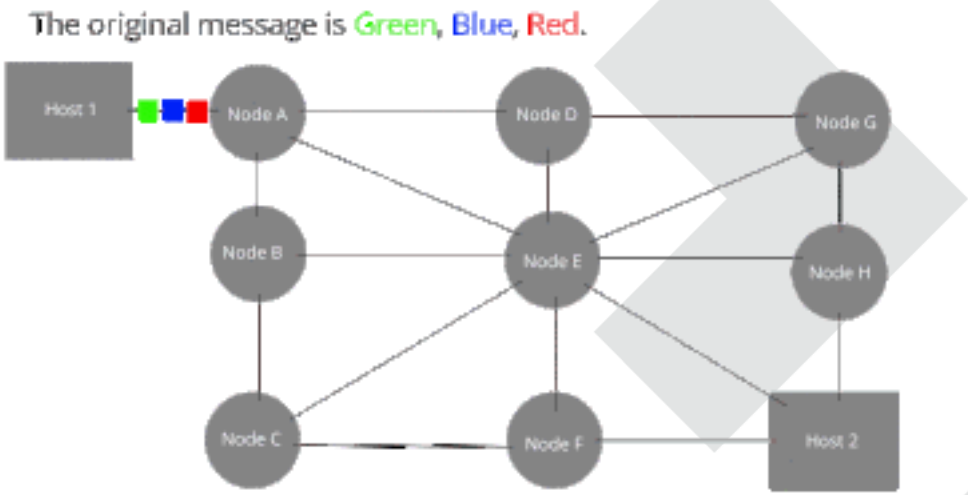


Computer Networks – classification (Switching)

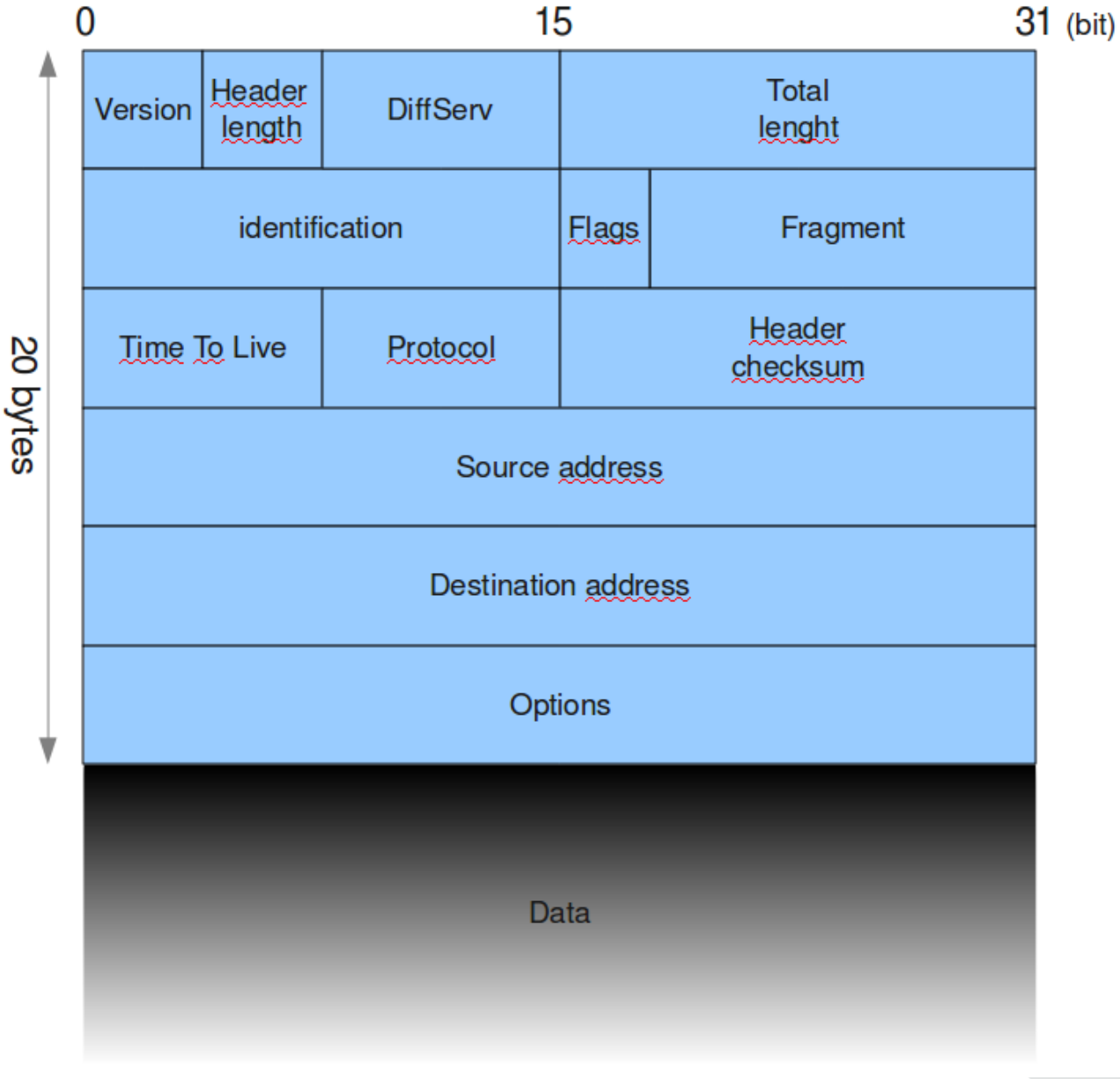
- Packet network
  - Most of data is transmitted in packets
  - Packet is formatted unit of data (~10B to kB long)
  - Packet = control information and data (payload)
  - Topology and active network nodes (routers, switches, usually FIFO)
  - Basis for the Internet communication
  - Used in mobile-phone comm. (GSM vs. GPRS/XG)

Computer Networks – classification (Switching)

- Packet network
  - –Bandwidth is shared among users (the packet route is not known „a priori“)

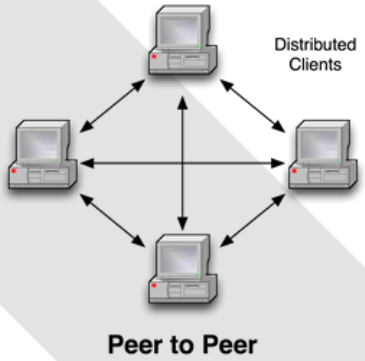


IP version 4 packet



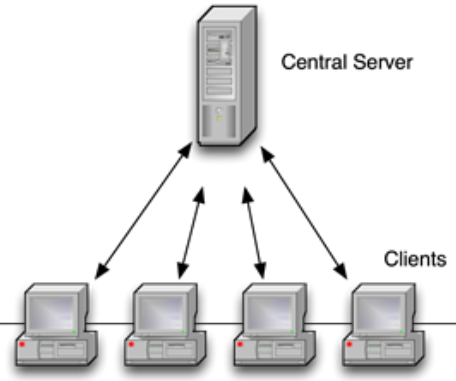
Computer Networks – classification (node conn.)

- Peer-to-peer (P2P)
  - all nodes are equal (no central coordination)
  - all computers can share their resources (memory, peripheries, files etc…)
  - common for data sharing/exchange
  - + more users --> overall available speed increases
  - - (i)legality – authors rights, attacks („infections“, spams, viruses, Troys), terrorism
  - example – BitTorrent, Napster (music), DC, Bitcoin…



Computer Networks – classification (node conn.)

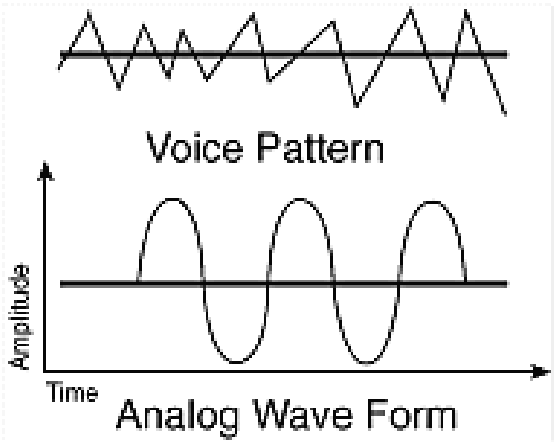
- Client-server
  - One (or more) computer (servers) is superior to another one (or more) computer (clients)
  - Server offers services to others „common“ computers (workstations)
  - example – file, email, print, WWW server etc.



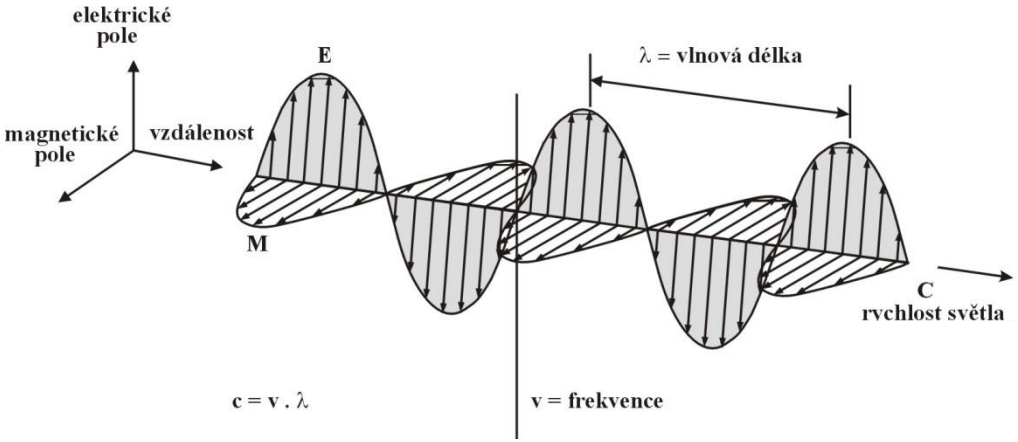
Client / Server

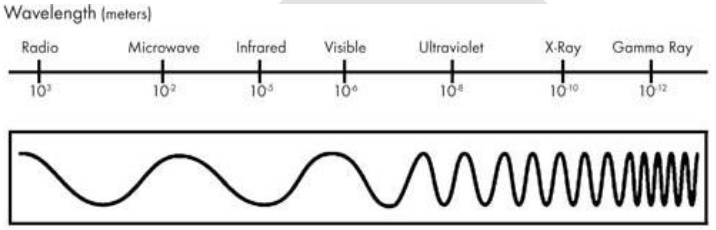
Computer Networks – classification (signal type)

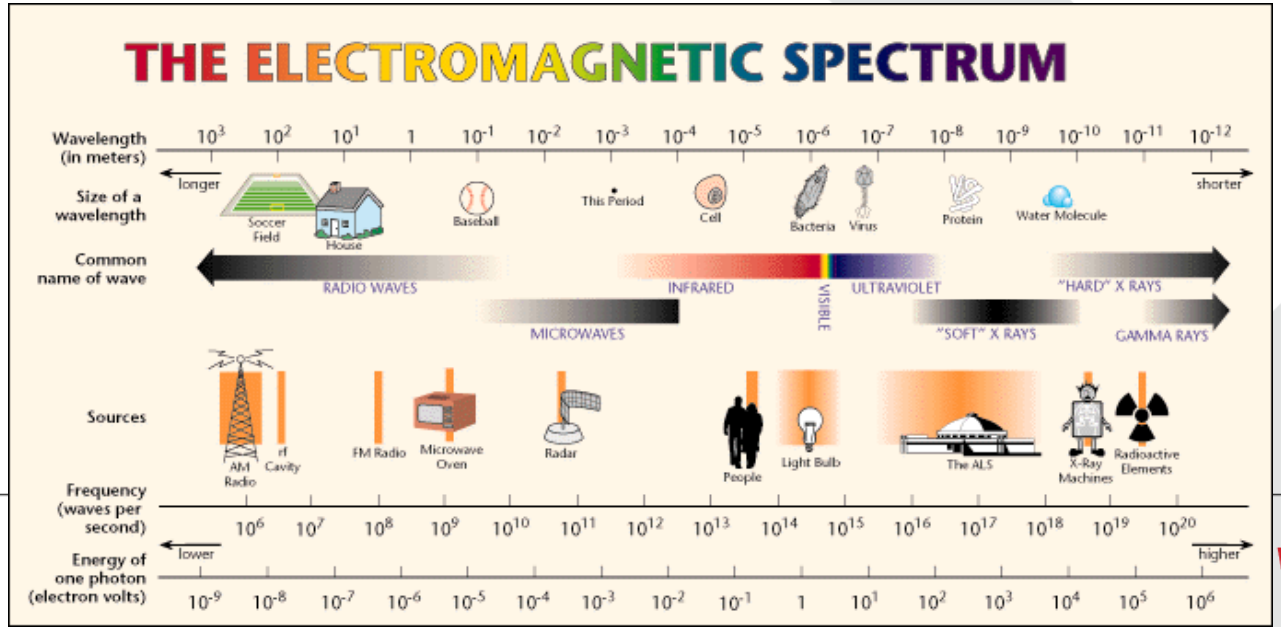
- Analogue network
  - Works with analogue (continuous) signal
  - Amplitude and frequency
  - Example:
    - you speak to handset – change in air pressure – collected by a handset -- amplified and then converted into current, or voltage fluctuations:



Computer Networks – classification (signal type)





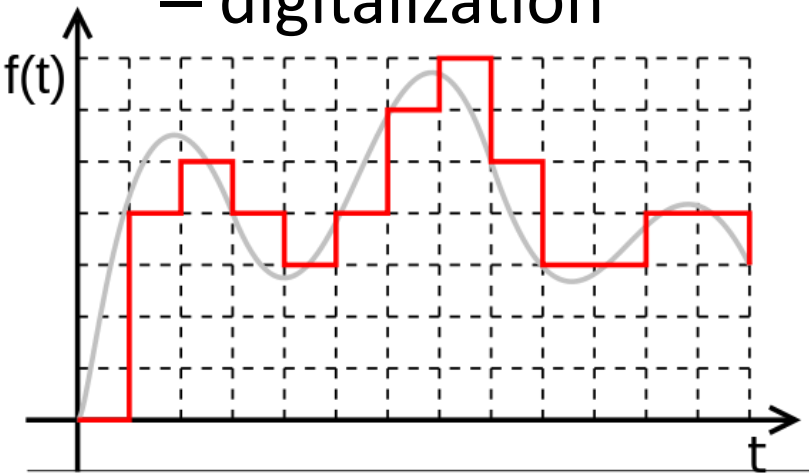


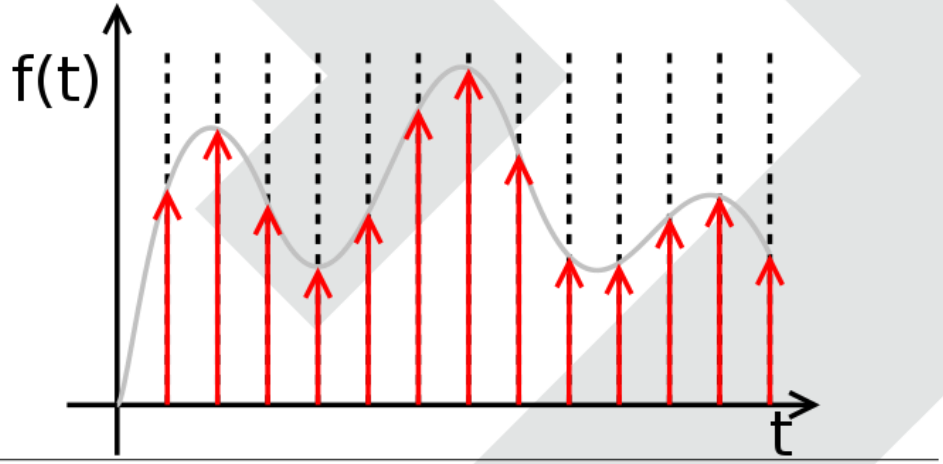
Computer Networks – classification (signal type)

- Digital network
  - Works with digital (discrete) signal pulses (1/0)
  - All techniques valid with analogue signal (amplifying, filtering etc.) could be applied on digital
  - Analogue signal is chopped to form digital one
  - advantages - ?

Computer Networks – classification (signal type)

- Digital signal
  - sampling - continuous-valued discrete-time signal
  - quantization (replaces each sample value by an approximation selected from a given discrete set)
  - digitalization





Computer Networks – classification (signal type)

Feature	Analog Characteristics	Digital Characteristics
Signal	Continuously variable, in both amplitude and frequency	Discrete signal, represented as either changes in voltage or changes in light levels
Traffic measurement	Hz (for example, a telephone channel is 4KHz)	Bits per second (for example, a T-1 line carries 1.544Mbps, and an E-1 line transports 2.048Mbps)
Bandwidth	Low bandwidth (4KHz), which means low data transmission rates (up to 33.6Kbps) because of limited channel bandwidth	High bandwidth that can support high-speed data and emerging applications that involve video and multimedia

Computer Networks – classification (signal type)

Feature	Analog Characteristics	Digital Characteristics
Network capacity	Low; one conversation per telephone channel	High; multiplexers enable multiple conversations to share a communications channel and hence to achieve greater transmission efficiencies
Network manageability	Poor; a lot of labor is needed for network maintenance and control because dumb analog devices do not provide management information streams that allow the device to be remotely managed	Good; smart devices produce alerts, alarms, traffic statistics, and performance measurements, and technicians at a network control center (NCC) or network operations center (NOC) can remotely monitor and manage the various network elements
Network capacity	Low; one conversation per telephone channel	High; multiplexers enable multiple conversations to share a communications channel and hence to achieve greater transmission efficiencies

Computer Networks – classification (signal type)

Feature	Analog Characteristics	Digital Characteristics
Power requirement	High because the signal contains a wide range of frequencies and amplitudes	Low because only two discrete signals—the one and the zero—need to be transmitted
Security	Poor; when you tap into an analog circuit, you hear the voice stream in its native form, and it is difficult to detect an intrusion	Good; encryption can be used
Error rates	High; 10^{-5} bits (that is, 1 in 100,000 bits) is guaranteed to have an error	Low; with twisted-pair, 10^{-7} (that, is 1 in 10 million bits per second) will have an error, with satellite, 10^{-9} (that is, 1 in 1 billion per second) will have an error, and with fiber, 10^{-11} (that is only 1 in 10 trillion bits per second) will have an error

Computer Networks – classification (geo scale)

- PAN
- LAN (WLAN)
- MAN
- WAN

- others – HAN (Home), SAN (Storage), CAN (Campus), GAN (Global), RAN (radio) VPN, Ambient network

Computer Networks – classification (geo scale)

- **PAN – Personal area network**
- Using devices such as mobile phone, PDA, laptop/notebook, tablet, smart watches, printers, video games consoles etc.
- Transfer via USB/FireWire, IrDA, Bluetooth
- Short distances (few meters – up to 10 meters)

Computer Networks – classification (geo scale)

- PAN – Personal area network

Computer Networks – classification (geo scale)

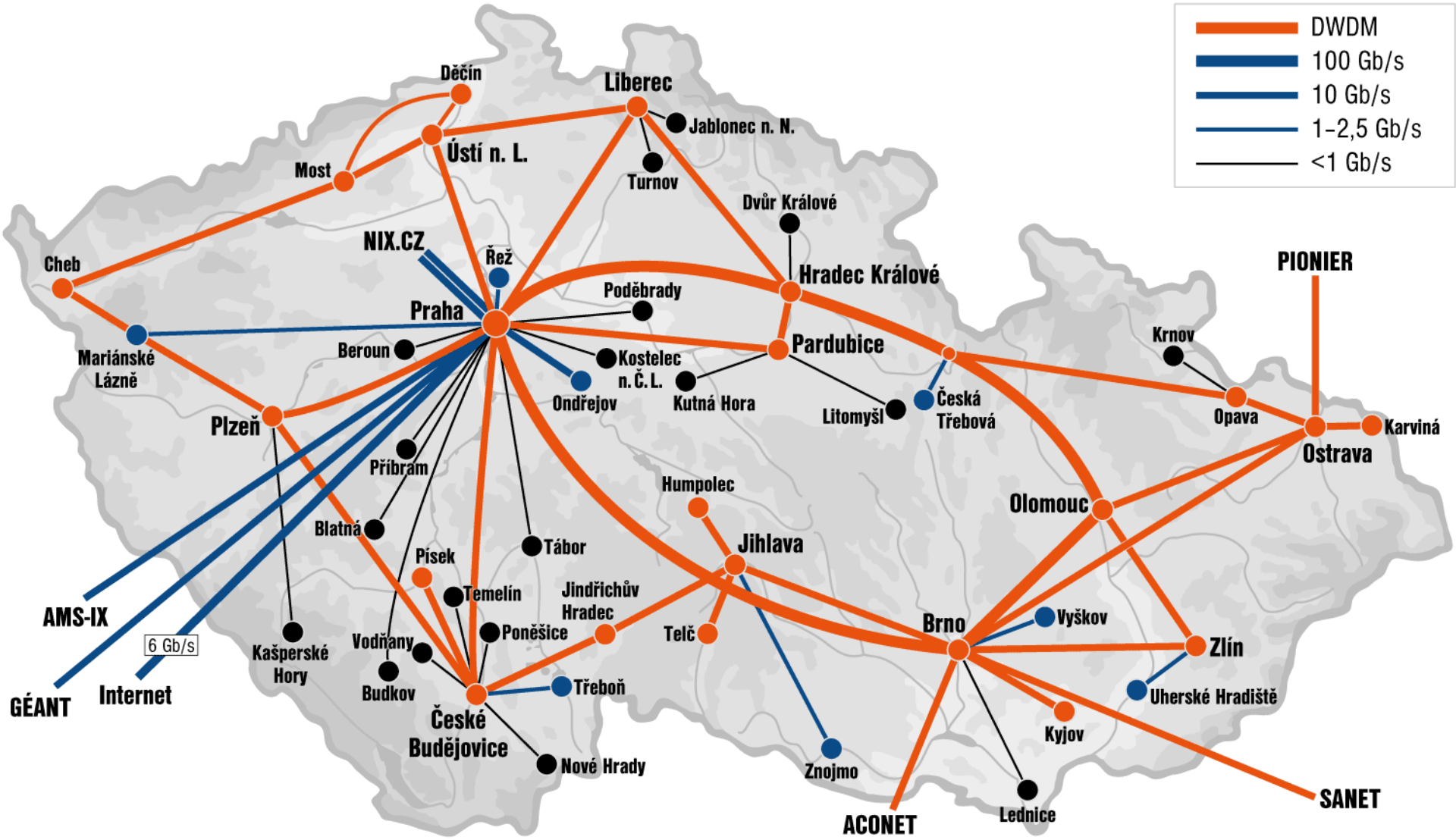
- **LAN – Local area network**
- smaller scale (room/building/block of buildings)
- own cabling and equipment (e.g. optical fiber, active network nodes,…)
- runs at 10 Mb/s to 10 Gb/s
- low error rate (wired networks)
- formerly for resources sharing
- example: MVSO + Tesco SW

Computer Networks – classification (geo scale)

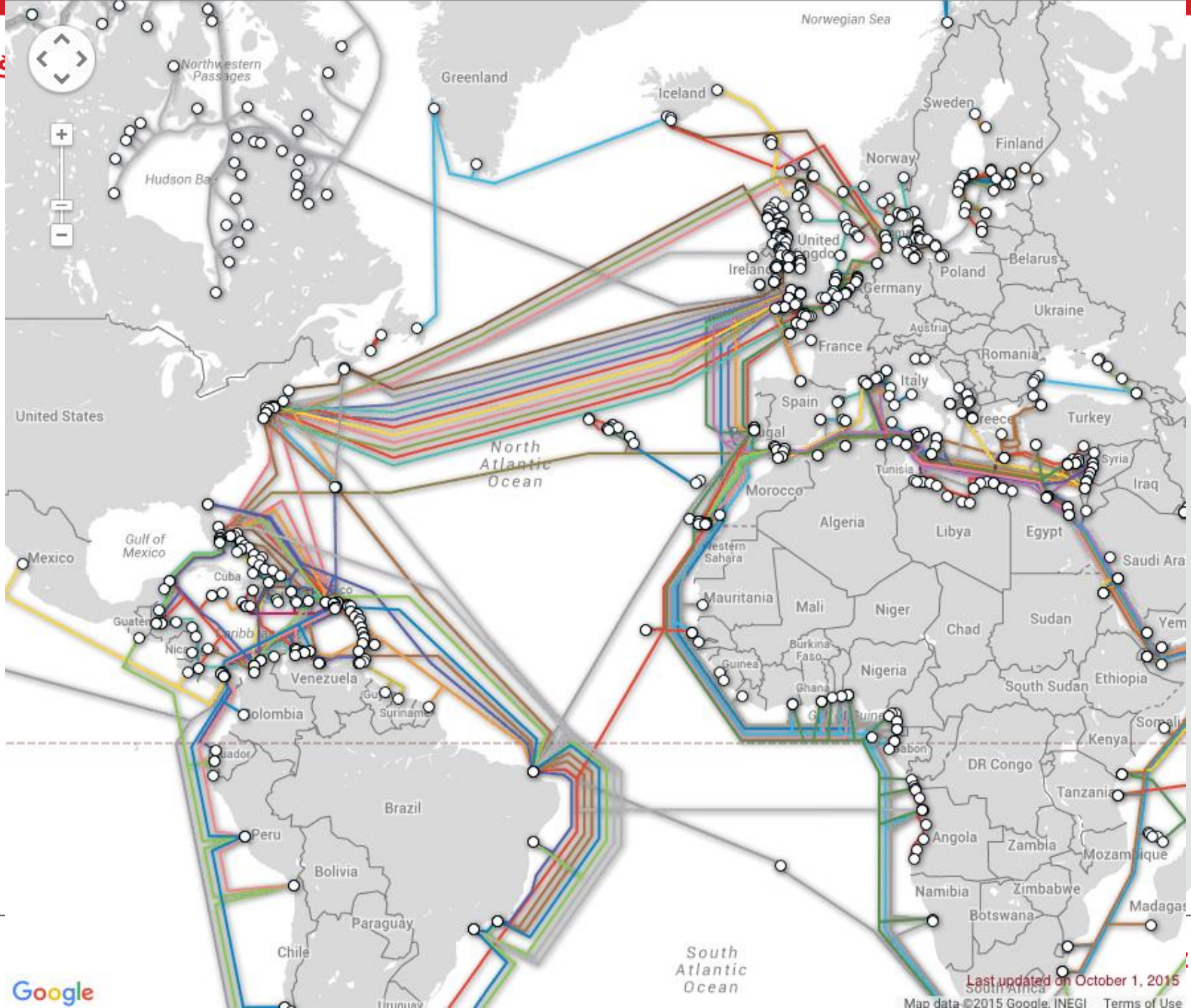
- **MAN – Metropolitan area network**
- covering the whole city/town (or several blocks)
- operated by one institution (company or local authority), but…
- … cabling and network equipment is rent/leased
- technically – more LANs wirelessly connected
- example: DQDB – up to 100 km (two nodes max 2km), up to 155 Mb/s

Computer Networks – classification (geo scale)

- **WAN – Wide area network**
- broad area – up to international scale
- leased cabling and infrastructure (optical fibres, microwave channels, satellites)
- great variety of bandwidth (65 kb/s to 100 Gb/s)
- formerly for remote access and communication among users
- WAN is being replaced by VPN


DWDM
100 Gb/s
10 Gb/s
1–2,5 Gb/s
<1 Gb/s
Děčín
Liberec
Jablonec n. N.
Ústí n. L.
Most
Turnov
Dvůr Králové
NIX.CZ
Řež
Cheb
Hradec Králové
PIONIER
Poděbrady
Praha
Mariánské Lázně
Beroun
Pardubice
Krnov
Kostelec n. Č. L.
Ondřejov
Kutná Hora
Litomyšl
Česká Třebová
Opava
Karviná
Ostrava
Plzeň
Příbram
Humpolec
Olomouc
Blatná
Jihlava
Písek
Tábor
AMS-IX
Temelín
Jindřichův Hradec
Vyškov
Brno
Zlín
6 Gb/s
Kašperské Hory
Vodňany
Poněšice
Telč
Budkov
Třeboň
Uherské Hradiště
GÉANT
Internet
České Budějovice
Kyjov
Nové Hrady
Znojmo
SANET
ACONET
Lednice


NORTH AMERICA
SOUTH AMERICA
INDIAN
OCEAN
PERSIA
Sahara or Great Desert
WESTERN AUSTRALIA
TASMANIA


Norwegian Sea
Northwestern Passages
Greenland
Iceland
Sweden
Finland
Norway
Hudson Bay
United Kingdom
Ireland
Belarus
Poland
Germany
Ukraine
Austria
France
Romania
Italy
Spain
Turkey
Greece
Syria
Iraq
United States
North Atlantic Ocean
Tunisia
Morocco
Algeria
Libya
Egypt
Saudi Arabia
Gulf of Mexico
Mexico
Cuba
Western Sahara
Mauritania
Mali
Niger
Chad
Sudan
Yemen
Burkina Faso
Guinea
Nigeria
Ghana
South Sudan
Ethiopia
Somalia
Venezuela
Colombia
Kenya
Gabon
DR Congo
Tanzania
Brazil
Peru
Angola
Zambia
Mozambique
Bolivia
Namibia
Zimbabwe
Botswana
Madagascar
Paraguay
Chile
South Atlantic Ocean
South Africa
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Computer Networks – classification (ownership)

- PDN – Public data network
  - – operated by a telecommunications administration, or a recognized private operating agency
- PN – Private network
  - – uses private IP address space, „private“ packets cannot be transmitted via public Internet
- VPN – Virtual private network
  - – connection to private computers via public network
  - – establishes access to intranet (security issues)

Computer Networks – classification (others)

- Ambient network
  - combination of PAN, LAN/WLAN and mobile networks
  - concept of „not disconnected“ communitation (joining networks) --- EU FP6
- Example:

Laptop → (Bluetooth) → Mobile → (GPRS) → mobile signal provider → Internet

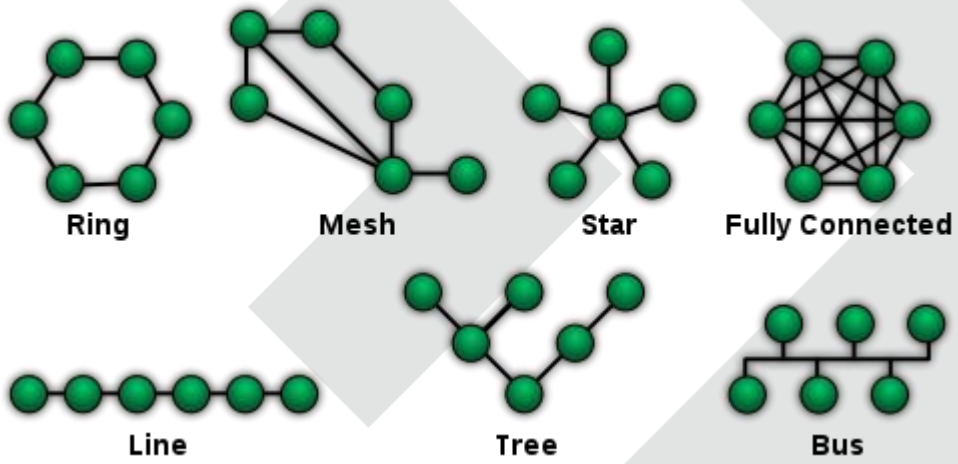
PDA → (bluetooth) → Laptop → (WLAN) → AP

Computer Networks – classification (others)

- Ambient network
  - combination of PAN, LAN/WLAN and mobile networks
- HAN – Home area network
  - communication among home digital devices
- SAN – Storage area network
  - connection to storage capacity of various devices, which appear like locally attached to the operating system

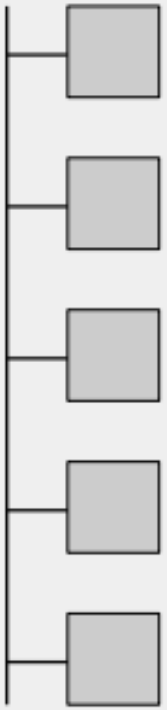
Computer Networks – topology

- Arrangement of various elements in computer network (mainly cabling and active components)
- Basic types:
  - Point-to-point
  - Bus network
  - Star network
  - Ring network
  - Tree network
  - Mesh network



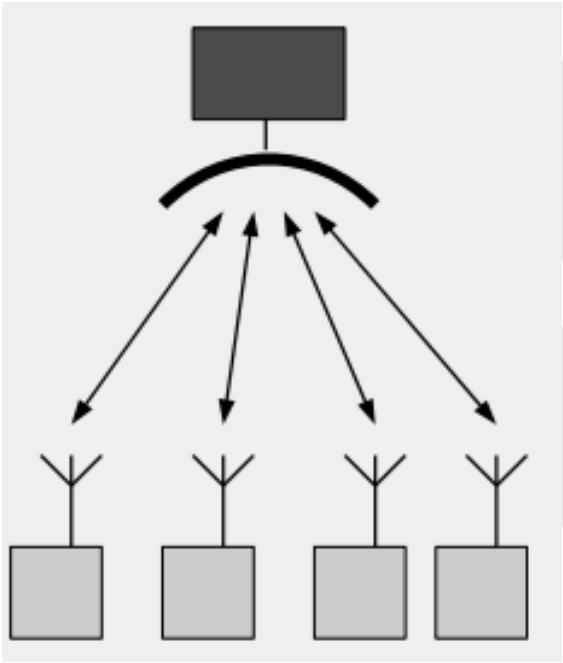
Computer Networks – topology (Bus network)

- one transmitting medium
- data are sent in one direction (async.)
- if a single node is damaged – all network transmission ceased
- every station receives all network traffic
- equal transmission priority
- + easy to connect, less cabling, small net
- - if something breaks, all net. collapse



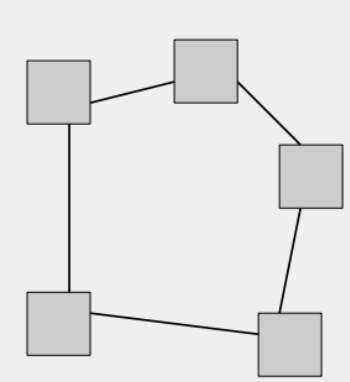
Computer Networks – topology (Bus network)

- with one central station
- used for WLAN



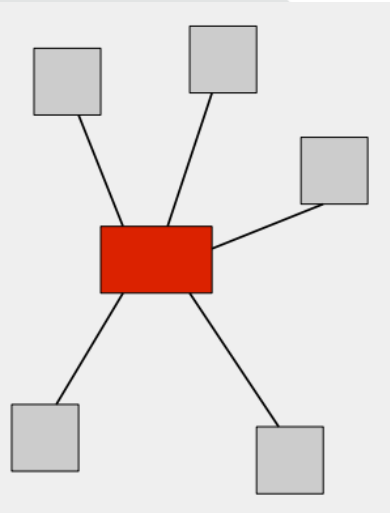
Computer Networks – topology (Ring network)

- every node (computer) is connected to another two (to form a circle)
- data have to pass through every single node between start/end node
- + easy-to-transmit, minimal delay time, no packets collision, highest bandwidth
- - if failure, then problem



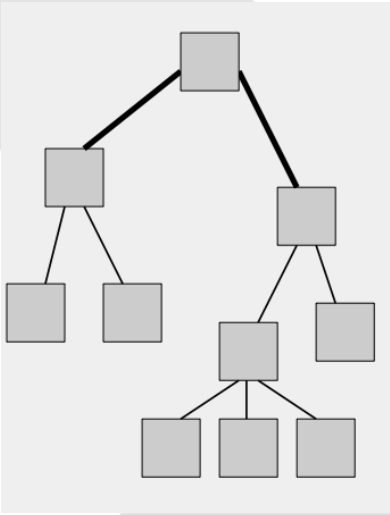
Computer Networks – topology (Star network)

- most used network topology
- computers are connected to the central point (hub or switch)
- one link between central point and computer
- + if failure of one computer, it works; no packets collision, easy to expand
- - many cables, special hw (central p.)



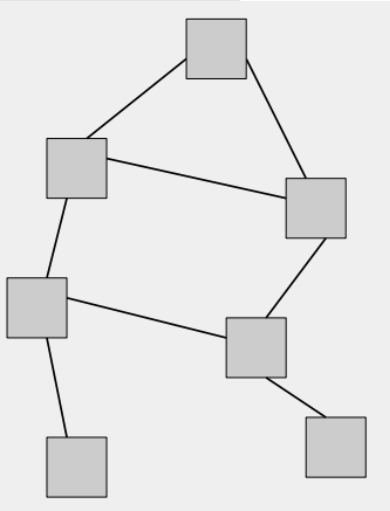
Computer Networks – topology (Tree network)

- combination of Bus and Star
- broad area networks
- in most cases B-tree types
- + scalable, point-to-point connection, easier fault identification and isolation
- - many cables, hard to maintain, if backbone fails, the entire network falls



Computer Networks – topology (Mesh network)

- connection among nodes
- no central feature
- represented by a general graph
- shortest path bridging
- + scalable, lower sensitivity to failures, decentralized
- - ???



Computer Networks – classification

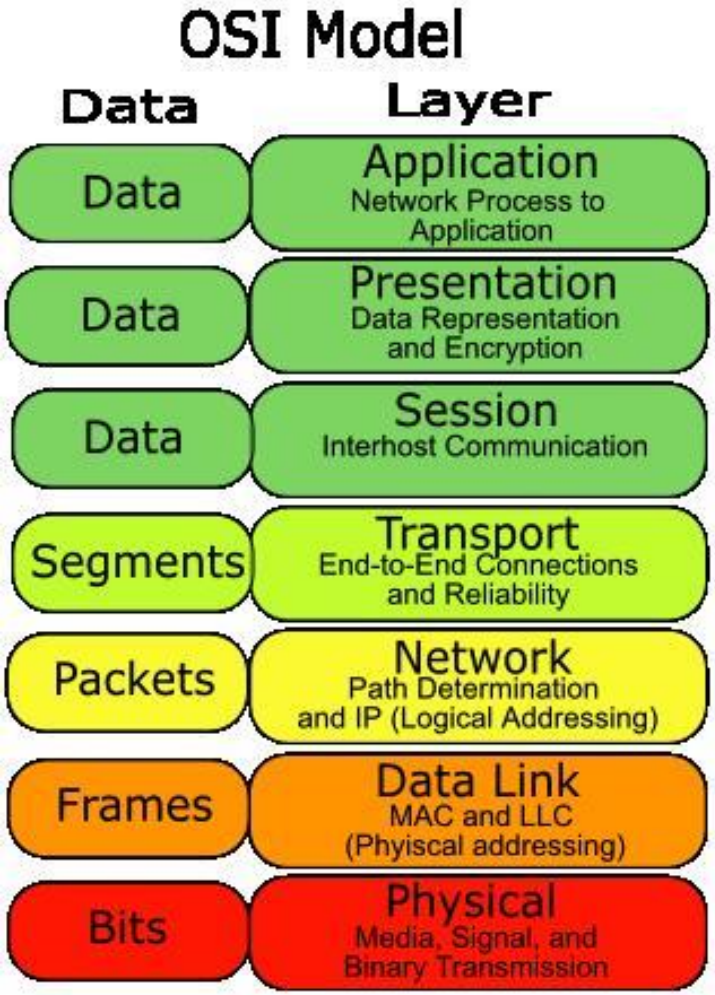
VIDEO

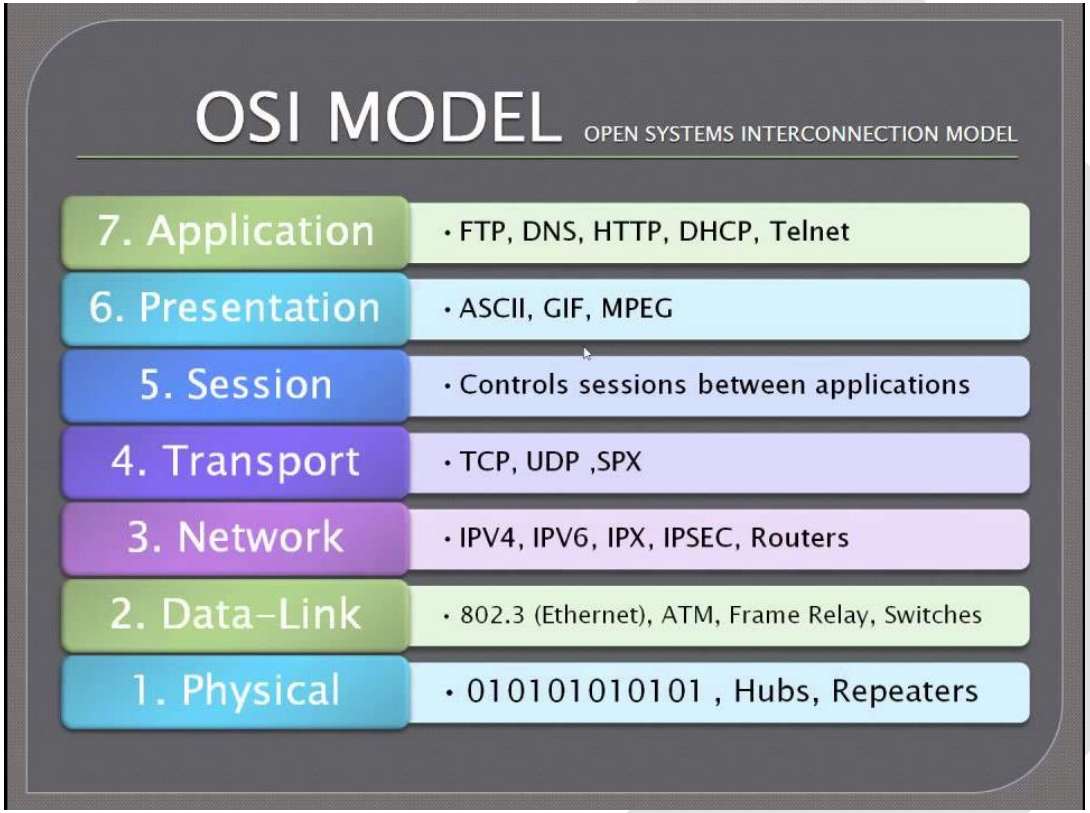
ISO/OSI model

Computer Networks – former heterogeneity

- Experimental networks (ARPANET, CYCLADES, SNA from IBM, DNA from DEC)
- Need for mutual inter-connection
- Layer architecture (main ideas):
  - individual layer for different abstraction degree
  - each layer should provide exactly specified functions
  - interface should minimize data-flow
  - number of layers should be optimized

Computer Networks – ISO OSI model



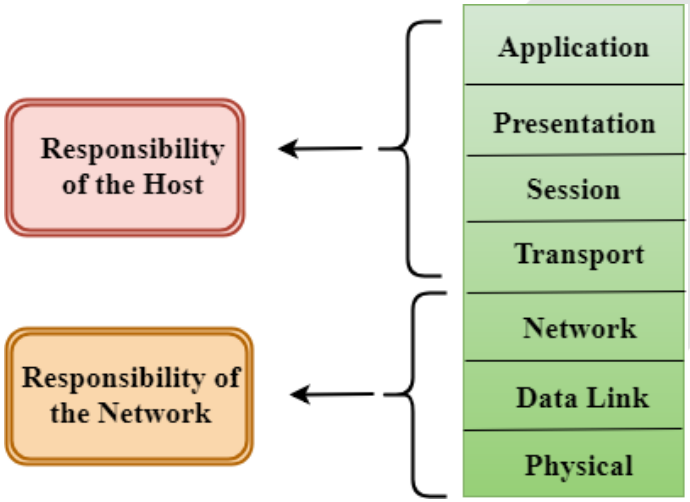


Computer Networks – ISO OSI

- Reference model OSI (Open Systems Interconnection)
  - Specified by ISO (International Organization for Standardization)
  - Needed for standardization of internet communication
  - ISO 7498 (y. 1984); ITU-T (X.200)
  - Layer-scheme describing the communication
  - Layers are independent and substitutable
  - Model objective = standards development
  - Implementation is not specified – but principles
  - Main aim = decomposition of the communication

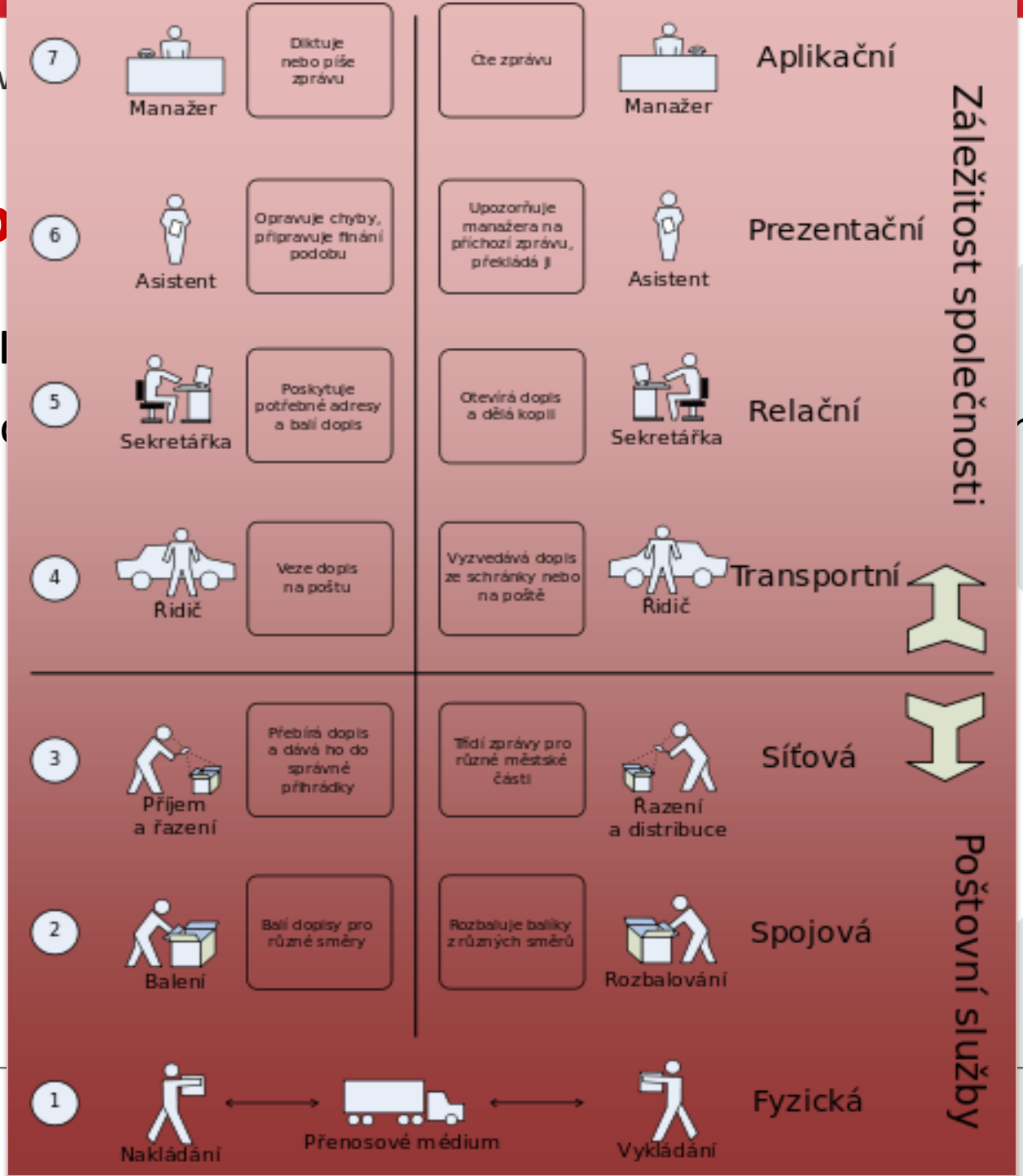
Computer Networks – ISO OSI

- Example:
  - Communication between companies‘ management
  - From UP to BOTTOM
  - Individual layers have communication „interface“



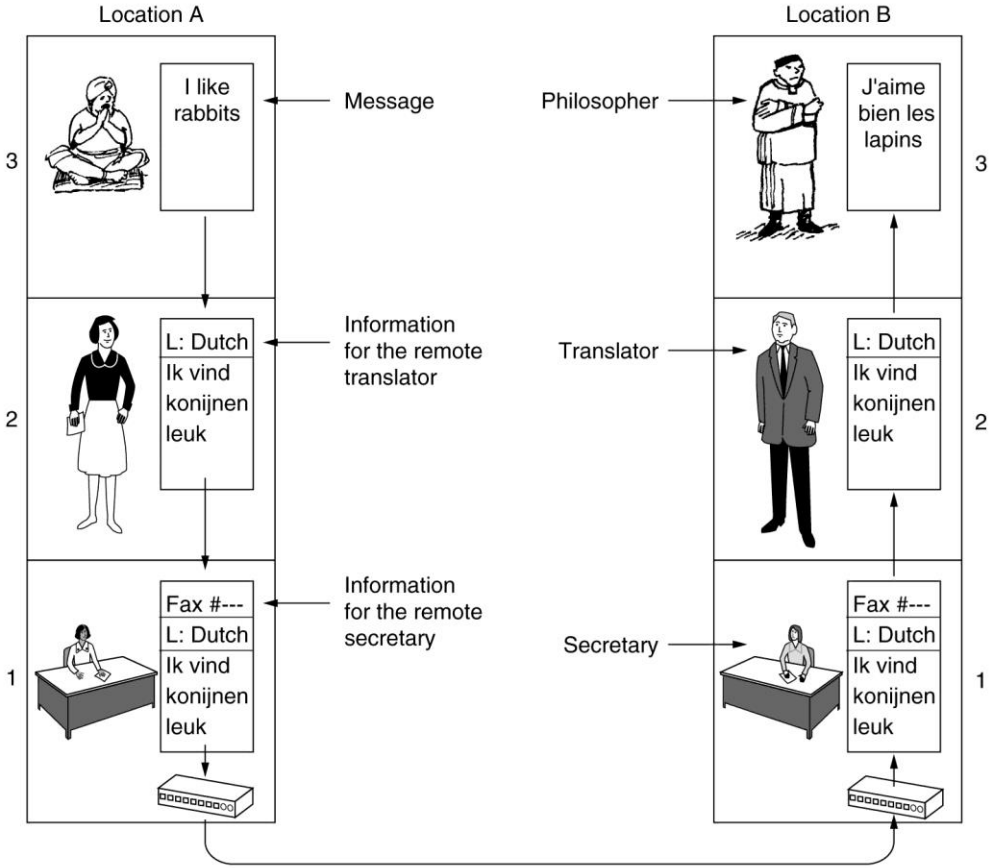
Comp

- Exa
  - C nt


7
Manažer
Diktuje nebo píše zprávu
Čte zprávu
Manažer
Aplikační
6
Asistent
Opravuje chyby, připravuje finání podobu
Upozorňuje manažera na příchozí zprávu, překládá ji
Asistent
Prezentační
5
Sekretářka
Poskytuje potřebné adresy a balí dopis
Otevírá dopis a dělá kopii
Sekretářka
Relační
4
Řidič
Veze dopis na poštu
Vyzvedává dopis ze schránky nebo na poště
Řidič
Transportní
Záležitost společnosti
3
Příjem a řazení
Přebírá dopis a dává ho do správné přihrádky
Třídí zprávy pro různé městské části
Řazení a distribuce
Síťová
2
Balení
Balí dopisy pro různé směry
Rozbaluje balíky z různých směrů
Rozbalování
Spojová
1
Nakládání
Přenosové médium
Vykládání
Fyzická
Poštovní služby

Computer Networks – ISO OSI

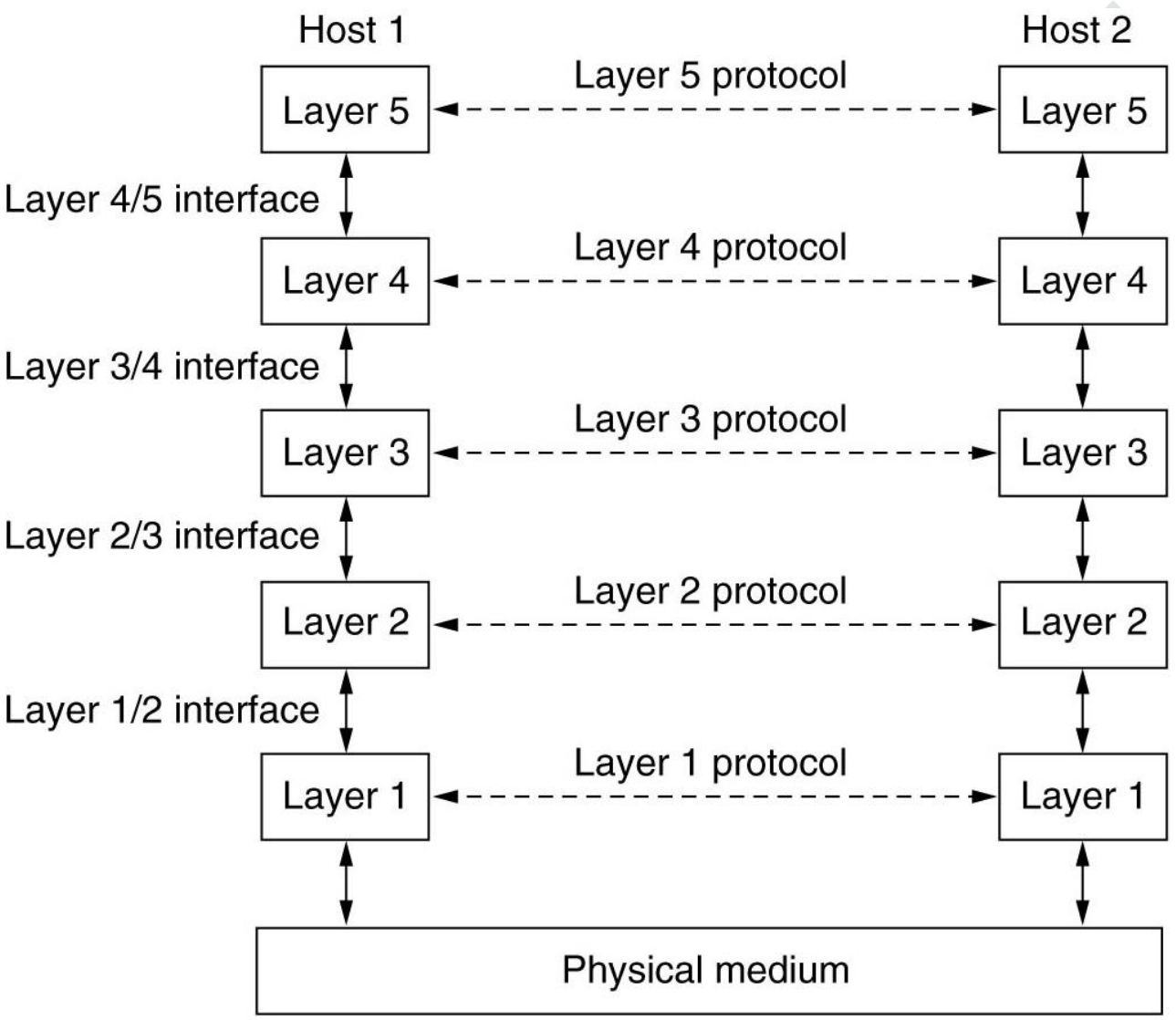
- Example (simplified):
  - Communication between two entities (people)



Computer Networks – ISO OSI

- Layer provides services to a higher-level layer
- Layer does not „bother“ higher layer
- Data are sent in packets and in each layer is enriched with new information (formatting, addresses etc.)
- If any layer is not active = it is null/transparent layer
- No layer can be skipped
- Communication:
  - Vertically -> via interface
  - Horizontally -> via protocols

ISO OSI – Communication



ISO OSI – Entities

- Entities:
  - are active objects of a layer
  - set of entities = layer
  - communicate with other system entities
  - carry functions and offer services (and consume services from preceding layer)
  - function = providing specified service
  - interact directly only with neighbouring layers‘ entities

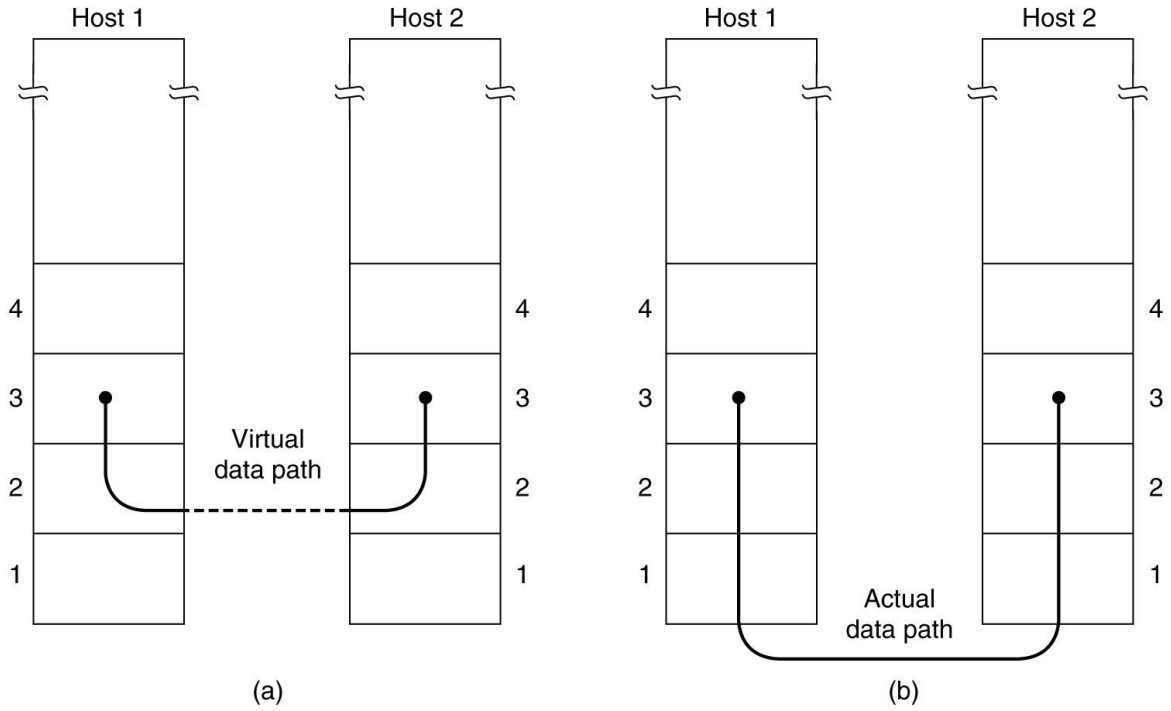
  - example (at lower layers) – hardware devices (I/O ports)

ISO OSI – Protocols & Services

- Protocol:
  - set of rules for communication of entities in the same layer
- Service:
  - for higher-level layer; using lower-level layer
  - offered in Service Access Points (SAP) having their addresses
  - interaction:
    - request (request for lower-level layer service)
    - confirm (no comment)
    - indication (info for higher-level layer to cause some action)
    - response (user reaction/action-end to indication)

ISO OSI – Protocols & Services

- Protocol:
  - set of rules for communication of entities in the same layer



ISO OSI – Services

- Services:
  - Connection-oriented services
    - connection – transmission – termination
    - connection is to be identified, both sides are communicating
    - example – telephony (classic, ISDN) or virtual connections (ATM)
  - Connectionless services
    - data are sent as a packets with end-point addresses (more than 1)
    - multicast (group of end-points) or broadcast (anyone could get it)
    - packets are independent to each other
    - example – link layer (LAN), IP protocol
  - Reliable (confirmation messages) or unreliable services

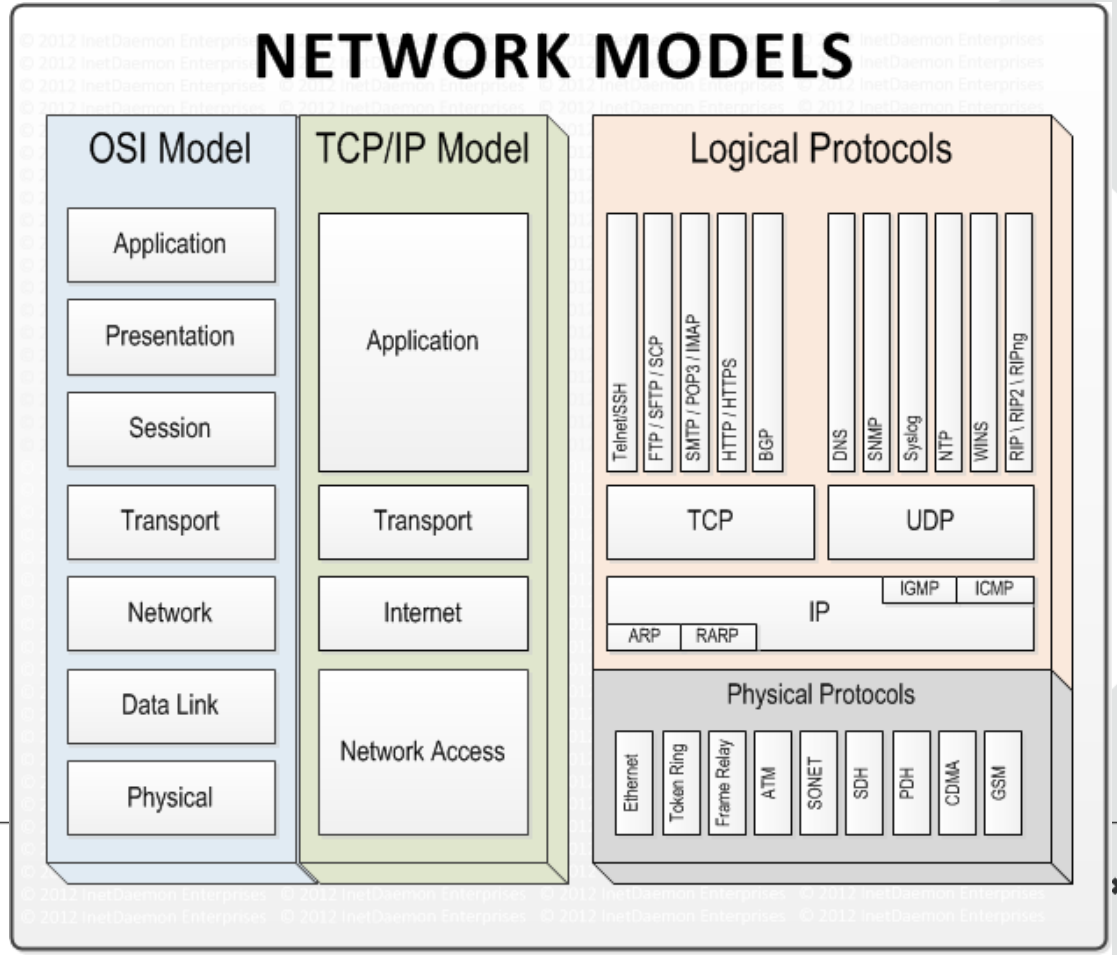
ISO OSI – Encapsulation

							L7 Header	Data			L7 PDU
						L6 Header	Data				L6 PDU
					L5 Header	Data					L5 PDU
				L4 Header	Data						L4 PDU
			L3 Header	Data							L3 PDU
		L2 Header	Data							L2 Trailer	L2 PDU
L1 Header		Data									L1 PDU

			Data	
		TCP	Data	
	IP	TCP	Data	
Data Link	IP	TCP	Data	Data Link

Computer Networks – Network architecture

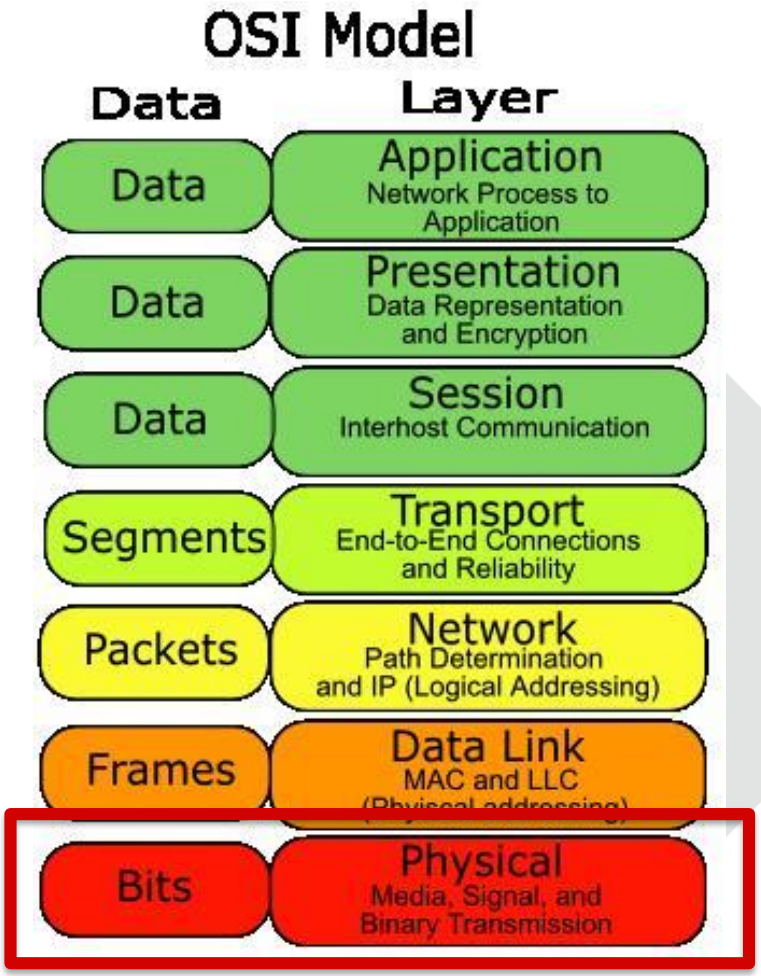
- ISO OSI vs. Internet (TCP/IP)



Computer Networks

Vít PÁSZTO

Network Layer



Physical layer

- Guarantee physical tasks
  - transforms bits into physical signal (and vice versa)
- Ensures electrical properties of a network:
  - voltage, frequency, modulation, speed, timing, synchronization, coding etc.
- And also mechanichal properties of connectors:
  - shape, size and connectors
- Works with signal => via hardware
- All about physical elements in a network

Physical layer

- Activation, sustaining and deactivation physical connection for bits transmission
- Half or full duplex
- Services:
  - open/close physical connection
  - bits arranging into serial current
  - error messages for link layer
- example: RS232, V.35

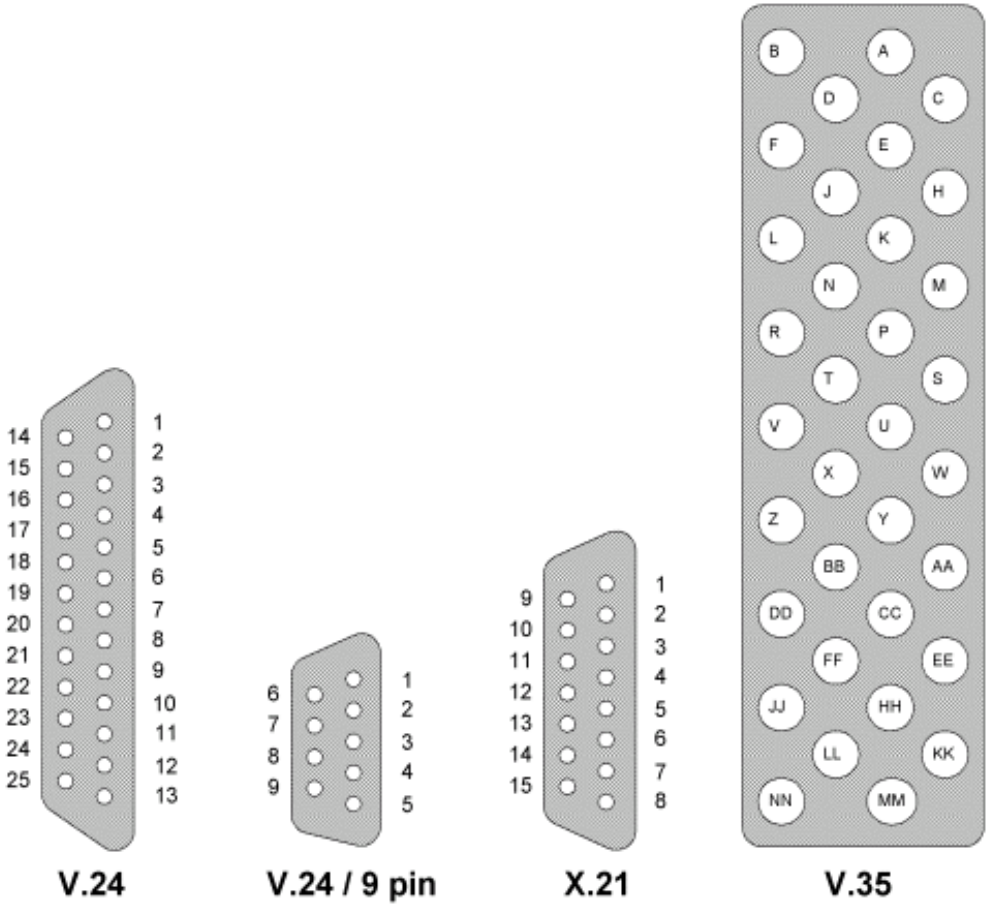
Physical layer

- What is it about?
  - modems
  - standards for communication
  - ISDN, DSL
  - cabels
  - transmission technologies (Bluetooth, IrDA etc.)
  - connectors
  - active nodes

Physical layer

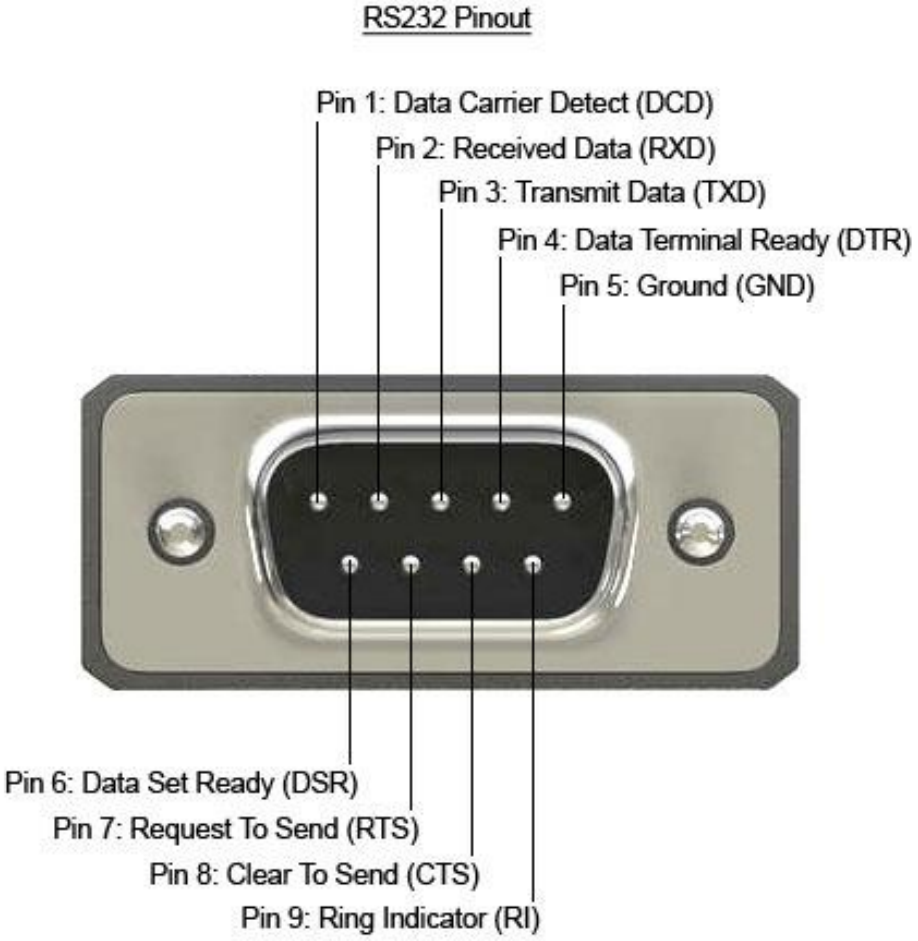
- Modem (http://goo.gl/SriaSc) - V.21, V.22, V.22bis, V.26bis, V.27ter, V.32, V.32bis, V.34, V.90, V.92, V.44
- Group of EIA standards – RS-232, RS-485 and RS-422
- ISDN (Integrated Services Digital Network)
- DSL (Digital Subscriber Line) / ADSL

Physical layer

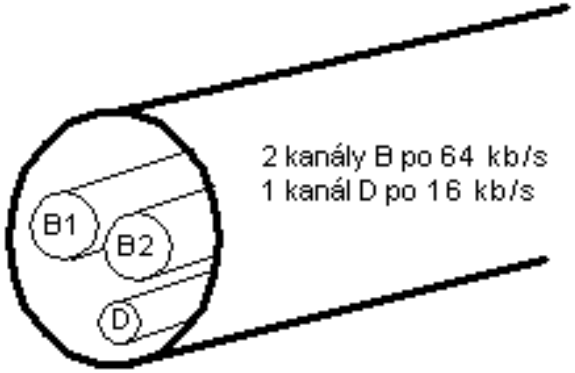


ITU	Kb/s
V.32	9,6
V.32bis	14,4
V.34	28, 8
V.34+	33,6
V.90	56 (switchboard to modem) 33,6 (modem to switchboard)

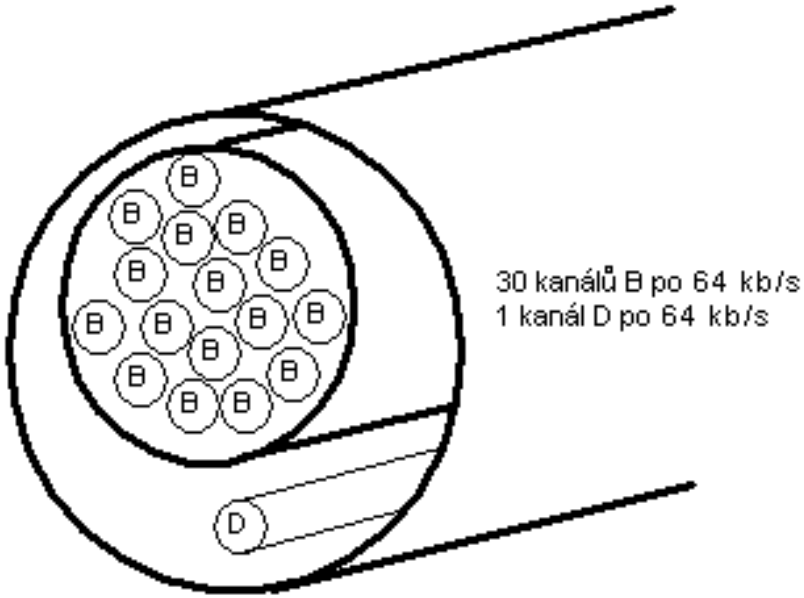
Physical layer



Physical layer



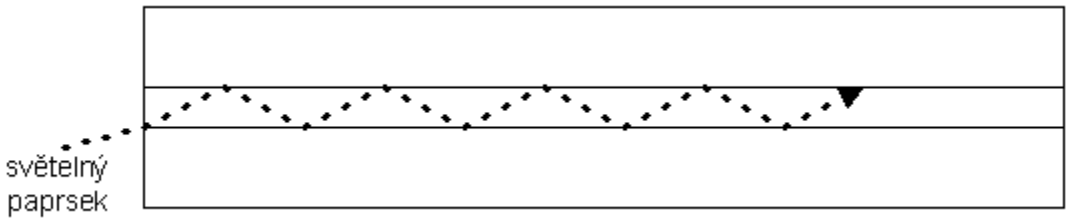
eurolSDN2
(Basic Rate)

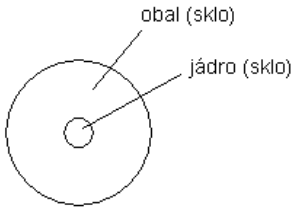


eurolSDN30
(Primary Rate)

Physical layer

- T1, E1 (multiplex digital data transmission)
- SONET/SDH (Synchronous Digital Hierarchy) – optical transmission
- 10Base2 (thin Ethernet) and 10Base-T (twisted pair cable)

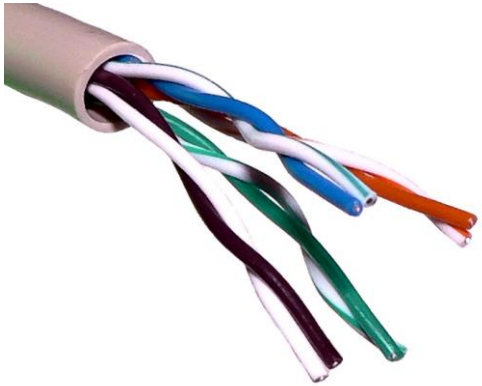




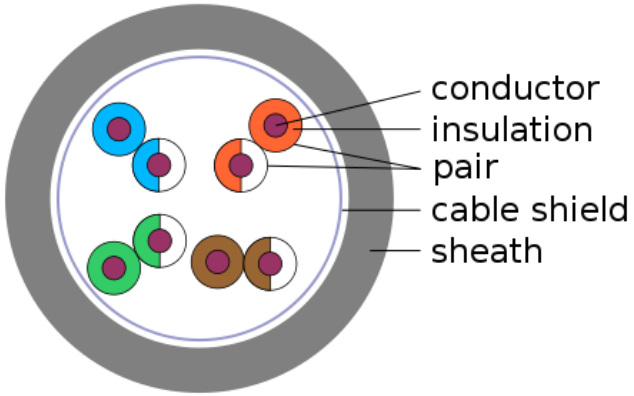
Signal	Speed
E0	64 kbit/s
E1	2,048 Mbit/s
E2	8,448 Mbit/s
E3	34,368 Mbit/s
E4	139,264 Mbit/s

Physical layer

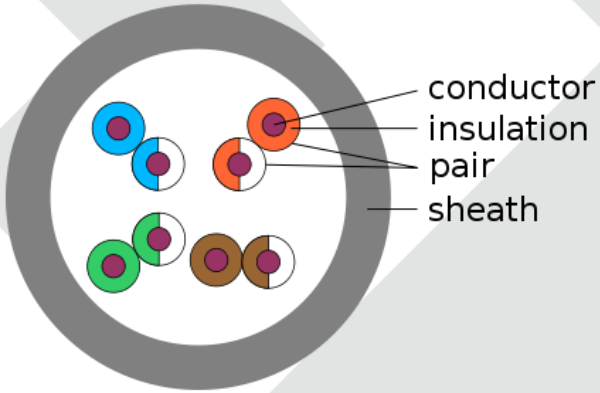
Physical layer



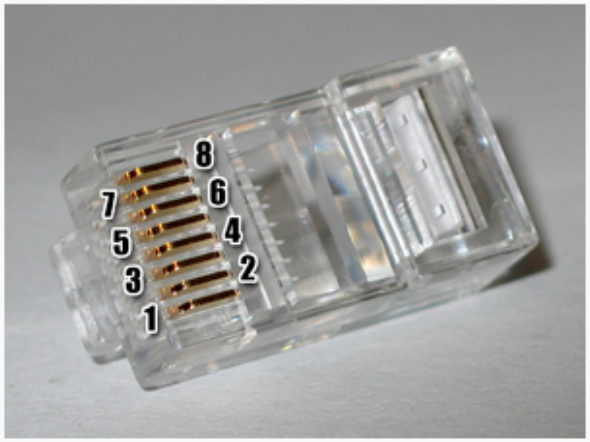
S/UTP



UTP



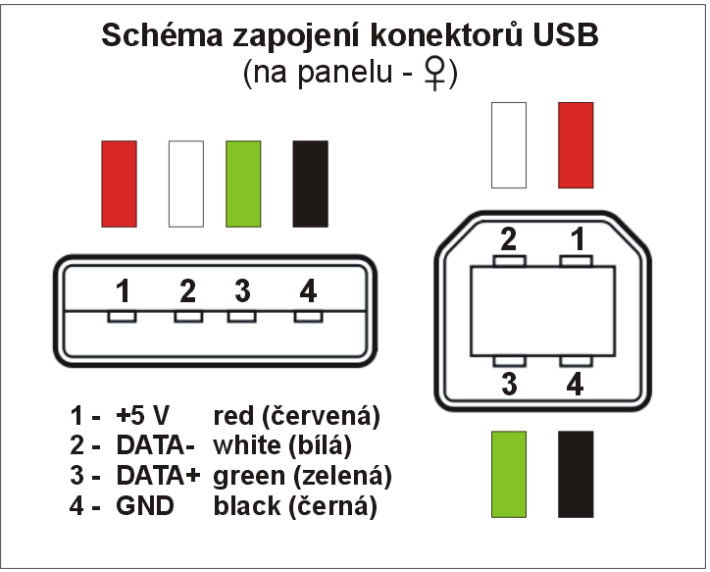
Physical layer

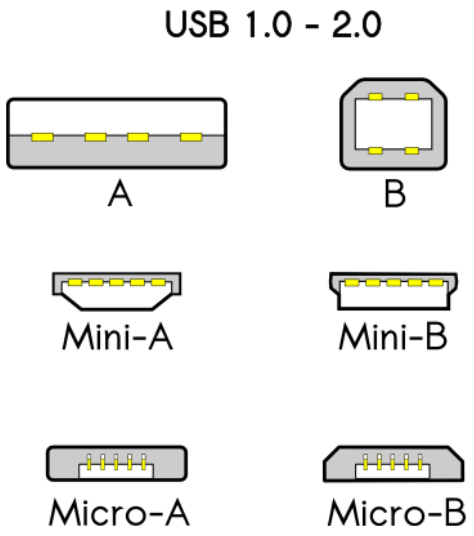
Pin	T568A Pair	T568B Pair	1000BASE-T Signal ID	Wire	T568A Color	T568B Color	Pins on plug face (socket is reversed)
1	3	2	DA+	tip	white/green stripe	white/orange stripe	
2	3	2	DA-	ring	green solid	orange solid	
3	2	3	DB+	tip	white/orange stripe	white/green stripe	
4	1	1	DC+	ring	blue solid	blue solid	
5	1	1	DC-	tip	white/blue stripe	white/blue stripe	
6	2	3	DB-	ring	orange solid	green solid	
7	4	4	DD+	tip	white/brown stripe	white/brown stripe	
8	4	4	DD-	ring	brown solid	brown solid	

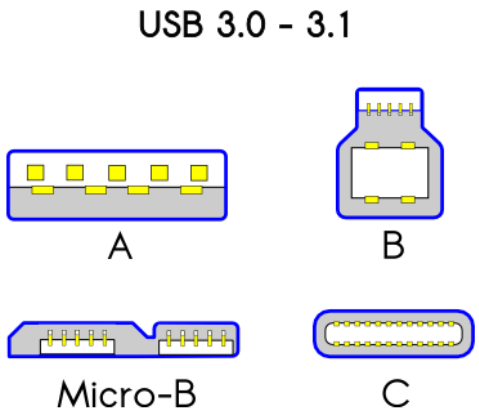
Physical layer

- Bluetooth
- IEEE 802.11
- FireWire
- IrDA
- USB

Physical layer







Physical layer

USB camera Lumix, * mini USB, * type B, * female type A, * type A

connectors	USB 1.0 1996	USB 2.0 2001	USB 2.0 Revised	USB 3.0 2011	USB 3.1 2014	USB 3.2 2017	USB4 2019
Data rate	1.5 Mbit/s (*Low Speed*)	480 Mbit/s (*High Speed*)		5 Gbit/s (*SuperSpeed*)	10 Gbit/s (*SuperSpeed+*)	20 Gbit/s (*SuperSpeed+*)	40 Gbit/s (*SuperSpeed+*)

Physical layer

Pin	Color	Signal name		Description
		A	B	
Shell	N/A	Shield		Metal housing
1	Red	VBUS		Power
2	White	D−		USB 2.0 differential pair
3	Green	D+		
4	Black	GND		Ground for power return
5	Blue	StdA_SSRX−	StdB_SSTX−	SuperSpeed receiver differential pair
6	Yellow	StdA_SSRX+	StdB_SSTX+	
7	N/A	GND_DRAIN		Ground for signal return
8	Purple	StdA_SSTX−	StdB_SSRX−	SuperSpeed transmitter differential pair

Physical layer

USB 3.0 host, VGA connector, DisplayPort connector, USB 2.0 host.

Physical layer

- HDMI
- High-Definition Multi-media Interface
- uncopressed transmission (video and sound)

Physical layer

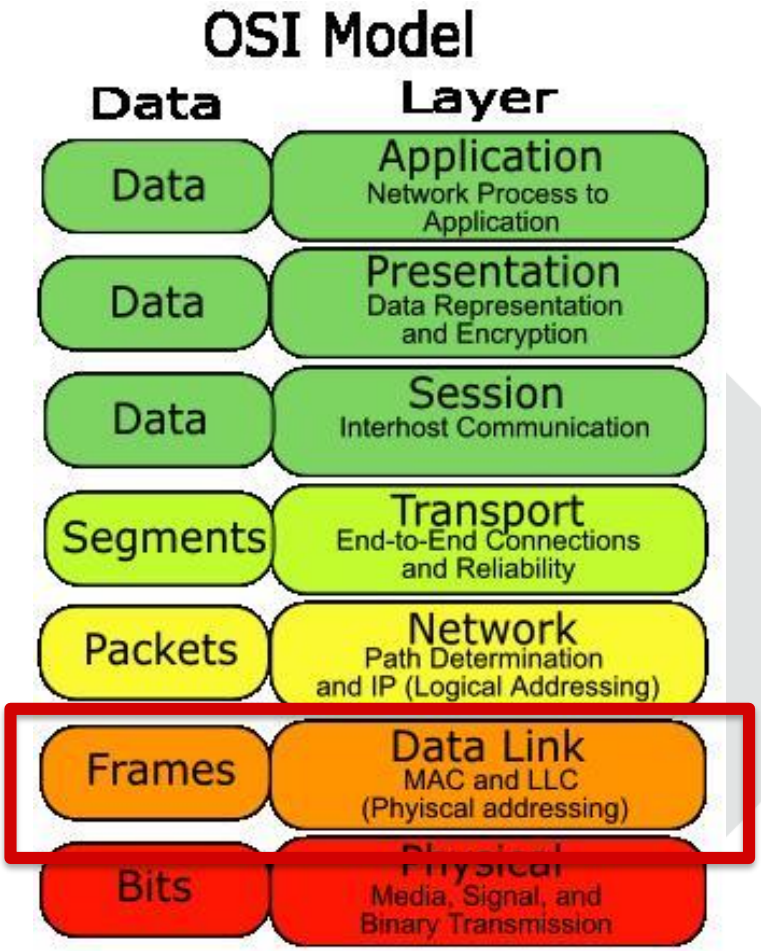
- Repeater:
  - signal correction (amplification), one input – one output
  - if different cables = transceiver
- Hub:
  - signal is multiplied (multiport repeater)
  - collision detection
  - sending signal to all (no adressing)
  - has been replaced by switches (but it is „faster“ than switch)

Physical layer - homework

- 3 slides presentation about one of the technologies here:

1-Wire
ARINC 818 Avionics Digital Video Bus
Bluetooth physical layer
CAN bus (controller area network) physical layer
DSL
EIA RS-232, EIA-422, EIA-423, RS-449, RS-485
Etherloop
Ethernet physical layer Including 10BASE-T, 10BASE2, 10BASE5, 100BASE-TX, 100BASE-FX, 100BASE-T, 1000BASE-T, 1000BASE-SX and other varieties
G.hn/G.9960 physical layer
GSM Um air interface physical layer
IEEE 802.15.4 physical layers
IEEE 1394 interface
IRDA physical layer
ISDN
ITU Recommendations: see ITU-T
I²C, I²S
LoRa
Low-voltage differential signaling
Mobile Industry Processor Interface physical layer
Modulated ultrasound
Optical Transport Network (OTN)
SMB
SONET/SDH
SPI
T1 and other T-carrier links, and E1 and other E-carrier links
Telephone network modems — V.92
TransferJet physical layer
USB physical layer
Varieties of 802.11 Wi-Fi physical layers
Visible light communication co-ordinated under IEEE 802.15.7
X10

Network Layer



Data-link layer

- Differences:

  – **Data link layer** -> larger data-blocks transfer -> frames

  – **Physical layer** -> bit transfer

  – **Data link layer** -> bits interpretation (distinguish what is info part – header – and what is the data itself payload)

  – **Physical layer** -> does not recognize bits (just sending them)

Data-link layer

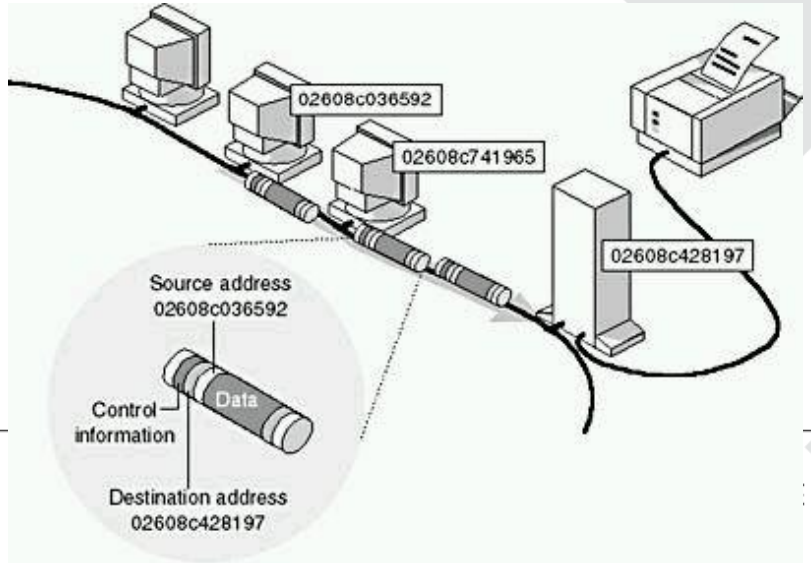
- Main task:
  - packet preparation for transport
  - access control to medium
- Creates data frames and receives data from network layer
- Creates connection/interface between programme processes and physical devices (IN/OUT)
- When data goes through different types of network (LAN vs. WAN) -> data frame is modified and adjusted to a specific network (no change of content)

Data-link layer

- Access control to a medium using several methods
- Source node (network device connected with transport medium) -> Network interface controller (NIC) -> using router to pass in between networks (e.g. LAN to WAN)
- Router unpacks a data frame (gets network adresss) -> makes routing decision -> pack a data into different data frame -> sends it to WAN

Data-link layer

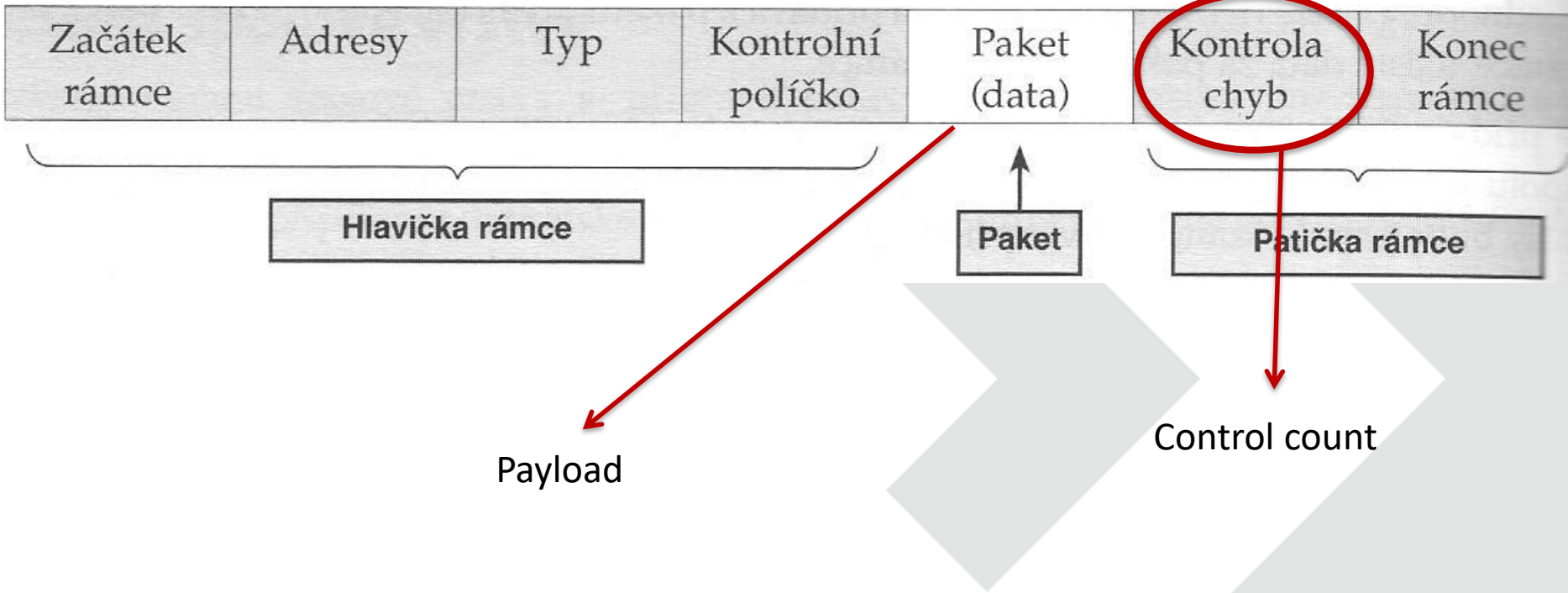
- Data-link layer adds a header and footer to a data:
  - Info about devices
  - Timing informaiton
  - Transmission errors
  - Which nodes will be communicating next time



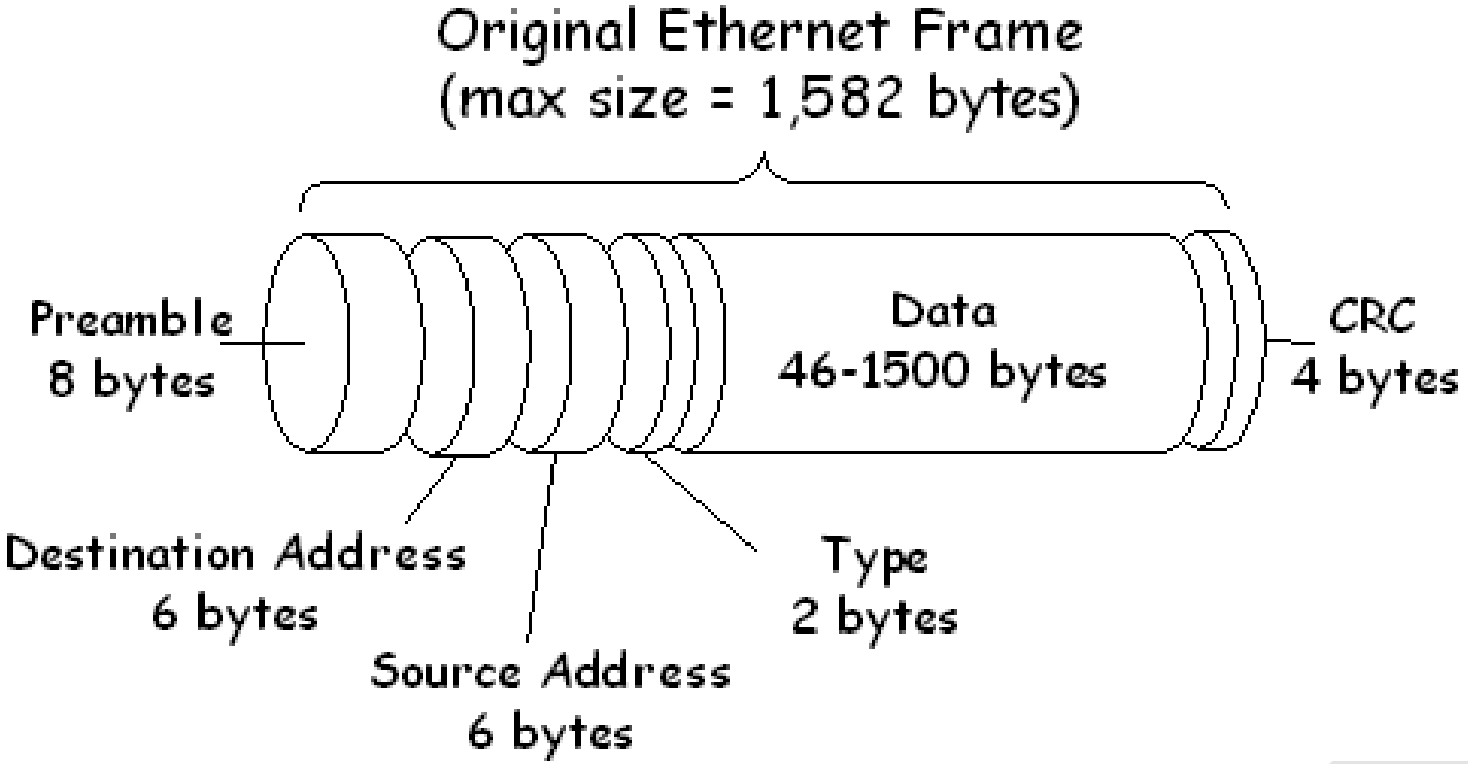
Data-link layer – data frame

- Data are sent in 1/0 (bits)
- Destination device recognizes Start and End delimiter (special sample of 1/0)
- Data frame structure is changing with a network type
- Typical fields (excluding a data/payload):
  - Start and End
  - addresses (MAC)
  - data type in a frame
  - control field

Data-link layer – data frame



Data-link layer – data frame



Data frame – header

- Start flag
- Physical address (MAC) of destination device
  - Set by a manufacturer (1st three) + uniques address
- MAC is important within one LAN
- If data frame is transmitted out -> router -> reads IP a generates MAC of the opposite device
- After receiving a data frame, node reads MAC addresses and decides, if A) receives a data frame or B) discard a data frame

Data frame – header

- If A), data frame is unpacked, modified (using protocols) and passed to higher level layer (network layer)
- If a data frame is not addressed to a receiving node, it could be passed via broadcast to others
- This is typical for LANs -> MAC is in the form of FF:FF:FF:FF:FF:FF

- Header also contains info about a data type

Data frame – footer

- Info about a data frame status:
  - if a data frame arrived with no change or errors
- Control field = FCS (Frame Check Sequence)
- Source node makes a logical count on sending data = CRC (Cyclic Redundancy Check), which is stored in FCS
- When data arrives, CRC is executed and is compared with FCS
- If a count does not match -> a frame is discarded

Data-link layer – Protocols

- Most typical – Ethernet, PPP (Point-to-Point), ATM (Asynchronous Transfer Mode), HDLC etc.
- Every protocol is for specific network (e.g. Ethernet and IEEE 802 LAN; PPP and HDLC for WAN)
- Umbrella organizations ISO, IEEE, ANSI, ITU-T
- Protocols working on sw as well as on hw (network devices)
- More protocols = more methods of medium access control

Access control to shared medium

- Deterministic method
  - Every nodes has set an access time (on network)
  - Access is controlled and ruled = during transmission, no other node can transmit -> transmission link (network) might not be used effectively
  - e.g. Token Ring

Access control to shared medium

- Non-deterministic method (stochastic method)
  - nodes are „competing/fighting“ of transmission to shared medium (I have something to send, so I try)
  - In order not to overload a link -> CSMA (Carrier sense multiple access)
  - node is listening whether there is transmission -> waits or sends
  - but transmission collision/conflict in the same moment => collision and discard all data frames

CSMA/CD and CSMA/CA

- CSMA addition of CD (Collision Detection) and CA (Collision Avoidance)
- CSMA/CD:
  - Ethernet, collision detection; device is waiting, then sends a data frame. If collision, then resends
- CSMA/CA:
  - WLAN, tries to avoid collision; node listens and if OK, sends an information that the node is about to transmit => avoids collision
  - But there could be a collision of information message

Access control to non-shared medium

- There is no need to avoid collision (example PPP)
- Protocol decides to send a data in modes:
  - simplex
  - half-duplex
  - full-duplex (PC-PC, PC–switch, switch-switch)
- In case of full-duplex and UTP cabel (100 Mbps Ethernet) one is receiving, second is transmitting (both in the same moment)
- Before transmission – „agreement“ of what mode will be used

Ethernet

- Technology/protocol used on LANs
- Many types according to speed (10 Mbps - 10 Gbps)
- Ethernet data frame is similar in all cases (differences are in the data placement system) Standard 802.2 and 802.3, method CSMA/CD -> frame has to contain source and destination address (MAC)
- On TCP/IP networks - protocol Ethernet II

Ethernet

- Using IEEE 802.3 there are 4 Ethernet variants:
  - 10 Mbps – Ethernet 10Base-T
  - 100 Mbps – fast Ethernet
  - 1 Gbps – gigabite Ethernet
  - 10 Gbps – 10 gigabite Ethernet
- Values stands for maximal theoretical bandwidth
- Transfer medium – optical or metallic fibres/cabels
- Many connectors for data transmission

Wireless transmission

- Radio and microwave frequency
- Used in open space (air transmission)
- Could be used by third-parties => security and encryption
- Advantages & Disadvantages
- Not so fast (max. hundreds of Mbps)
- 4 basic types:
  - 802.11 (WLAN) - 802.16 (WiMAX)
  - 802.15 (WPAN) - GSM (using GPRS protocol)

Wireless transmission

- 802.11 (WLAN)
  - Wi-Fi, local networks, CSMA/CA
  - sends a frame -> waits for confirmation -> if does not come, sends a frame again
  - supports authenticity (verification of communicating sides), association with access-point and transmission security/encryption
- 802.15 (WPAN)
  - Wireless PAN, typically Bluetooth
  - Transmission range from 1 to 100 meters

Wireless transmission

802.11 network PHY standards [hide]

802.11 protocol	Release date[8]	Frequency (GHz)	Bandwidth (MHz)	Stream data rate[7] (Mbit/s)	Allowable MIMO streams	Modulation	Approximate range[citation needed] Indoor	Approximate range[citation needed] Outdoor
802.11-1997	Jun 1997	2.4	22	1, 2	N/A	DSSS, FHSS	20 m (66 ft)	100 m (330 ft)
a	Sep 1999	5	20	6, 9, 12, 18, 24, 36, 48, 54	N/A	OFDM	35 m (115 ft)	120 m (390 ft)
		3.7[A]						5,000 m (16,000 ft)[A]
b	Sep 1999	2.4	22	1, 2, 5.5, 11	N/A	DSSS	35 m (115 ft)	140 m (460 ft)
g	Jun 2003	2.4	20	6, 9, 12, 18, 24, 36, 48, 54	N/A	OFDM	38 m (125 ft)	140 m (460 ft)
n	Oct 2009	2.4/5	20	Up to 288.8[B]	4	MIMO-OFDM	70 m (230 ft)	250 m (820 ft)[8]
			40	Up to 600[B]				
ac	Dec 2013	5	20	Up to 346.8[B]	8		35 m (115 ft)[9]	
			40	Up to 800[B]				
			80	Up to 1733.2[B]				
			160	Up to 3466.8[B]				
		0.054-0.79[C]	6-8	Up to 568.9[10]	4			
ad	Dec 2012	60	2,160	Up to 6,757[11] (6.7 Gbit/s)	N/A	OFDM, single carrier, low-power single carrier	3.3 m (11 ft)[12]	
ah	Dec 2016	0.9	1-16	Up to 347 [13]	4	MIMO-OFDM		
aj	Est. Jul 2017	45/60						
ax	Est. Dec 2018	2.4/5		Up to 10.53 Gbit/s		MIMO-OFDM		
ay	Est. Nov 2019	60	8000	Up to 20,000 (20 Gbit/s) [14]	4	OFDM, single carrier,	10 m (33 ft)	100 m (328 ft)
az	Est. Mar 2021	60						

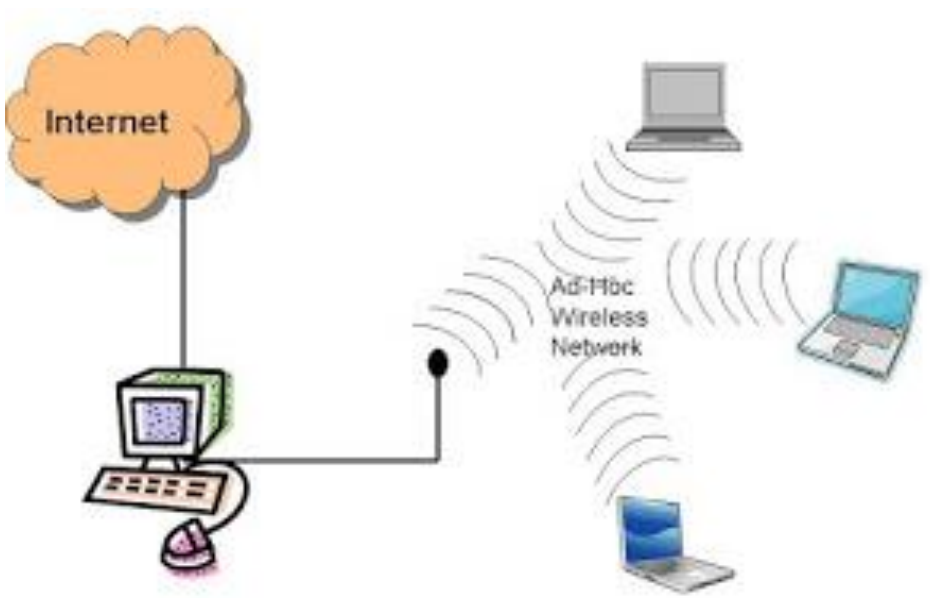
– transmission range from 1 to 100 meters

Wireless transmission

- 802.16 (WiMAX)
  - Worldwide Interoperability for Microwave Access
  - Broadband wireless internet access
  - Outdoor networks, supplement to Wi-Fi (which is more or less indoor)
  - Range up to 50 km
- GSM (Global System for Mobile Communication)
  - Digital transmission (voice call, SMS, MMS, …)
  - protocol GPRS
  - Range up to hundreds km (depending on antennas type and height, terrain, etc.)

Wireless transmission

- Structure:
  - ad hoc networks (peer to peer)
  - access point (client-server type networks)



Wireless transmission – security issues

- Protection from „eavesdropping “ or unauthorized use
- For user – there‘s no need to be connected via wire-based devices (switch, HUB, router, …)
- It is sufficient to be in WiFi range
- Protection possibillities:
  - MAC addresses filtering (list of permitted MACs)
  - transmission encryption

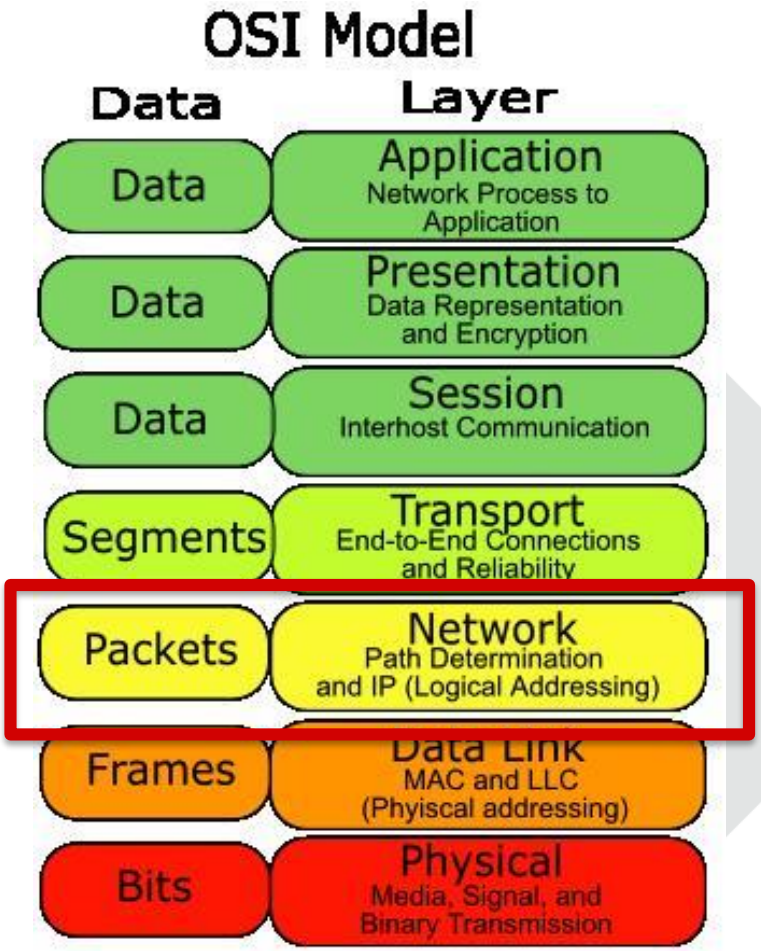
Wireless networks - encryption

- WEP (Wired Equivalent Privacy)
  - from 1999, authenticity of workstations and transmission encryption, algorithm RC4 and security key of 40 or 104 bits + 24 bit initiation vector
  - vulnerability of RC4 => is not safe anymore
- WPA (WiFi Protected Access)
  - substitution of WEP, in 2002, RC4 again but + 128 bit key and 48 bit initiation vector
  - fundamental improvement via dynamic key (TKIP)
  - hard to break through

Wireless networks - encryption

- WPA 2 (WiFi Protected Access 2)
  - in 2004
  - protocol CCMP (used for 802.11i)
  - AES encryption (Advanced Encryption Standard)
  - high security
  - needs higher computer performance => older devices could not work with WPA2

Network Layer



Network Layer

- Is responsible for:
  - routing and adressing in the network
  - connection among networks (that are not adjacent)
  - packet forwarding
- Allows to bridge different properties of networks
- More „intelligent“ networking layer
- It needs to distinguish individual computers:
  - using IP addresses (in case of the Internet)

Network Layer

- Creates a virtual homogeneous network that has:
  - unified way of addressing
  - unified way of packet‘s format
  - unified way of transferring service (nor reliable connection-less datagram service)
- Information unit = packet
- Typical active network device/node is router
- Protocols:
  - IP (v4, v6), ICMP, ARP, DDP, Ipses, IPX, many more

Network Layer

- IP address (v4):
  - symbolic address of a computer
  - identifies a computer in a network
  - 32 bit number = four decimal numbers from 0 – 255 delimited by „.“
  - each decimal number represents 8 bits
  - example: 213.145.55.12
- IP address has two parts – first identifies a network, second identifies a computer

Network Layer

- It is not allowed to use all ones (decimal 255) or zeros (decimal 0)
- These addresses are decicated for special purposes:
  - all ones = broadcast
  - all zeros = for LAN
- Addresses 127.x.x.x are for loopback (localhost)
- How to convert decimal numbers to binary:
- e.g.: 192.168.252.111 is …

Network Layer

http://www.converter.cz/baster/baster.php

Transport Layer

- Provides transfer and communication between end-nodes (end-to-end, host-to-host)
- The aim is to provide quality of service that is desired by higher level layers
- It provides:
  - transparency, reliability, flow control, multiplexing
- Equals different properties and quality of networks
- Converts transport addresses to network ones (but doesn‘t care about routing)

Transport Layer

- TCP (Transmission Control Protocol):
  - – provides reliable, ordered, and error-checked delivery data between applications („no packet could be lost“)
  - – information unit = TCP segment
  - – transmission of files, e-mails, webpages etc.
- UDP (User Datagram Protocol):
  - –a simple connectionless transmission (minimalize protocols usage)
  - – it is used in cases, where error checking and correction is not necessary (or performed by the application)

Transport Layer

Feature Name	UDP	UDP Lite	TCP	Multipath TCP	SCTP	DCCP	RUDP
Packet header size	8 bytes	8 bytes	20–60 bytes	50–90 bytes	12 bytes	12 or 16 bytes	6+ bytes
Transport layer packet entity	Datagram	Datagram	Segment	Segment	Datagram	Datagram	Datagram
Connection oriented	No	No	Yes	Yes	Yes	Yes	Yes
Reliable transport	No	No	Yes	Yes	Yes	No	Yes
Unreliable transport	Yes	Yes	No	No	Yes	Yes	Yes
Preserve message boundary	Yes	Yes	No	No	Yes	Yes	Yes
Ordered delivery	No	No	Yes	Yes	Yes	No	Yes
Unordered delivery	Yes	Yes	No	No	Yes	Yes	Yes
Data checksum	Optional	Yes	Yes	Yes	Yes	Yes	Optional
Checksum size (bits)	16	16	16	16	32	16	16
Partial checksum	No	Yes	No	No	No	Yes	No
Path MTU	No	No	Yes	Yes	Yes	Yes	Unsure
Flow control	No	No	Yes	Yes	Yes	No	Yes
Congestion control	No	No	Yes	Yes	Yes	Yes	Unsure
Explicit Congestion Notification	No	No	Yes	Yes	Yes	Yes	
Multiple streams	No	No	No	Yes	Yes	No	No
Multi-homing	No	No	No	Yes	Yes	No	No
Bundling / Nagle	No	No	Yes	Yes	Yes	No	Unsure

Session Layer

- Aim is to organize and synchronize dialog between cooperating session layers
- Provides opening, closing and managing of session connection
- Provides:
  - authentication (identity check)
  - authorization (access to files, operations, functions etc.)
  - session restoration
- Protocols: AppleTalk (ADSP, ASP), RPC, SSL, SPDY, …

Presentation Layer

- Aim is to transform data into a form, which is used by applications („syntax“ layer)
- Provides codes and alphabet conversions, graphic order modification, Byte order adjustment and so on
- Deals with data structure but not with interpretation
- Provides – encryption, conversions, compression,…
- Protocols: TLS, XML, Telnet, ASCII, MIME, MPEG etc.

Application Layer

- Aim is to allow applications to access communication system in order to enable cooperation among applications
- Shared protocols and interface methods
- Protocols:
  - FTP, SMTP, DNS, DHCP, HTTP, IMAP, POP3, BitTorrent, Bitcoin
  - and much more…

Application Layer

- Supports applications and end-user processes
- Everything is application-specific
- Services as: File transfers, Emails
- Telnet and FTP entirely in this layer

•Examples: www browsers, NFS, SMTP, POP, HTTP, DNS, FTP, Telnet

Computer Networks

Vít PÁSZTO

End…