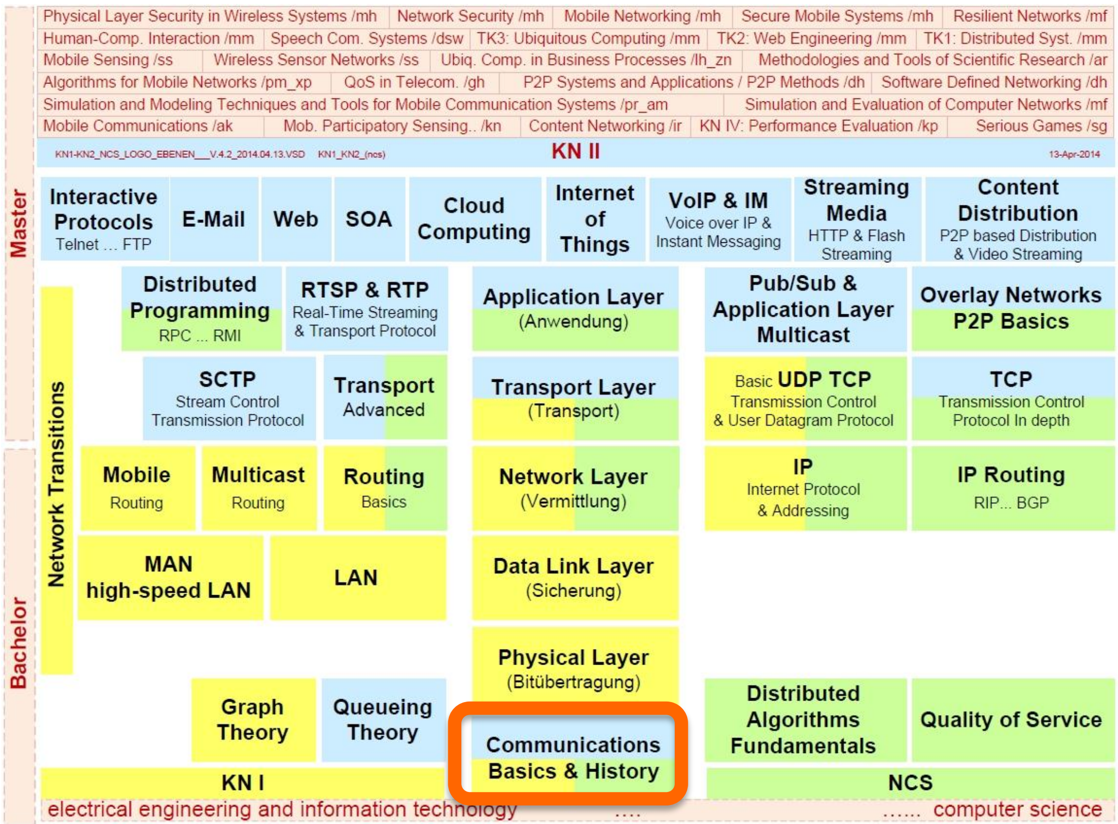
Communication Networks I

Introduction



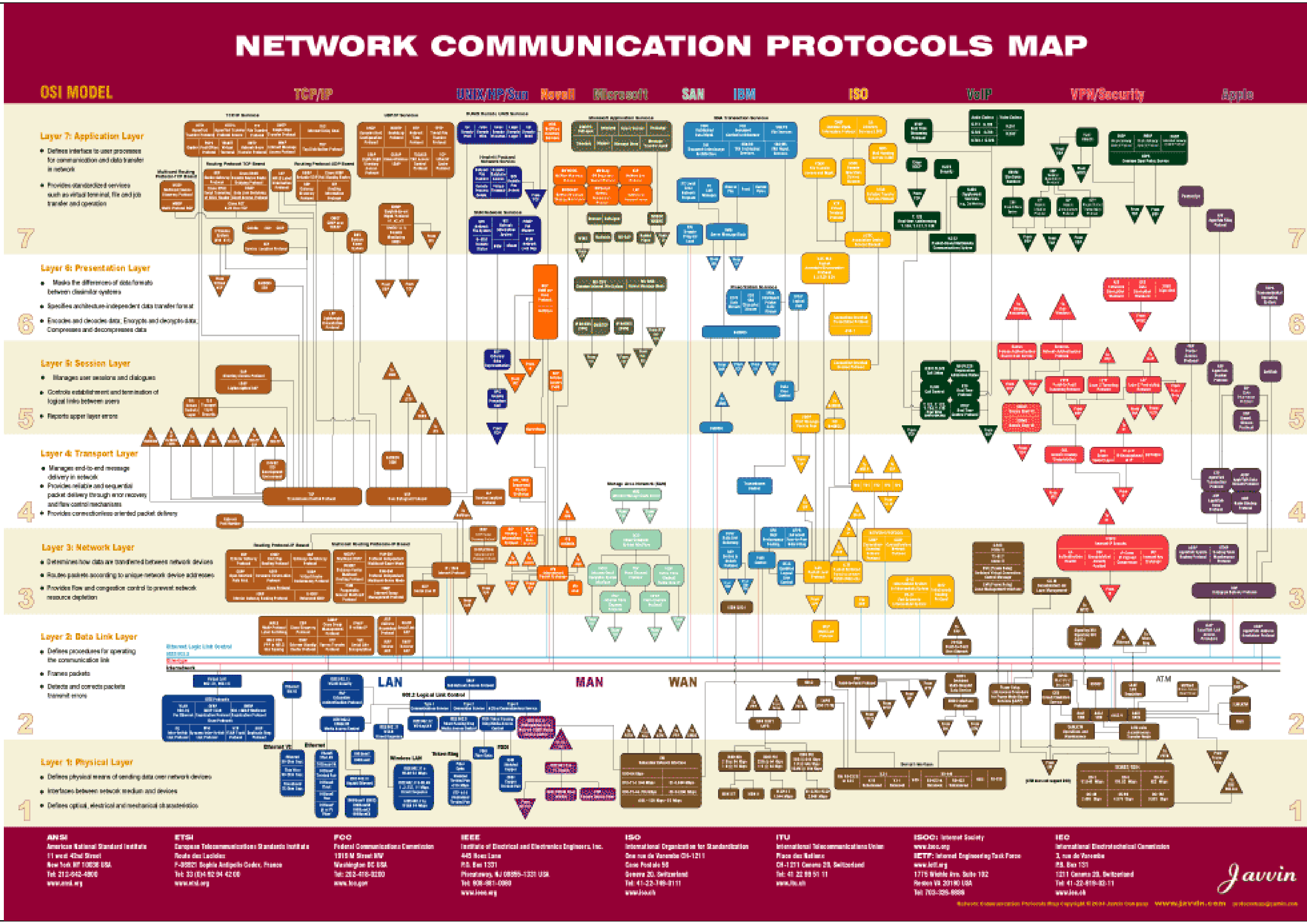
Prof. Dr.-Ing. **Ralf Steinmetz**
KOM - Multimedia Communications Lab

Overview

History

Basics

Networking Protocol Map … (Source www.javvin.com)



Networking Protocol Map … (Source www.javvin.com)

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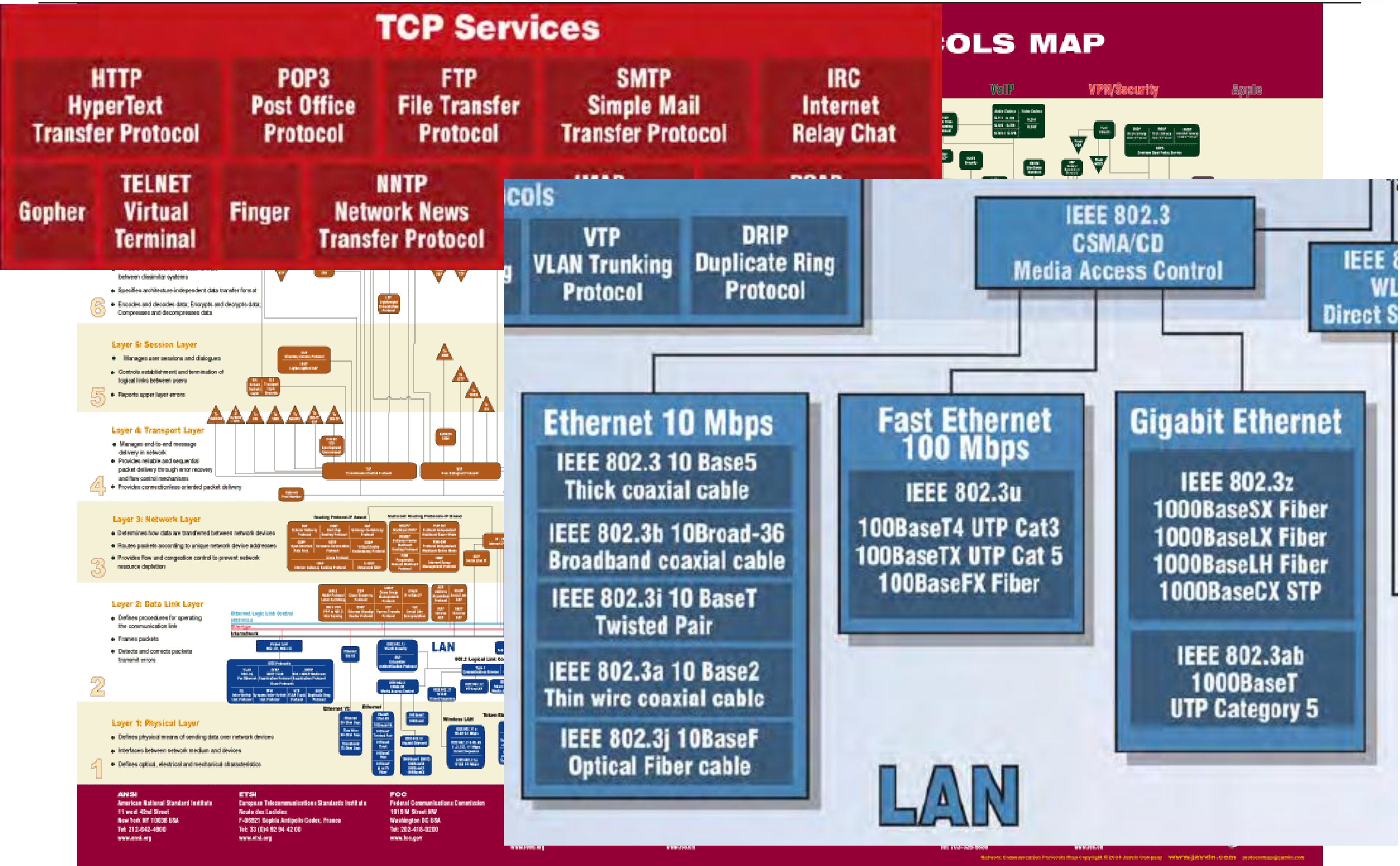
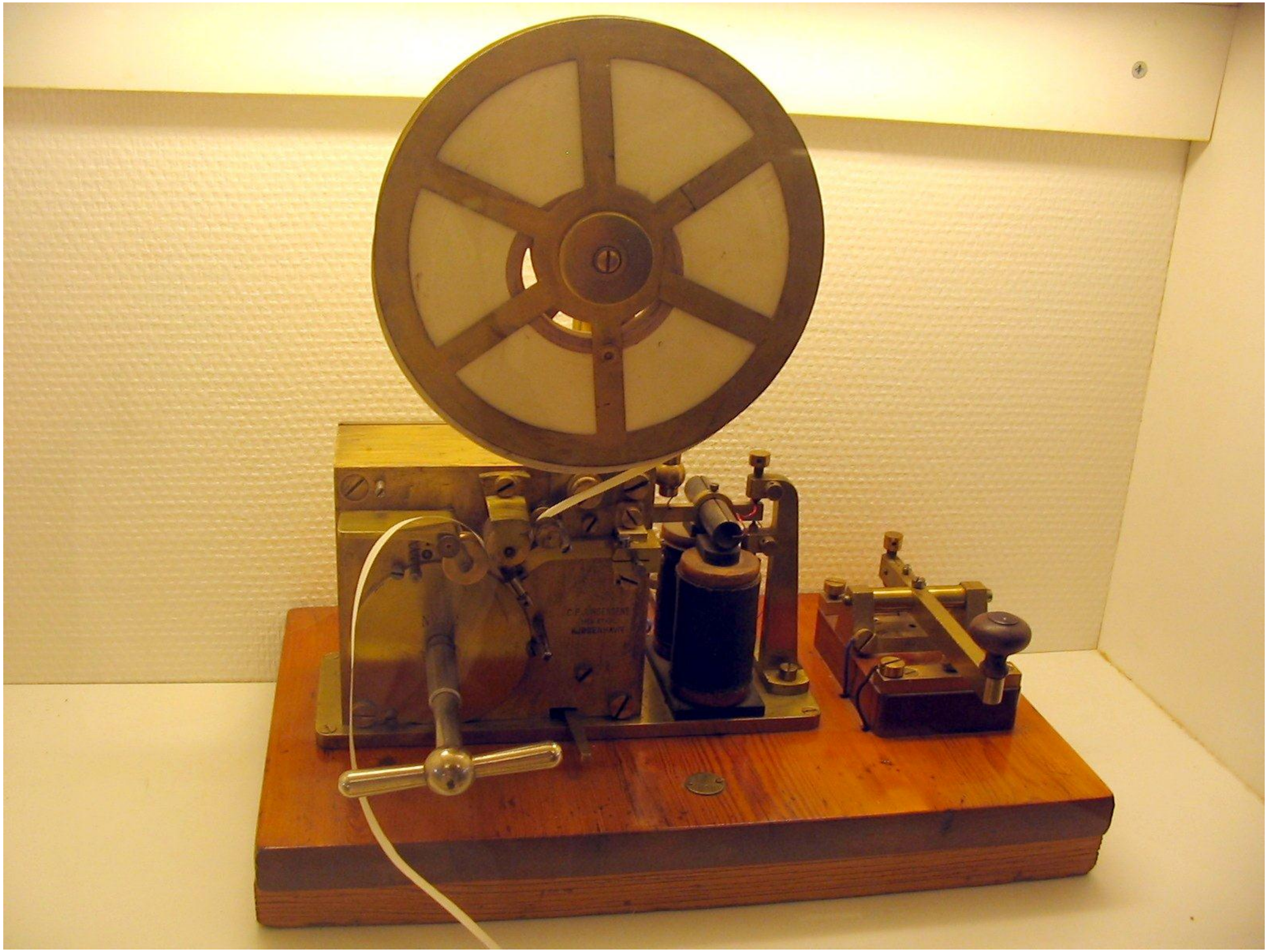
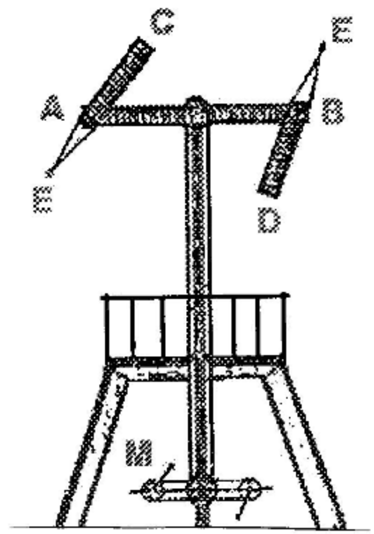


1 Telegraphy

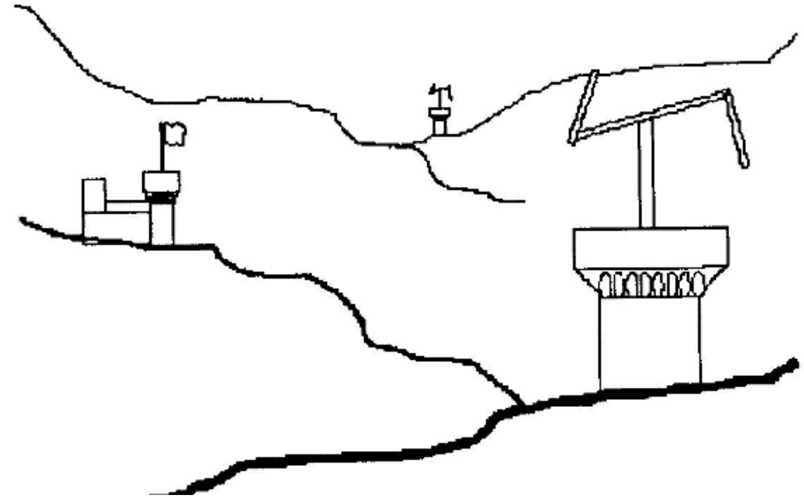


and before

Chappe-Code



Source: www.mathematik.uni-muenchen.de



e.g. 18th century

1791: Semaphoric Telegraph (Chappe)

Brief History of Electronic Communications

Telegraphy

~1750: first experiments with electrostatic telegraphs

~1804: first experiments with electrochemical telegraphs

- Voltaic pile (1800 by Volta) used as power source

~1830: first experiments with electromagnetic telegraphs

- Electromagnet (1825 by Sturgeon) used as basis for receiver

1844: first Morse telegraph line between Washington and Baltimore

- Telegraph network then grew rapidly
  - 1846: 40 miles, 1850: 12000 miles

1866: first operational transatlantic telegraph cable

- Connecting North America and Europe

1874: Baudot multiplex system

- Time multiplexing with fixed length code

- to be continued…

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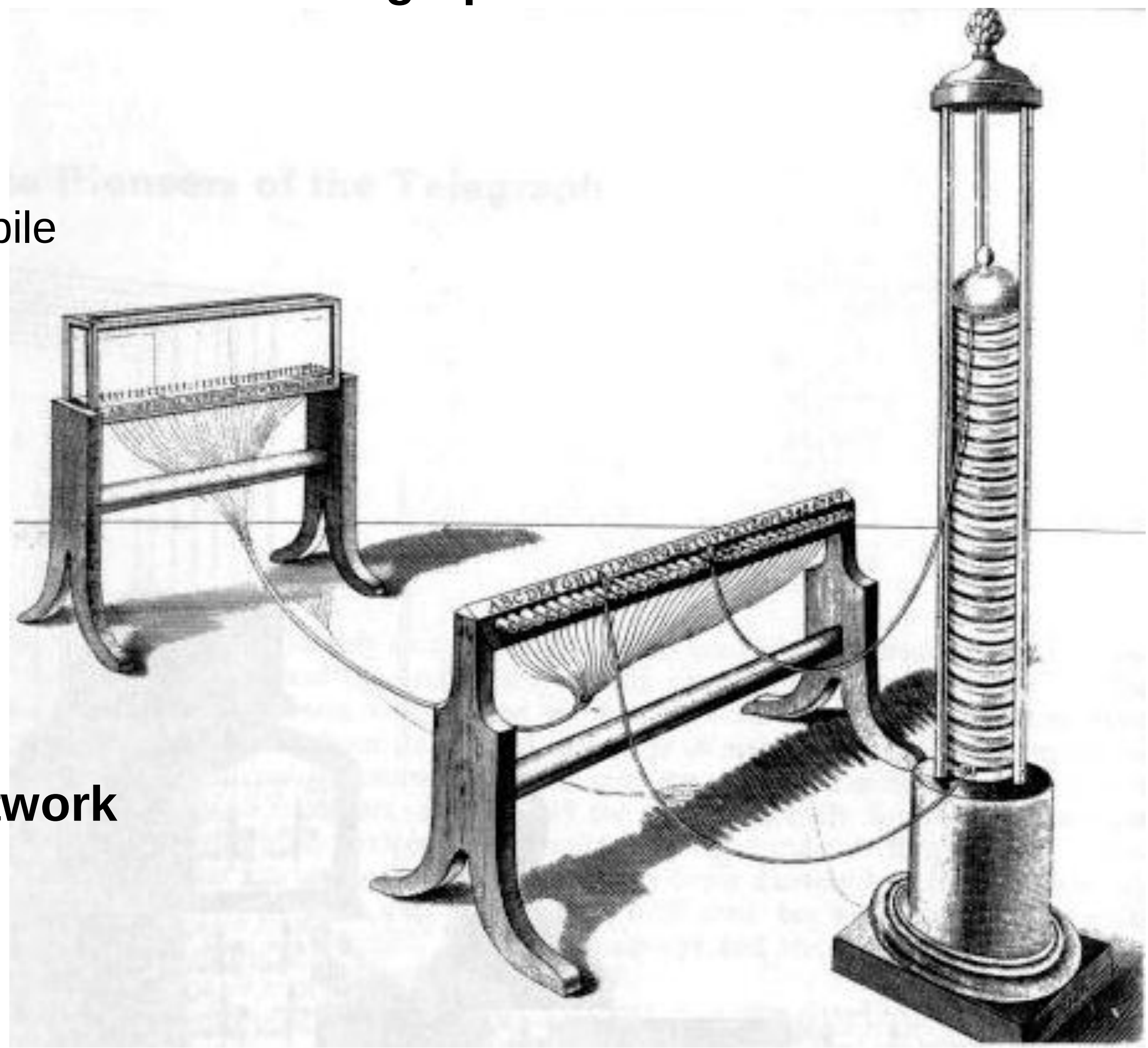
Von Sömmering's electrochemical telegraph

- Presented 1809
- Sender:
  - 35 switches (a-z,1-9) connected to voltaic pile
- Network:
  - 35 wires (2000 ft)
- Receiver:
  - 35 electrodes in acid bath



→ **Communication network is point to point line**

Image source: From Semaphore to Satellite, ITU, 1965

Morse Telegraph

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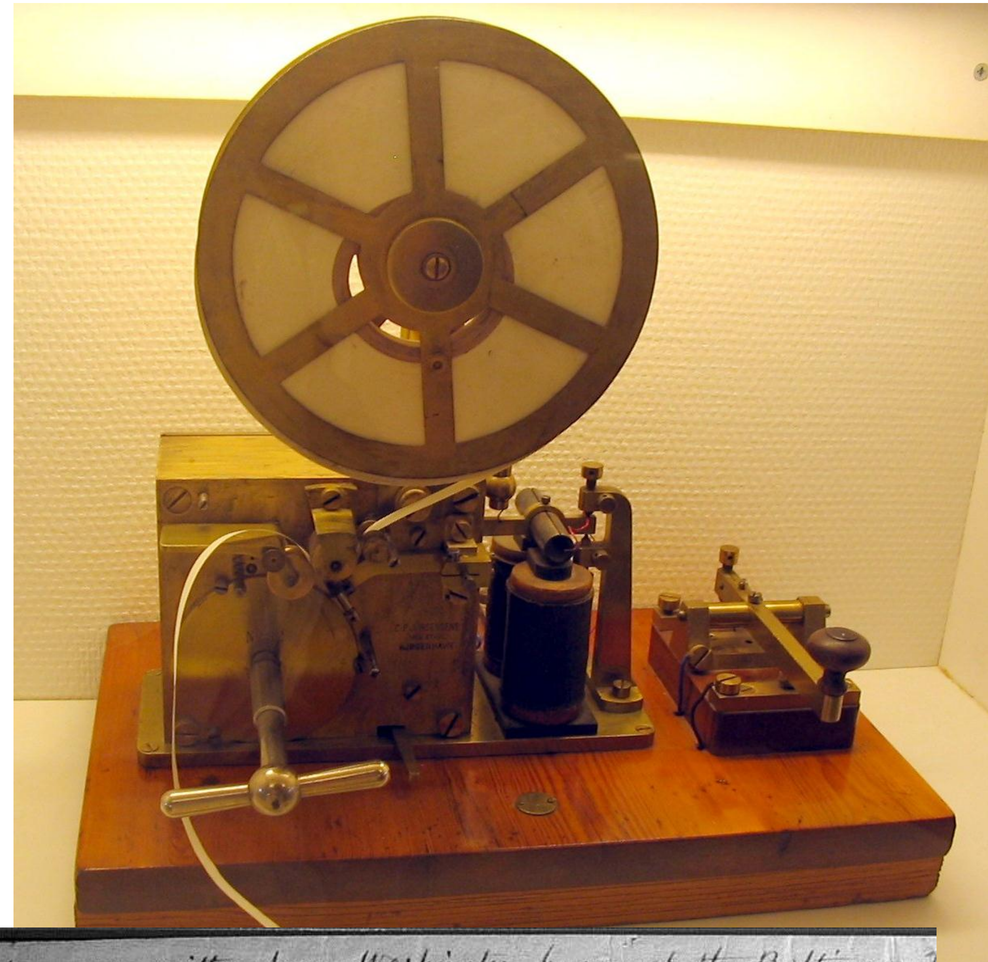
Morse transceiver

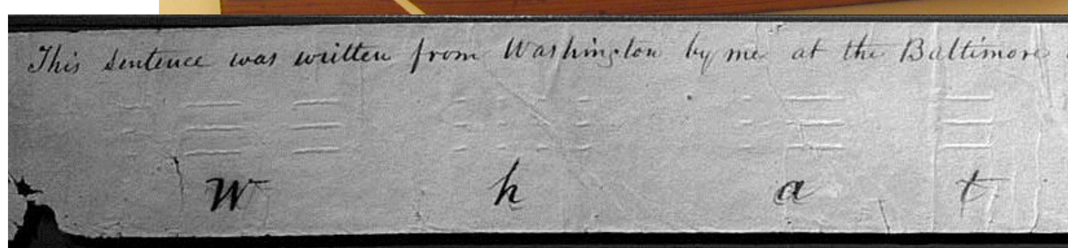
- One switch to send long and short impulses at sender
  - dahs and dits or
  - dashes and dots

- Dashes and dots
  - punched into paper strip at receiver

- See beginning of first telegraph ‘What hath God wrought’ (Num 23,23) sent in 1844 from Washington to Baltimore

- Communication network?





Telegraph Network in United States 1916

- Similarities to today's Internet?
- Signal coding?
- Type of switching?
  - Packet?
  - Message?
  - Circuit?
- Type of service?
  - Connection oriented?
  - Connectionless?
- Repeaters?
- Routers?

Image source: Wikimedia Commons

Morse Code

- Variable length
- Short code for frequently used letters

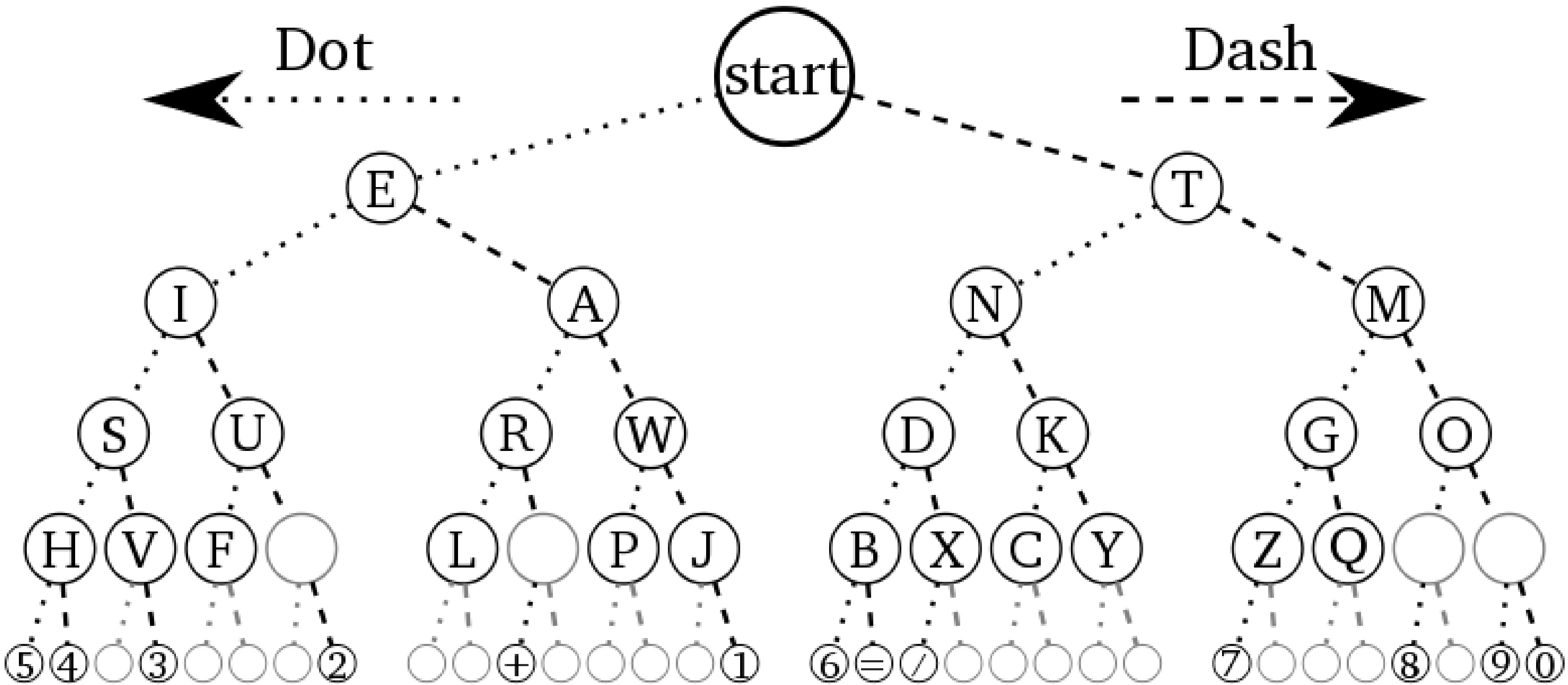


Image source: Wikimedia Commons

Baudot Telegraph

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Baudot time multiplex system:

Forefather of teletypewriters (TTYs)
- Baud rate (symbol rate) of transmission named after Baudot

Challenge:
- to increase number of telegraph messages

Solution:
- time multiplexing
- To connect multiple telegraphs over same line

First attempts failed
- Problems with synchronization of sender and receiver
- Reason:
  - variable length morse code

Baudot solved problem
- Fixed length (5 bit) code
- Synchronized time multiplexing

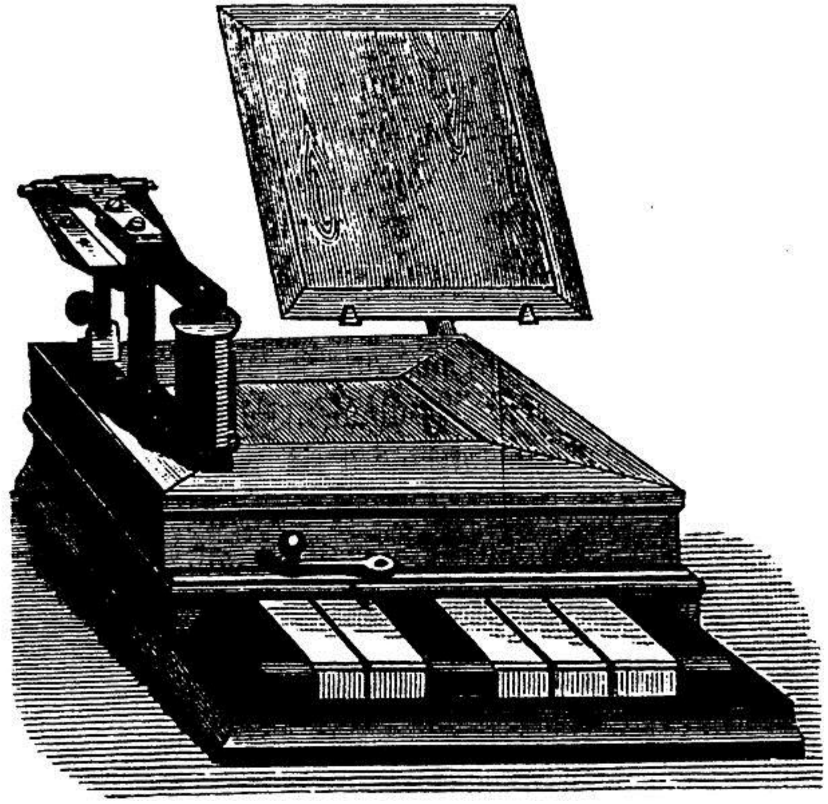


Image source: Wikimedia Commons

Baudot Telegraph

Baudot code:

Fixed length 5 bit code

- Allows for $2^5=32$ symbols
- Restricted to five bits due to hardware constraints
  - Workaround by shifting alphabet to represent more characters

Later standardized by CCITT (ITU-T)

- International telegraph alphabet 1
- Forefather of ASCII code

V	IV			I	II	III	V	IV			I	II	III
		A	/	●			●	●	P	%	●	●	●
	●	B	8			●	●	●	Q	/	●		●
	●	C	9	●		●	●	●	R	–			●
	●	D	0	●	●	●	●		S	;			●
		E	2		●		●		T	!	●		●
		É	&	●	●				U	4	●		●
	●	F	[illegible]		●	●	●		V	'	●	●	●
	●	G	7		●		●		W	?		●	●
	●	H	[illegible]	●	●		●		X	,		●	
		I	[illegible]		●	●			Y	3			●
	●	J	6	●			●		Z	:	●	●	
●	●	K	(	●			●		[illegible]	.	●		
●	●	L	=	●	●		●	●	*	*	Erasure		
●	●	M	)		●			●	Figure Blank				
●	●	N	№		●	●	●		Letter Blank				
		O	5	●	●	●							

Baudot time multiplex system

- Multiple senders/receivers connected to distributor
  - Copper segments with rotating brushes
- Distributors
  - at sender and
  - receiver side synchronized
- Serialization of characters typed on Baudot keyboard
- Time multiplexing of input from multiple keyboards

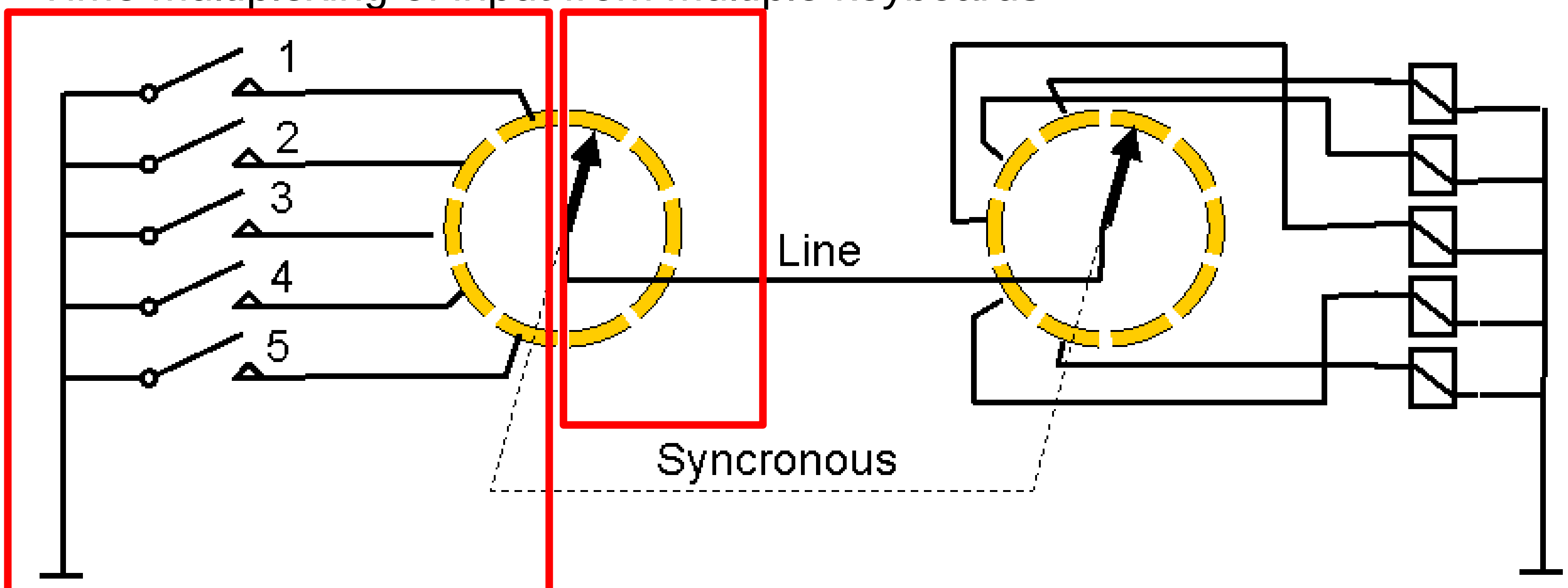


Image source: Wikimedia Commons

2 Telephony

Image source: Wikimedia Commons

Brief History of Electronic Communications

Telephony

~1860: first successful electronic sound (nearly voice) transmission

- Make and break transmitter by Johann Philipp Reis

1876/77: first patents for telephone technology granted in US

- Elisha Gray, Alexander Graham Bell, Thomas Edison
- Different approaches for voice conversion / reproduction

1877: first manually switched phone exchange in US

1892: first automatic telephone exchange patented in US (Strowger)

- Driving factor was competition in undertaker business …
- Dial pulse sent by telegraph keys
- Stepping switch with two degrees of freedom at phone exchange

To be continued…

First telephones in 1870s sold pairwise

- With dedicated, direct line

Assuming a full mesh

- Each customer can call any other customer

→ Each customer has n-1 phones

→ $\frac{n \times (n-1)}{2}$ lines required for n customers

Scalability?

- O(?) phones required?
- O(?) lines required?

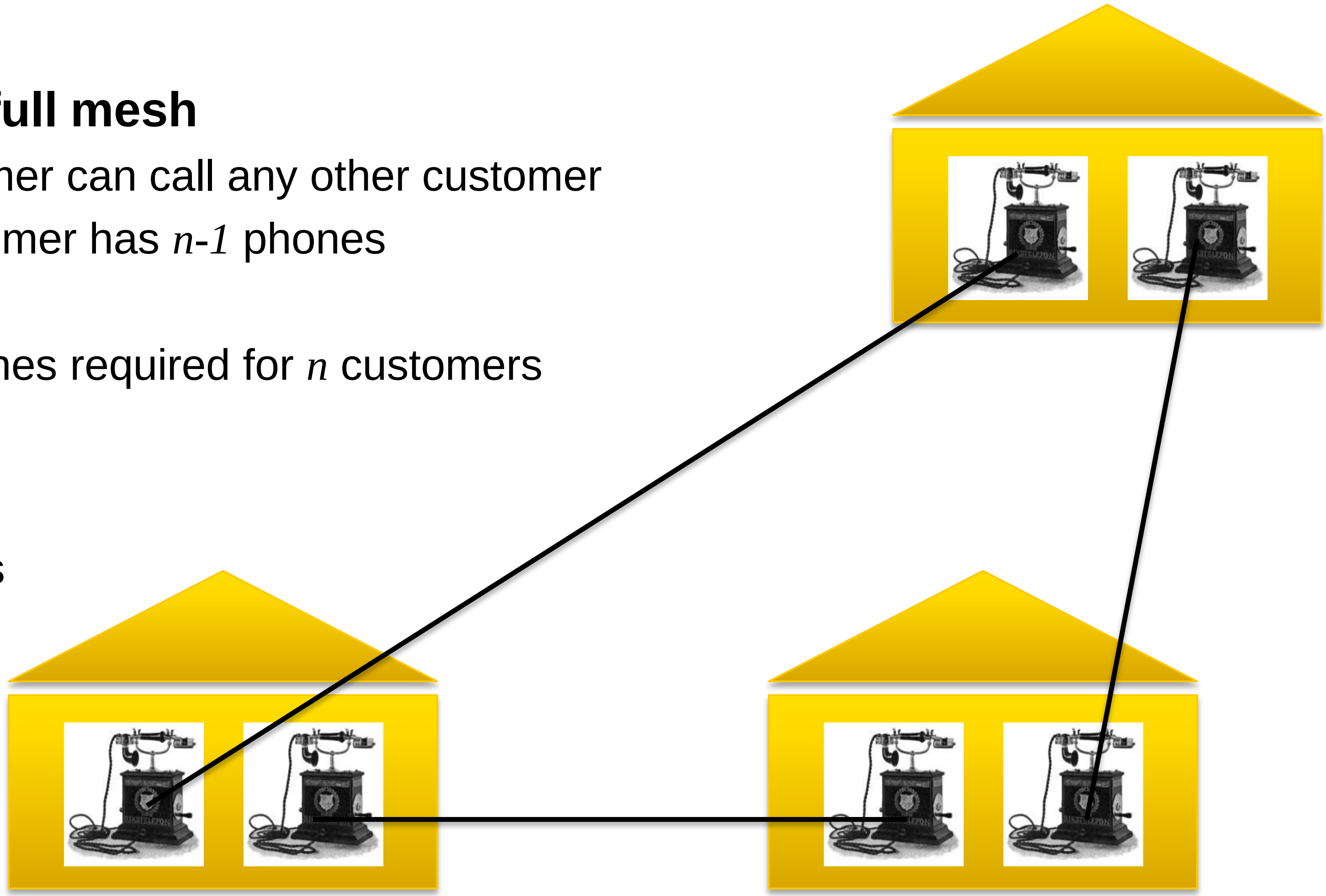


Image source: Wikimedia Commons

Telephony

Telephone switches reduced complexity of phone network

- Line from each phone to central switchboard
- Long distance lines between switchboards
- First switches manually operated
- Complexity?
  - O(?) phones required?
  - O(?) lines required?
- Basic principle in use till today

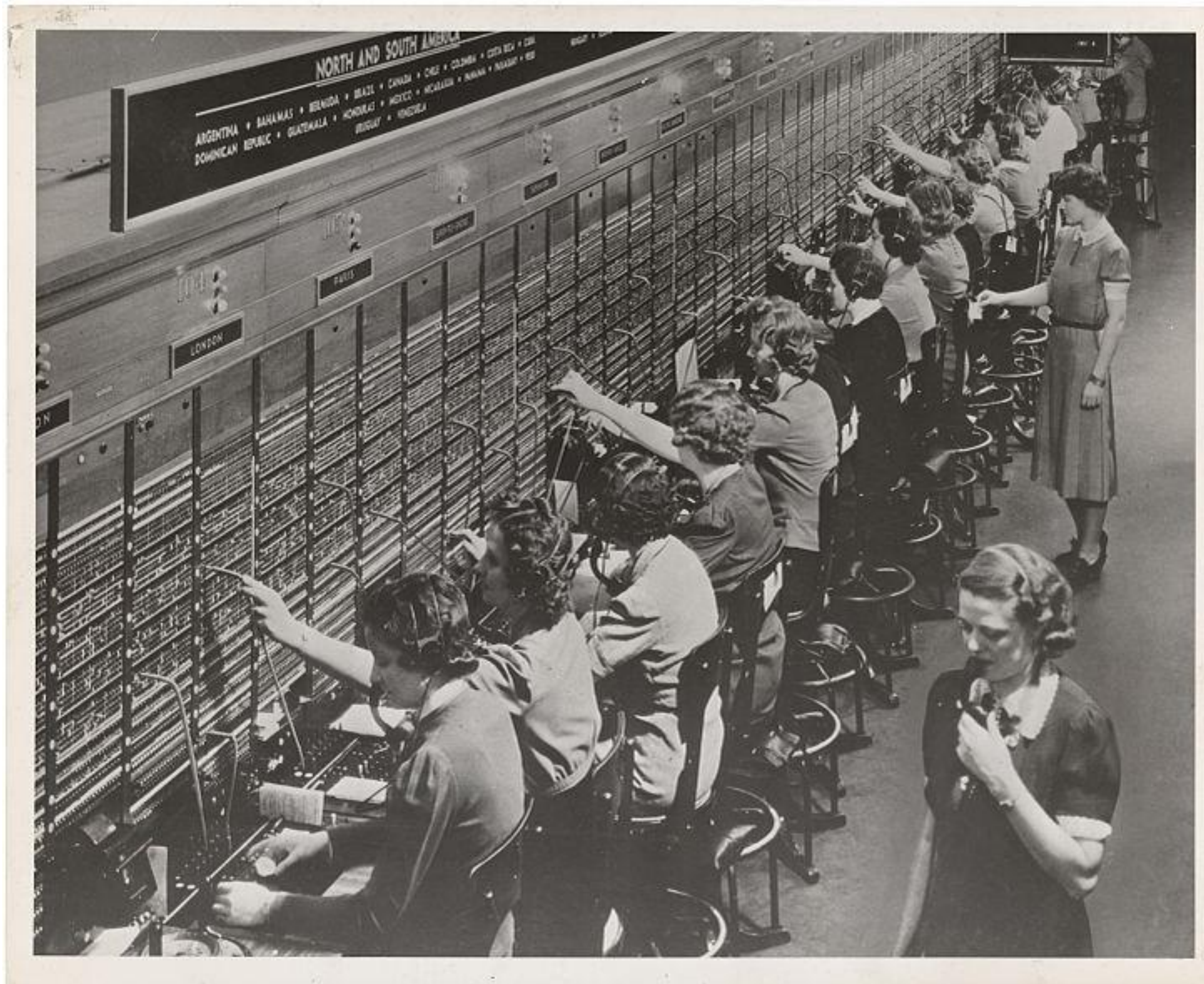
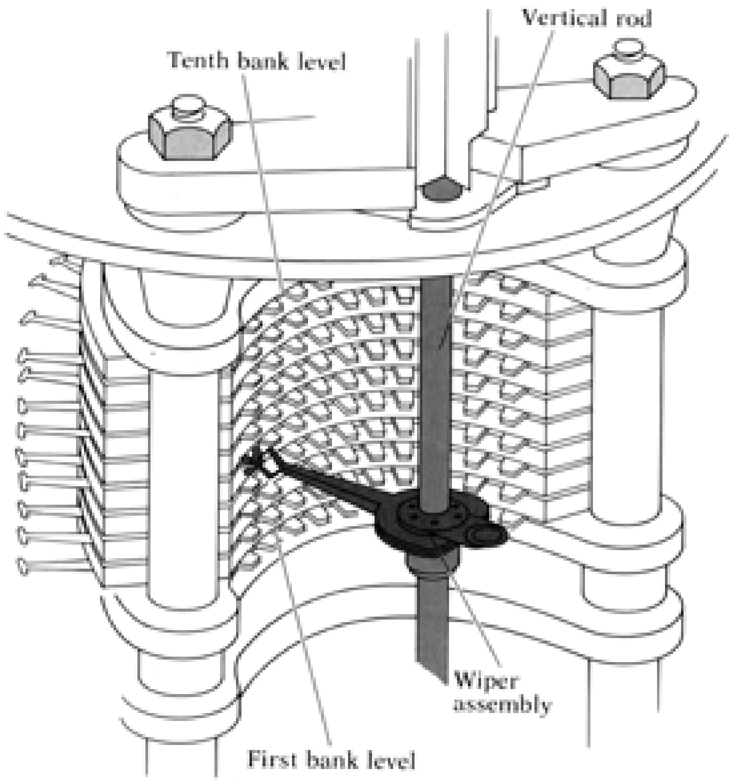


Image source: Wikimedia Commons

Strowger switches automated phone exchange

- Stepping switch with two degrees of freedom
- Used in former GDR until 1995



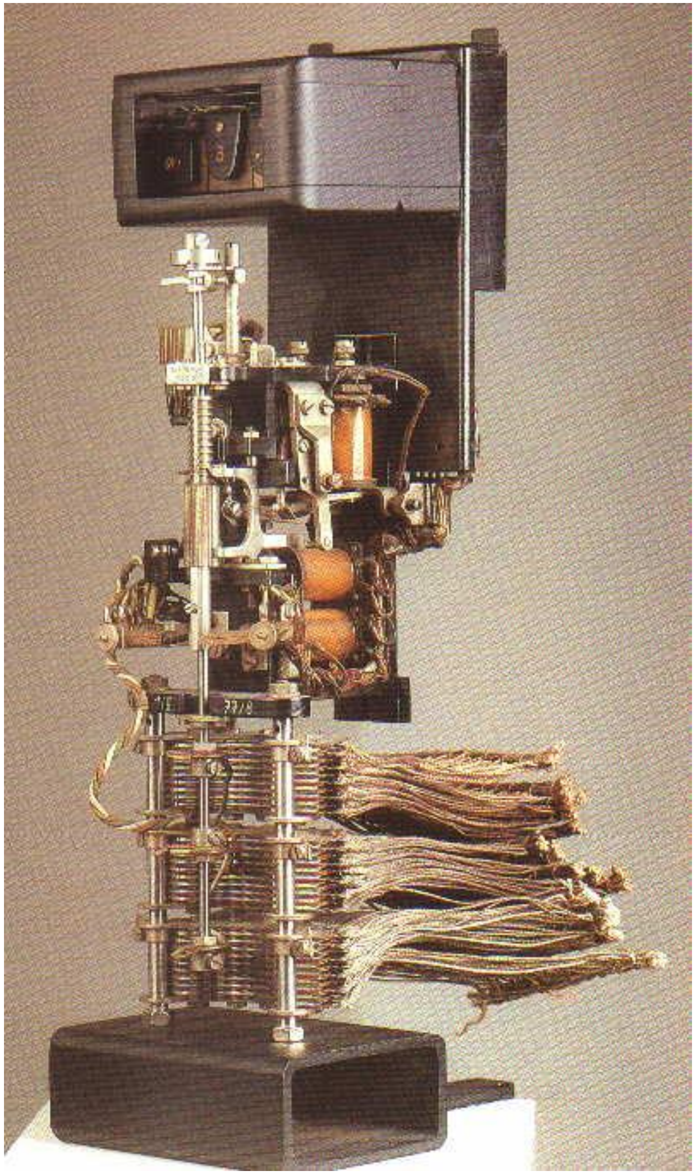


Image source: harvard.edu

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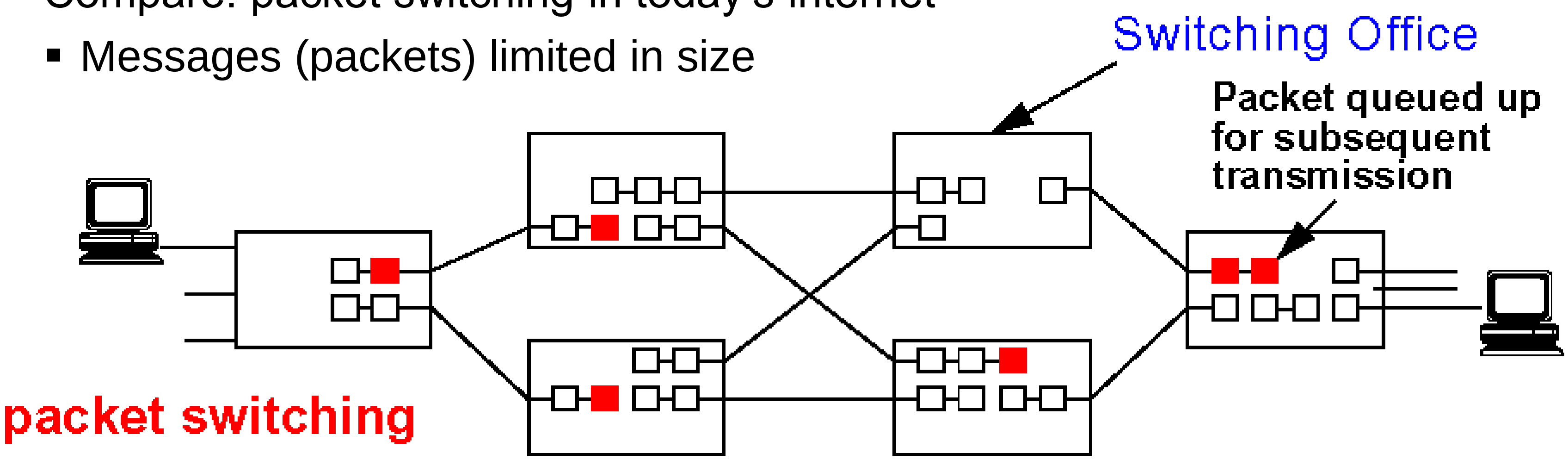
Concepts of early telegraphy and telephony systems still in use today

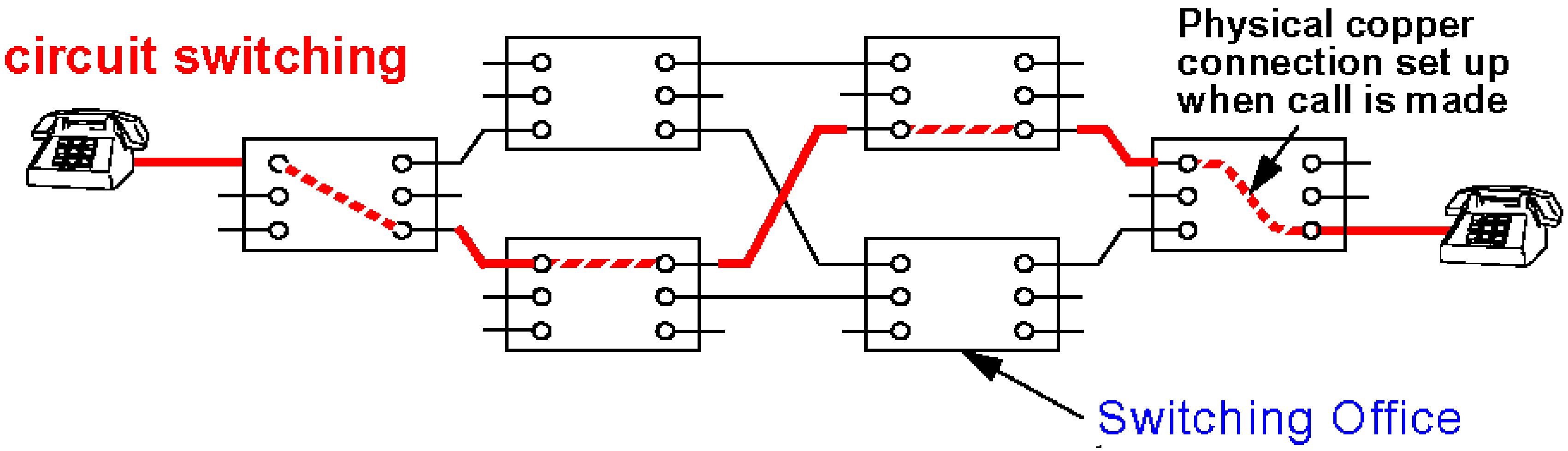
Telegraph networks

- Message switching
  - Telegram as discrete unit forwarded from sender to receiver via relay stations
  - No dedicated line between Sender S and Receiver R
- Connectionless service
  - Subsequent telegrams from S to R may use different lines
  - E.g. in case of line failures
- Compare: packet switching in today's internet
  - Messages (packets) limited in size



Telephone networks

- Circuit switching
  - Dedicated line between Sender S (caller) and Receiver R (callee)
  - Reserved exclusively for entire call duration
- Connection oriented service
  - Communication always follows same path
  - Three phases: connect (dial), talk (data exchange), disconnect (hang up)
- Concepts still in use in today
  - No dedicated lines but reserved resources
  - E.g., connecting an ISDN call reserves 64kbit/s between caller and callee



4 Television

Brief History of Electronic Communications

Television

~1831 - 1890: Basics of radio transmission

- Electromagnetic induction (Faraday)
- Theory of electromagnetic fields (Maxwell)
- Wave character of wireless electrical transmissions (Hertz)

1895: Wireless telegraphy demonstrated by Marconi

- Long wave transmission, high transmission power >200kW

1926: First demonstration of transmission of moving images (Baird)

- Electromechanical television
- 12.5 frames per second, 30 lines resolution

1928: First (wireless) TV broadcast stations appear

1996: First commercial digital TV station (DirecTV, US)

To be continued…

Schematic representation of mechanical TV

- Strong light beam scans object through rotating disc with holes (Nipkow Disc)
  - Photoelectric cells detect light reflections
- Output of photoelectric cells reproduced at receiver side
  - Light source with varying intensity watched through Nipkow Disc

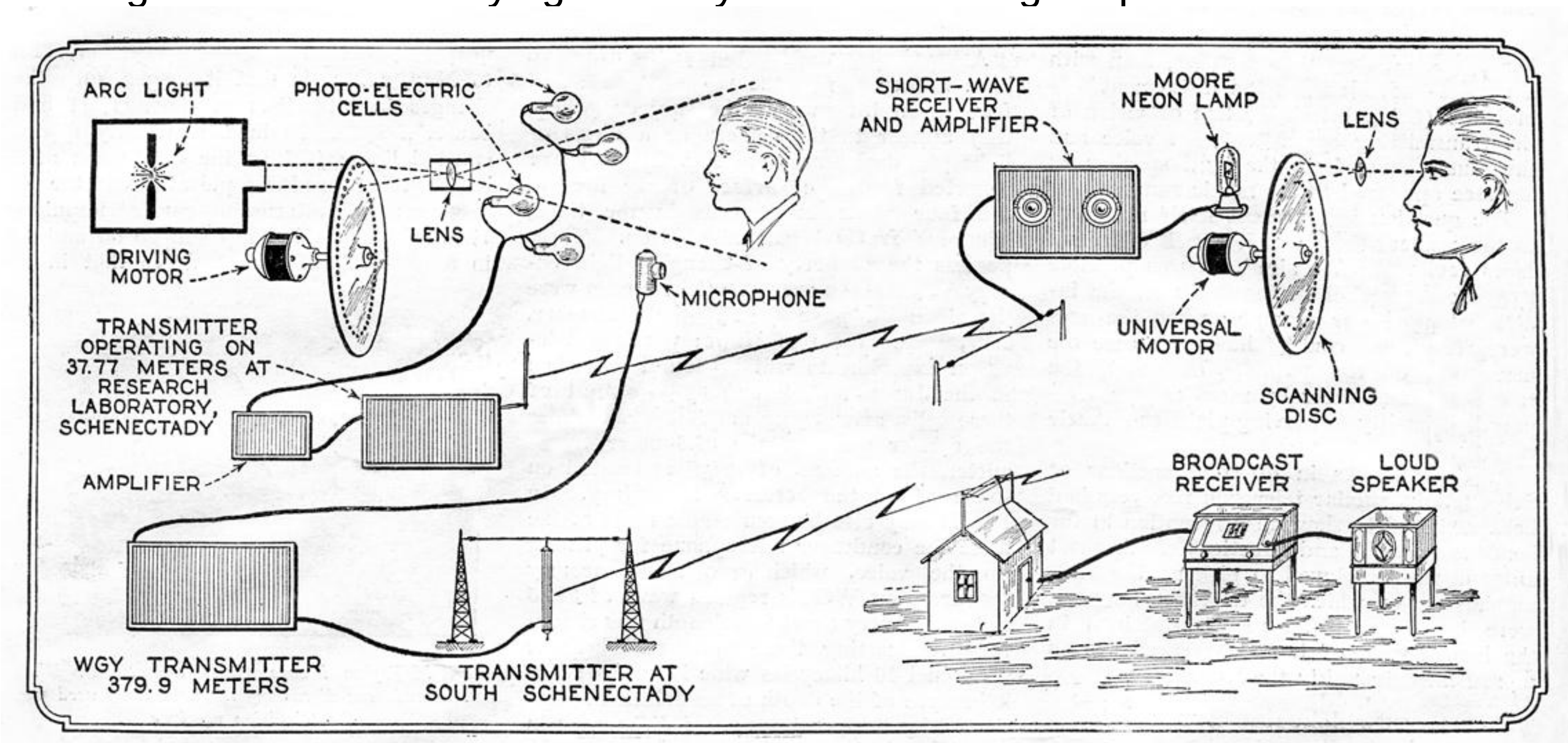


Image source: Wikimedia Commons

Television

TV is broadcast medium

- One sender
- Many Receivers

- E.g.,
  coverage of
  WABC TV station,
  New York
  - Covers ~9 million households

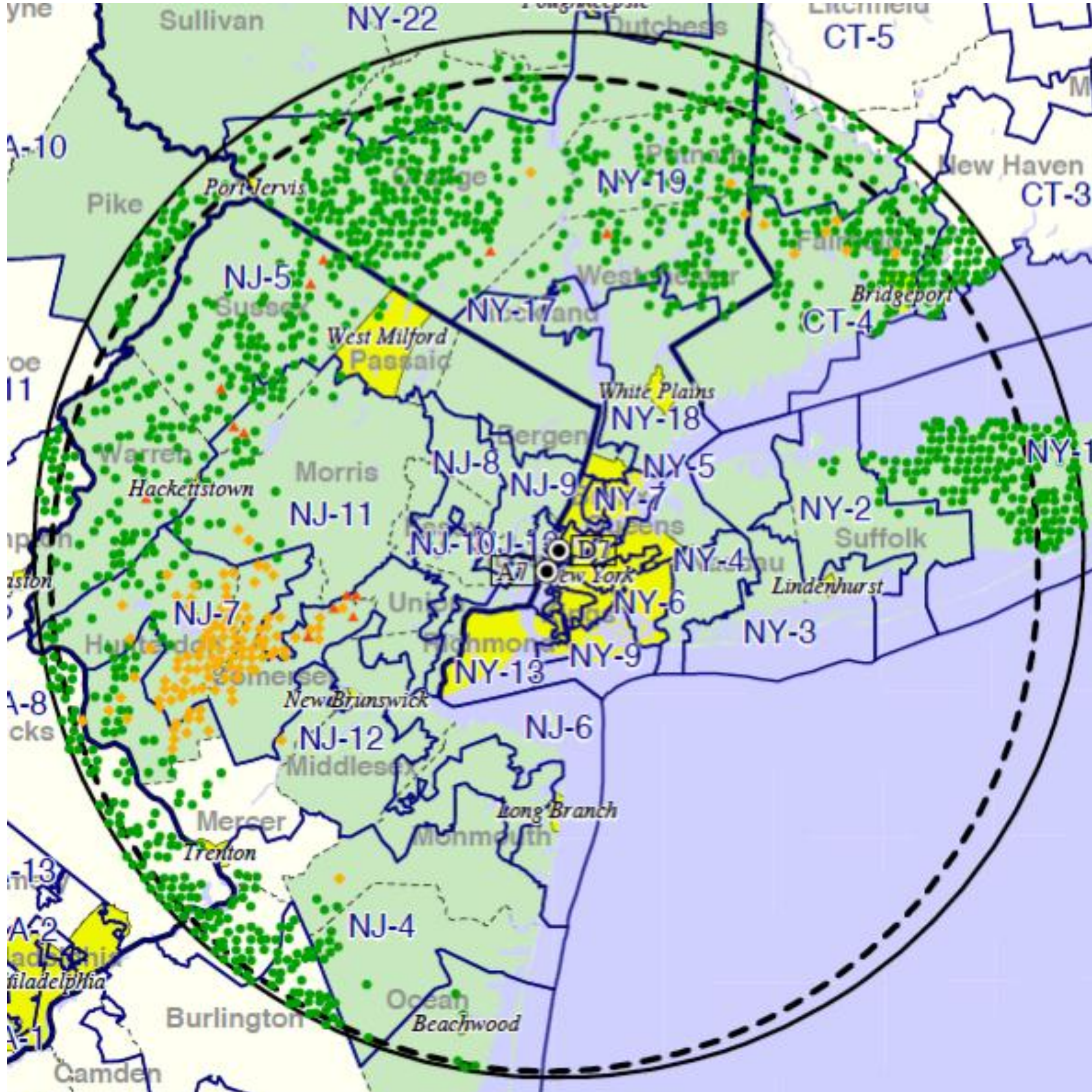


Image source: fcc.gov

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Terrestrial digital TV broadcast - DVB-T

- Terrestrial analogue TV replaced completely by DVB-T in 2009
  - Satellite and cable TV will follow
- Closest stations at Feldberg, Frankfurt, Wiesbaden
  - Cover ~2 million households

Sample calculation

- DVB-T data rate is ~4 Mbit/s
- ~2 million households in Rhine/Main area

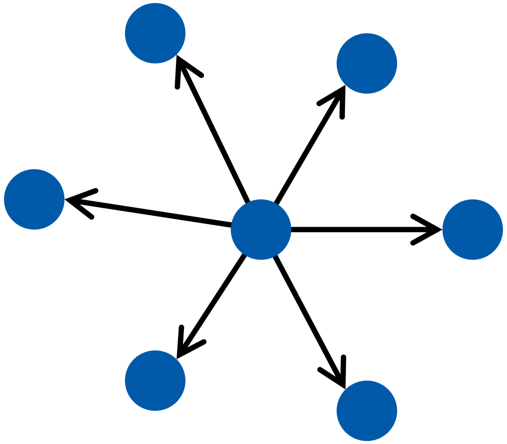
→ ~8 Tbit/s (Terabit per second) received during primetime

  - Compare:
    global average Internet traffic was ~46 Tbit/s in 2010
    - (source: Cisco visual networking index)

Image source: ueberallfernsehen.de

Television developed as broadcast medium

- One sender, many receivers
  - In order of millions for TV stations
- Inherent property of radio transmission



Telephony (and telegraphy) developed as unicast medium

- One sender, one receiver
- Inherent property of circuit switched network

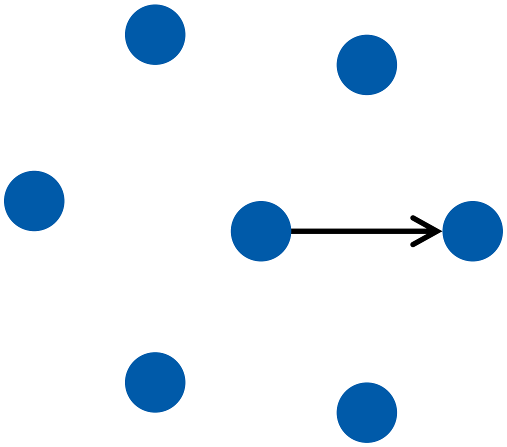


Image source: Wikimedia Commons

Brief History of Electronic Communications

The Internet

1961: Packet switching theory described by Kleinrock at MIT

- Shows performance of packet switching (compared to circuit switching)

1962: “Galactic Network” idea presented by Licklider at MIT

- Vision of possibilities achieved by globally interconnected computers

1965: First computer network by Roberts and Marill

- Two computers at MIT and UCLA connected by dial-up telephone line

1967: ARPANET concept published by Roberts

1969: First IMP (Interface Message Processor) installed at UCLA by BBN

- First host connected to ARPANET
- Three more followed at Stanford, UC Santa Barbara, University of Utah
- Research on network itself as well as on network applications

1969: Request for Comments (RFC) established by Crocker at UCLA

- First RFC describes IMP architecture

Source: http://www.isoc.org/internet/history/brief.shtml

Brief History of Electronic Communications

The Internet (cont'd)

1970-1972: First communication protocol implemented in ARPANET

- Network Control Protocol (NCP) for host-to-host communication
- Basis for application development

1971: 23 hosts connected

1972: First application presented – electronic mail by Tomlinson

1972: Open architecture internetworking idea presented by Kahn at DARPA

- Motivation: Connecting different networks

1973: Initial TCP/IP idea presented by Cerf and Kahn at Stanford and BBN

- ARPANET's NCP does not meet internetworking requirements

1983: Cutover from NCP to TCP/IP in ARPANET

Source: http://www.isoc.org/internet/history/brief.shtml

6.1 Forefather of the ARPANET (1965)

First wide-area network built by Marill and Roberts in 1965

- ‘Toward a Cooperative Network of Time-shard Computers’
  - American Federation of Information Processing Systems conference 1966
- Connecting a TX-2 at MIT to a PDP-1 at Santa Monica
  - TX-2 built at MIT, spin-off: Digital Equipment Corporation (DEC)
  - PDP-1 built by DEC
- Connection via telephone line at 1200 bits per second

Motivation: connecting heterogeneous systems

- Early software highly specialized for machine it ran on
  - Software written in assembler code
  - Platform independent languages yet to come
- Using software written for machine A on machine B required high effort
  - Porting code or rewriting from scratch equally complex tasks

Forefather of the ARPANET

Elementary approach

- In general: connect remote computer instead of local terminal
  - Remote computer looks like local terminal for local computer
  - No changes to hardware or operating system required
- User program handles all networking tasks
  - Communication with user and remote computer

Remember: we are in the age of mainframe computers

Image source: Wikimedia Commons

6.2 The ARPANET (here: ~1967 - 1972)

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Concept proposed by Roberts

- Based on preceding experiment on connecting computers in 1965
- Funded by Advanced Research Projects Agency (ARPA)
  - US military research agency (now DARPA – Defense Advanced …)
  - Why? Because Roberts moved from MIT to ARPA.

Goals (had been tried before)

- Load sharing
  - Send program and data for processing to remote machine
  - Required identical computers at that time
- Message service

Had been tried before

Goals (of ARPANET for heterogeneous environments)

- Data sharing
  - Send program for processing to remote data
- Program sharing
  - Send data for processing to remote program
- Remote service
  - Send query to remote program and data
  - Harness specialized hardware and software

Extended goals of ARPANET for heterogeneous environments

Core component: network connections

- 50 kbit/s full-duplex leased telephone lines (AT&T)
- Min. two paths between any two IMPs

Topology as planned in 1970

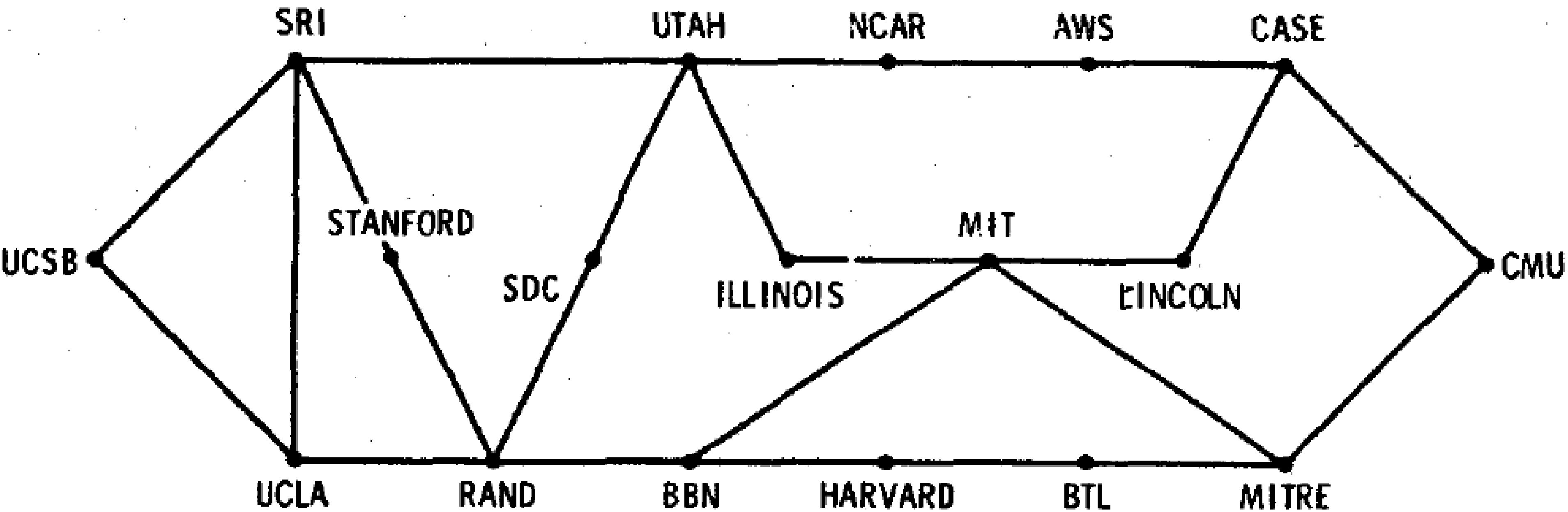

Image source: Computer network development to achieve resource sharing, AFIPS 1970

6.3 Standardization (1969 onwards)

Problem: developing communication protocols requires consensus

- Different locations, institutions, manufacturers, operators … involved
  - → Standards required
- But:
  - scientific publication process too slow
  - industrial standardization process too slow and to expensive
- Remember: ARPANET was research project with restricted funding

Solution: request for comments (RFCs)

- At first: memos, minutes of meetings
  - Circulated by mail
    - (standard old fashioned, not electronic)
- Later: published electronically
  - FTP, HTTP

request for comments (RFCs)

- Provide fast and open access to

RFC Index

Num	Information
0001	**Host Software** S. Crocker [April 1969] (TXT = 21088) (Status: UNKNOWN) (Stream: Legacy)
0002	**Host software** B. Duvall [April 1969] (TXT = 17145) (Status: UNKNOWN) (Stream: Legacy)
0003	**Documentation conventions** S.D. Crocker [April 1969] (TXT = 2323) (Obsoleted-By RFC0010) (Status: UNKNOWN) (Stream: Legacy)
0004	**Network timetable** E.B. Shapiro [March 1969] (TXT = 5933) (Status: UNKNOWN) (Stream: Legacy)
0005	**Decode Encode Language (DEL)** J. Rulifson [June 1969] (TXT = 26408) (Status: UNKNOWN) (Stream: Legacy)
0006	**Conversation with Bob Kahn** S.D. Crocker [April 1969] (TXT = 1568) (Status: UNKNOWN) (Stream: Legacy)
0007	**Host-IMP interface** G. Deloche [May 1969] (TXT = 13408) (Status: UNKNOWN) (Stream: Legacy)
0008	**ARPA Network Functional Specifications** G. Deloche [May 1969] (PDF = 750612) (Status: UNKNOWN) (Stream: Legacy)
0009	**Host Software** G. Deloche [May 1969] (PDF = 722638) (Status: UNKNOWN) (Stream: Legacy)
0010	**Documentation conventions** S.D. Crocker [July 1969] (TXT = 3348) (Obsoletes RFC0003) (Obsoleted-By RFC0016) (Updated-By RFC0024, RFC0027, RFC0030) (Status: UNKNOWN) (Stream: Legacy)
0011	**Implementation of the Host - Host Software Procedures in GORDO** G. Deloche [August 1969] (TXT = 46971, PDF = 2186431) (Obsoleted-By RFC0033) (Status: UNKNOWN) (Stream: Legacy)
0012	**IMP-Host interface flow diagrams** M. Wingfield [August 1969] (TXT = 177, PS = 1489750, PDF = 1163721) (Status: UNKNOWN) (Stream: Legacy)
0013	**Zero Text Length EOF Message** V. Cerf [August 1969] (TXT = 1070) (Status: UNKNOWN) (Stream: Legacy)

Internet standardization

- http://www.rfc-editor.org/rfc-index.html

Who is behind RFCs?

- Started in 1969 by ARPANET working group (WG)

- International Internet growth demanded for more coordination
  - International Cooperation Board (ICB)
  - Internet Research Group (IRG)
  - Internet Configuration Board (ICB)

- Continuing growth demanded for restructuring organizational institutions
  - Task forces (TFs) founded for particular technology areas
    - Routers, protocols, …
  - Internet Architecture Board (IAB) coordinates task forces

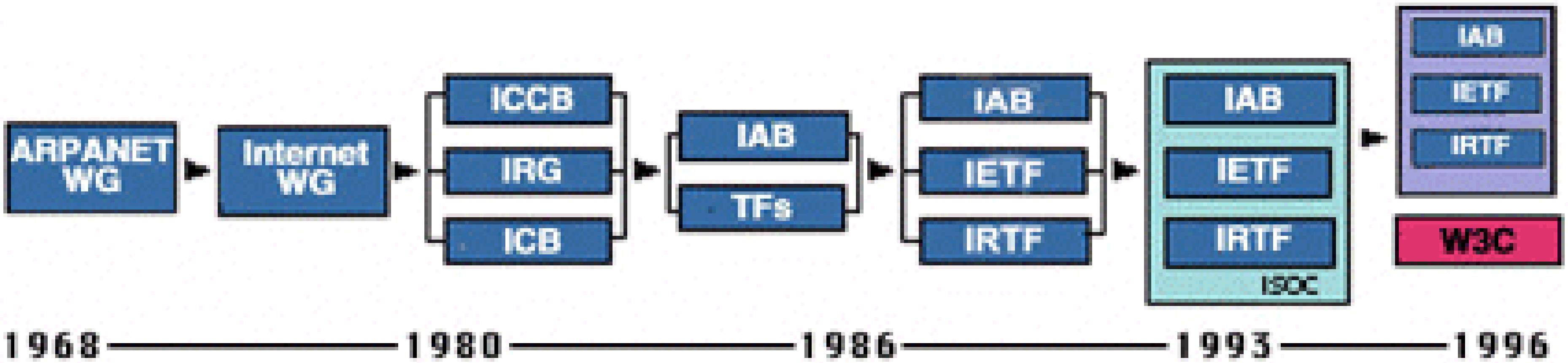

Image source: http://www.isoc.org/internet/history/brief.shtml

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Who is behind RFCs?

- Strong activities in practical/engineering aspects
  - Internet Engineering Task Force (IETF) became major player
  - Other task forces combined into Internet Research Task Force (IRTF)

- Commercialization of the Internet led to shifted interests
  - Internet Society (ISOC) coordinates business and research efforts

Development of Word Wide Web (WWW / W3)

- World Wide Web Consortium (W3C) founded
  - Responsible for protocols and standards of the web

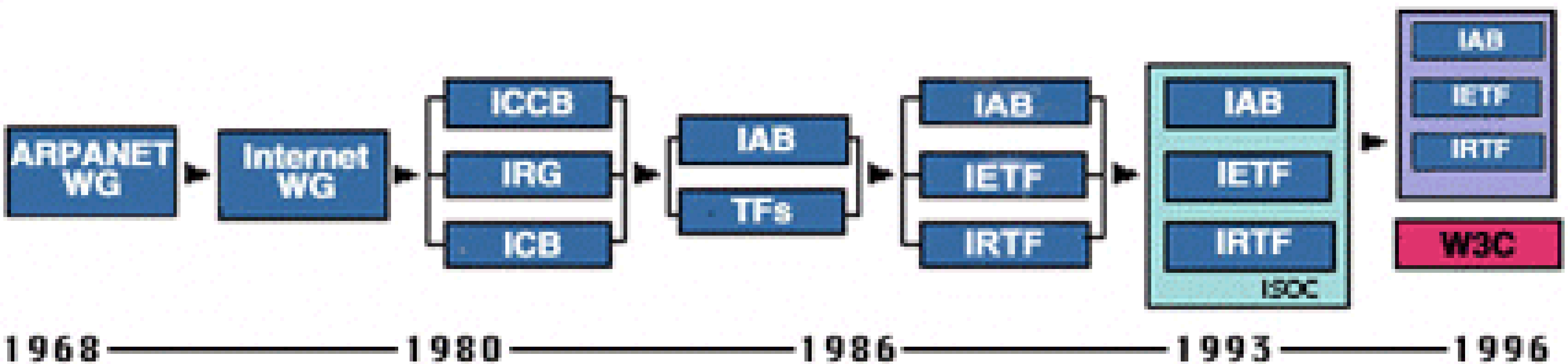


Image source: http://www.isoc.org/internet/history/brief.shtml

Besides ARPANET many other networks appeared in/after 1970s

- E.g. NSFNET by US National Science Foundation
  - Advanced research and education networking
- E.g. JANET by UK government
  - Research and education network
- E.g. German DATEX-P by Deutsche Bundespost
  - Commercial packet switched service

Internetworking concepts proposed by Kahn in 1973

- Goal: to connect different networks
- Ground rules valid until today
  - No internal changes required to connect a network to the Internet
  - Best effort communication
  - Stateless gateways/routers used for connection of networks
  - No global control
  - Also:
    - dealing with packet loss, pipelining, fragmentation, global addressing, flow control, …

ARPANET's NCP does not meet internetworking requirements

- TCP/IP presented by Cerf and Kahn at Stanford and BBN in 1974
- Concept of byte streams
- Flow control by sliding window with cumulative acknowledgements
- First only TCP (nearly as we know it today) implemented
- Research on packet voice demanded for more simple protocol → UDP
- Other applications:
  - File and disk sharing, mobile agents
- Not foreseen:
  - proliferation of LANs and PCs
  - Considered were national level networks
  - 32 bit IP addresses with 8 bit network address, 24 bit host address

TCP/IP evolved to deployment version until 1981

- IPv4 as used today
  - Details see forthcoming lectures
- ARPANET switched to TCP/IP in 1983

Brief History of Electronic Communications

The Internet (cont'd)

- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: ftp protocol defined
- 1988: TCP congestion control
- early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web
- late 1990's – 2000's:
  - more killer apps: instant messaging, P2P file sharing
  - network security to forefront
  - est. 50 million host, 100 million+ users
  - backbone links running at Gbps
- 2010:
  - ~750 million hosts
  - voice, video over IP
  - P2P applications: BitTorrent (file sharing) Skype (VoIP), PPLive (video)
  - more applications: YouTube, gaming, Twitter
  - wireless, mobility

Source: Computer Networking: A Top Down Approach ,5th edition. Jim Kurose, Keith Ross, Addison-Wesley, April 2009

7 In the last Years

Mobile telephony

- GSM .. UMTS … lte ..5G

And still

- SMS

Web (last century)

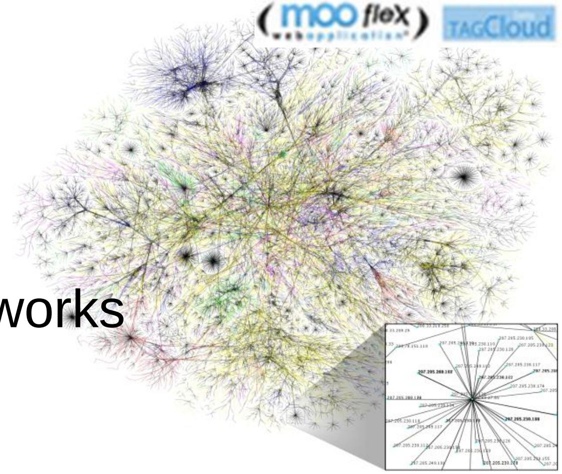
Peer-to-Peer

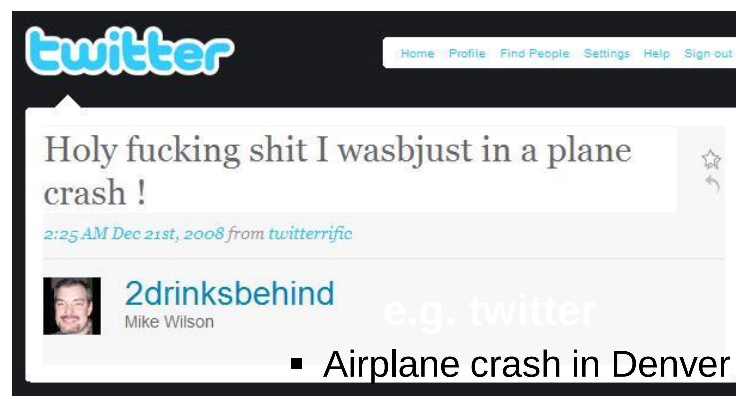
Cloud Services

- like dropbox, …

and

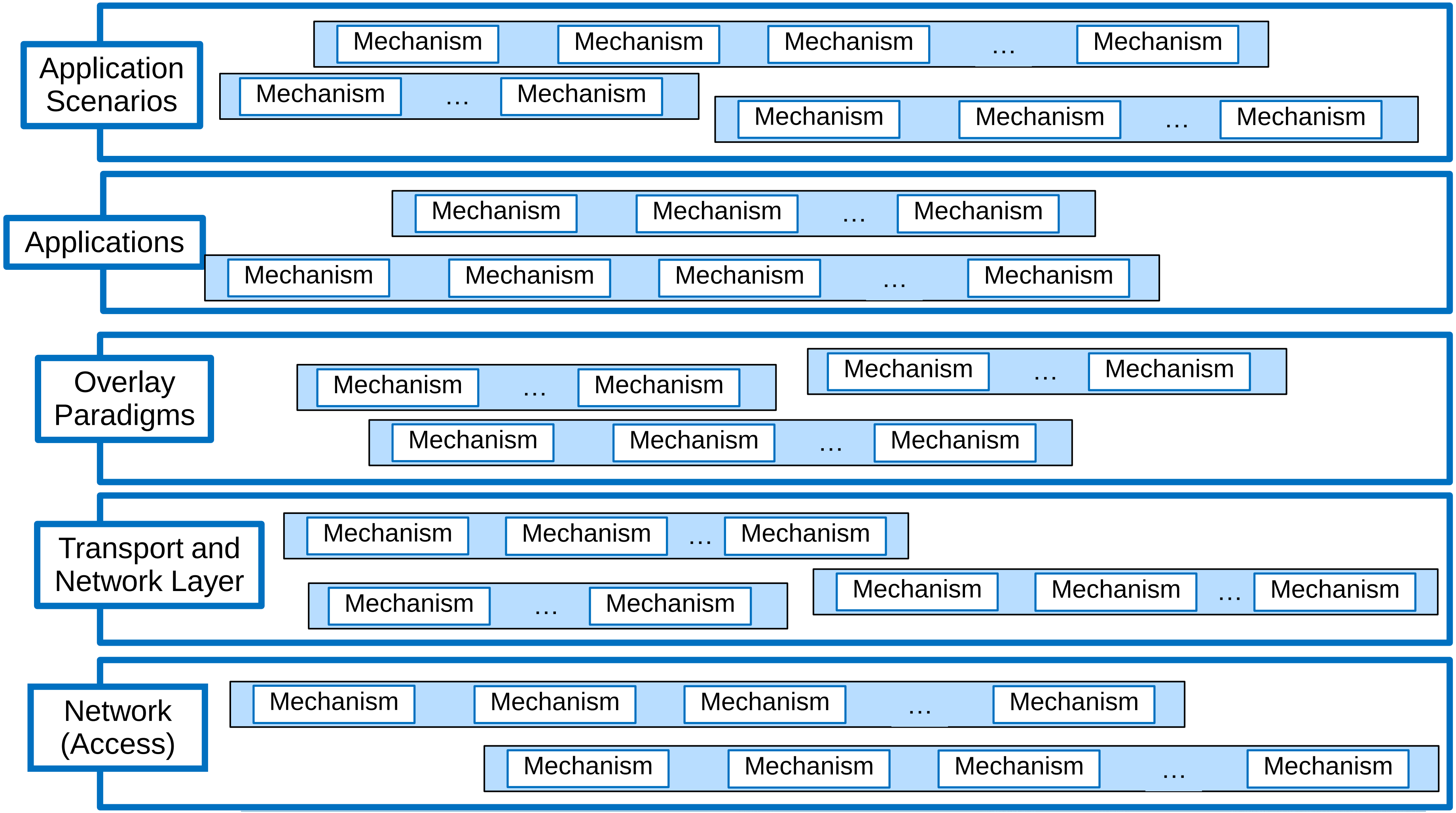
- Web services
- …
- Twitter
- Online social networks
- …



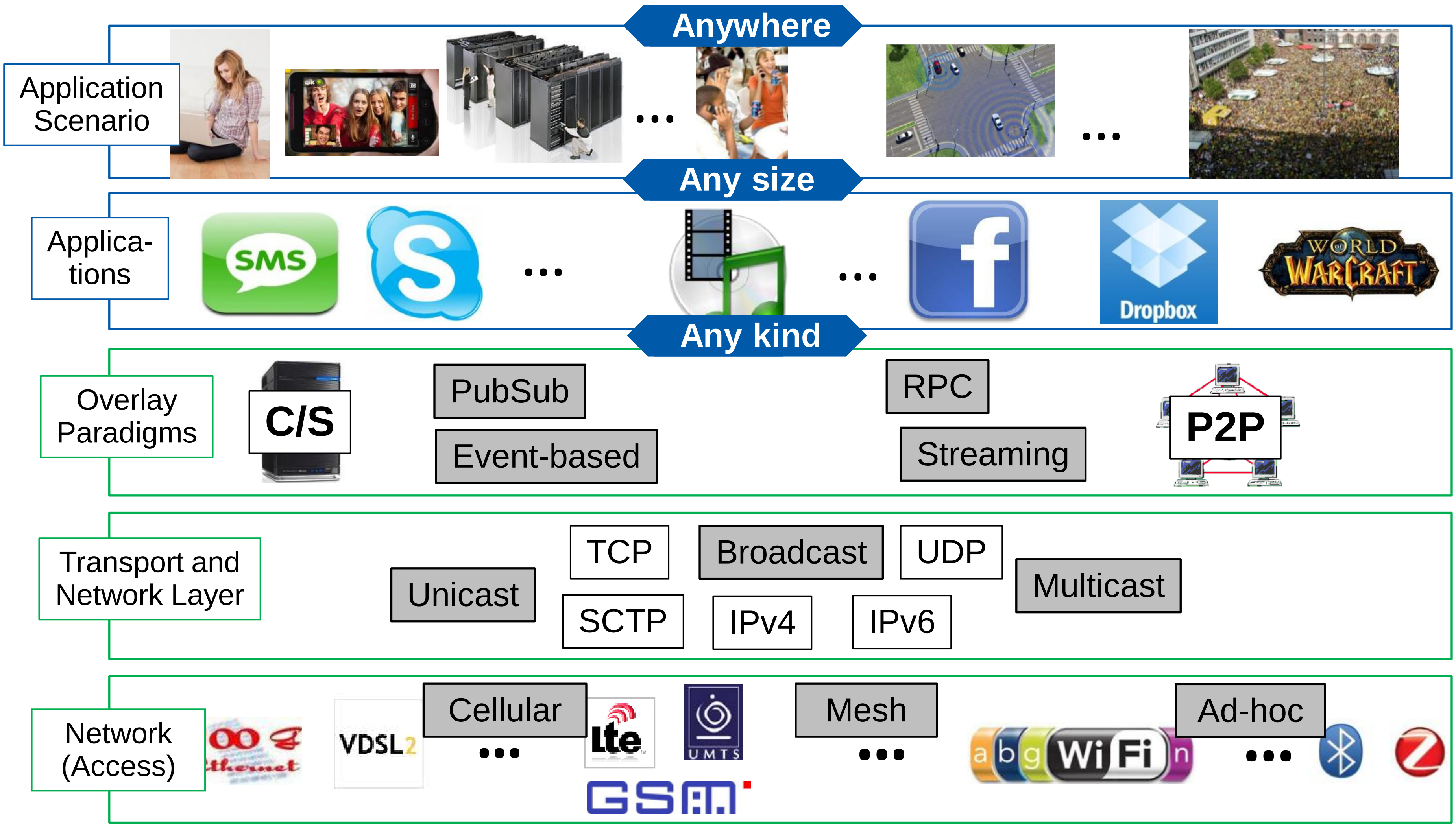


- Airplane crash in Denver

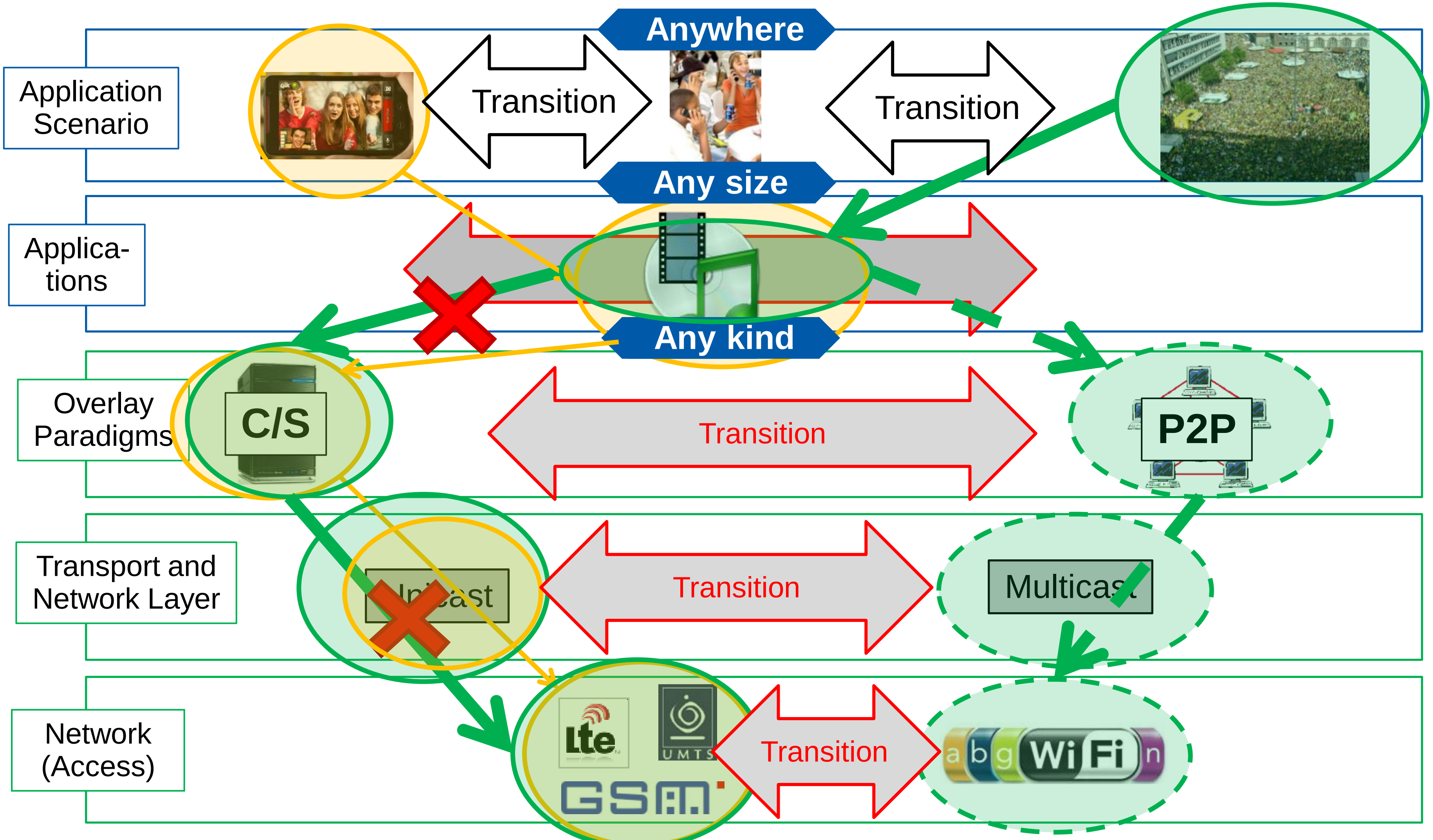
Mechanisms, Protocols, Services, Architecture - the Situation today



Mechanisms, Protocols, Services, Architecture - the Situation today



Future Challenges in the so called Future Internet



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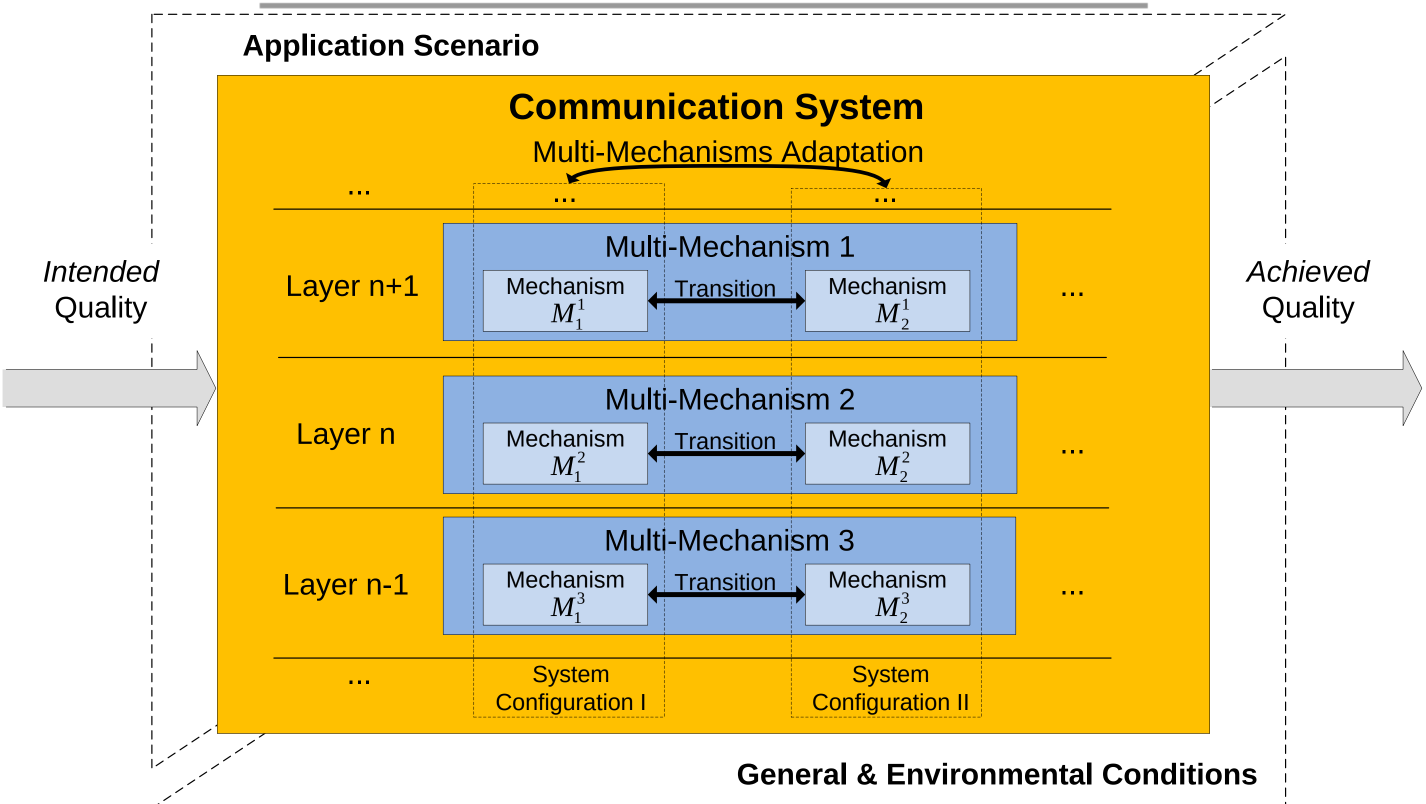
Happens TODAY In Darmstadt (together with RWTH Aachen, UIUC)

- approx. 50 scientists involved
- Targets towards 2016, 2022 and 2026



SFB 1053

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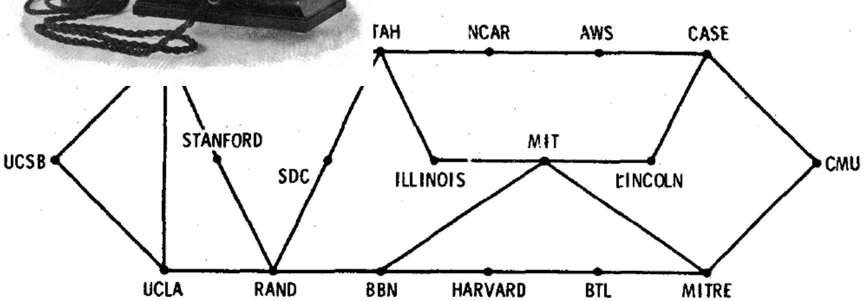
Part I – History



Part II – Basics

- Network Structures
- Architecture
- Layers
- Protocol
- Service
- Connection, connection oriented, connectionless
- Terminology

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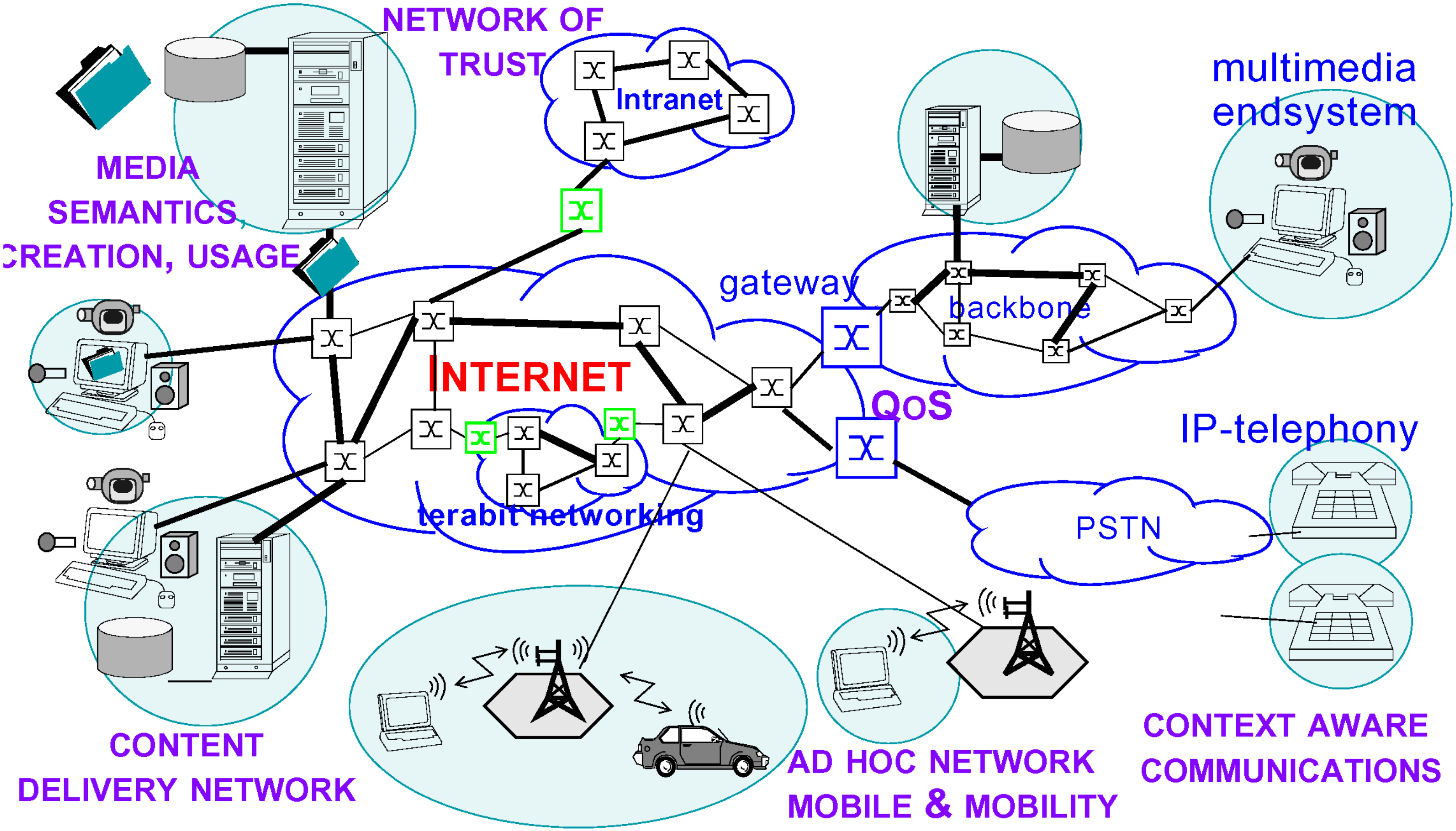
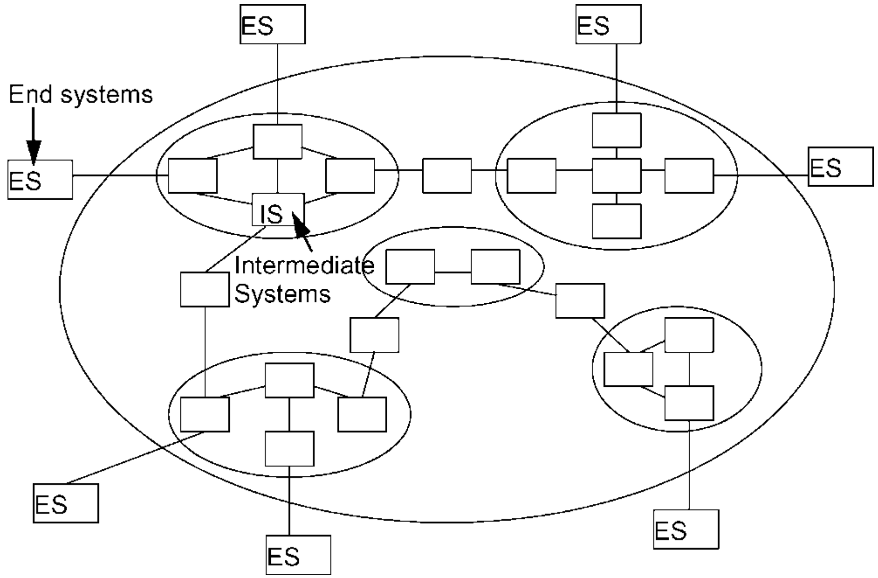


Network Components



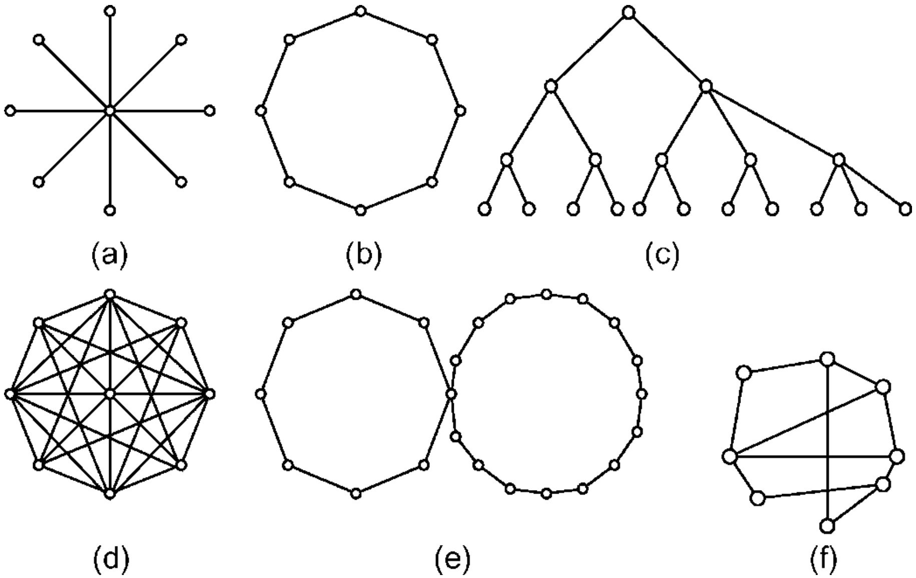
Data transfer from end system to end system

- END-SYSTEM (ES) also known as Data Terminal Equipment (DTE)
  - e.g. terminal, computer, telephone
  - and Data Circuit terminating Equipment (DCE) and Data transfer equipment
    - e.g: modem, multiplexer, repeater
- INTERMEDIATE SYSTEM (IS) also called Data Switching Exchange (DSE)
  - e.g. router

Point-to-point channels

- net = multitude of cable and radio connections often also called a network
- whereby a cable always connects two nodes
- more prevalent in wide area domains (e. g. telephone)

Topologies:



Network Structures

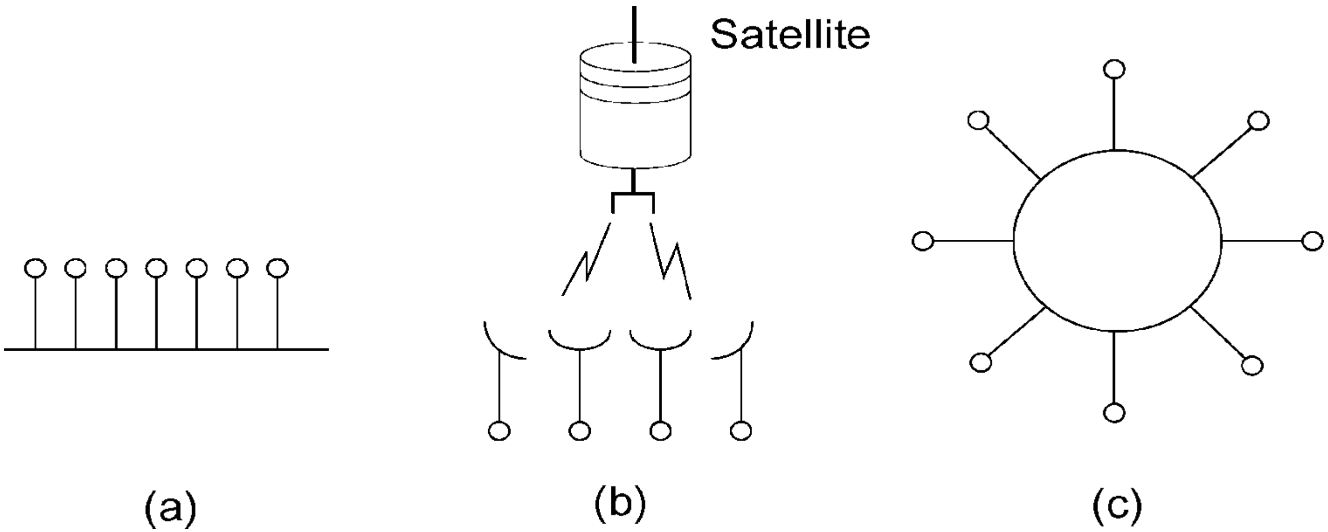
Broadcasting channels

- systems share one communication channel
- one sends, all others listen

Used for

- wide area: radio, TV, computer communication
- local area: local networks

Topologies:



Network Types

Distance between Processors	CPUs jointly located on/in..	Example
<= 0,1 m	Boards	usually tightly coupled multi-processor system
1 m	Systems	e.g. body area network e.g. sensor area network e.g. storage area network
10 m	Rooms	
100 m	Buildings	LAN
1 km	Campuses	
10 km	Cities	MAN
100 km	Countries (national)	
1.000 km	Continents (intern.)	WAN
>= 10.000 km	Planets	

- Local Area Network (LAN)   e.g. IEEE 802.3 = Ethernet, IEEE 802.11
- Metropolitan Area Network (MAN):
  - (being replaced by LAN + WAN) e.g. FDDI
- Wide Area Network (WAN): example SDH, ATM, all optical networks
- Inter-Planetary Internet: http://www.ipnsig.org/

Network Types: Mobile Communication

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Expansion

- with the areas: LAN, MAN and WAN

Examples for "Wireless"

- GSM, UMTS, ..
- wireless telephony: DECT, ..
- LANs: Bluetooth, WaveLAN, ..

wireless communication   mobile communication

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">Wired or Radio Connection</th></tr>
<tr><th>Wired</th><th>Wireless</th></tr>
<tr><td rowspan="2">Connection to network either static or dynamic (at different locations)</td><td>Mobile</td><td>mobile IP
e.g. laptop in the hotel</td><td>mobile telephony
e.g. laptop in the car
PDA at customer’s site</td></tr>
<tr><td>Fixed</td><td>POTS
Existing LANs
e.g. workstation in the office</td><td>wireless LAN
cordless telephone
e.g. wireless “last mile”</td></tr>
</table>

Problem: engineering communication means

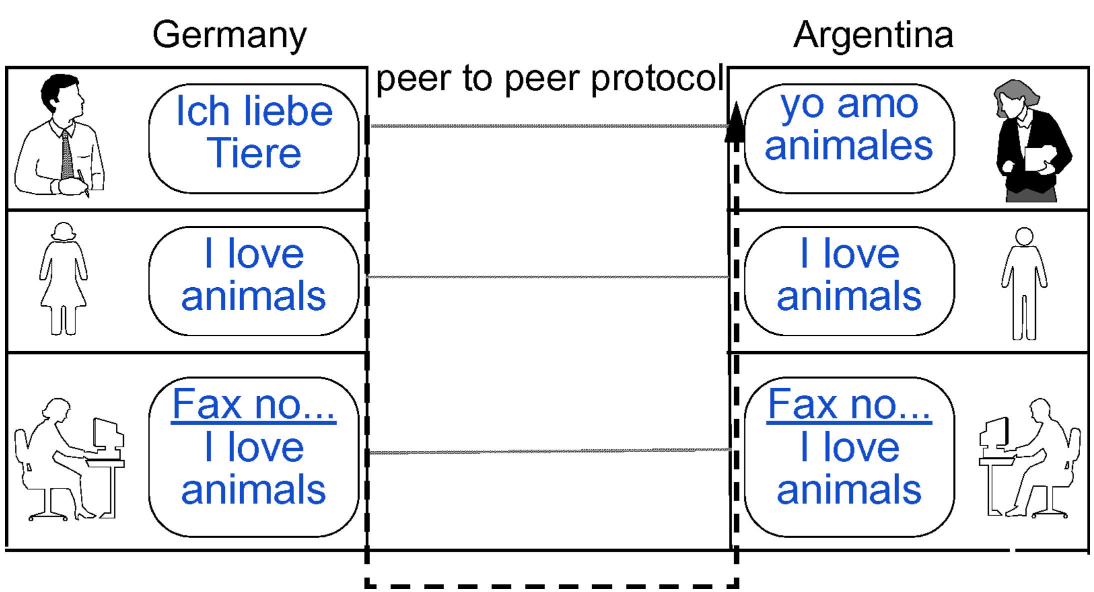
- multitude of partially very complex tasks
- interaction of differing systems and components

Simplification:

- to introduce abstraction levels of varying functionalities
- general module, preferable: layer, level

Example (here using ISO-OSI reference model, later 5 layers

- biologists with translator and e.g. secured encrypted FAX-office



9.1 Layered Architecture

Layer content („service“)

- may be exchanged at any layer independently

Use protocol

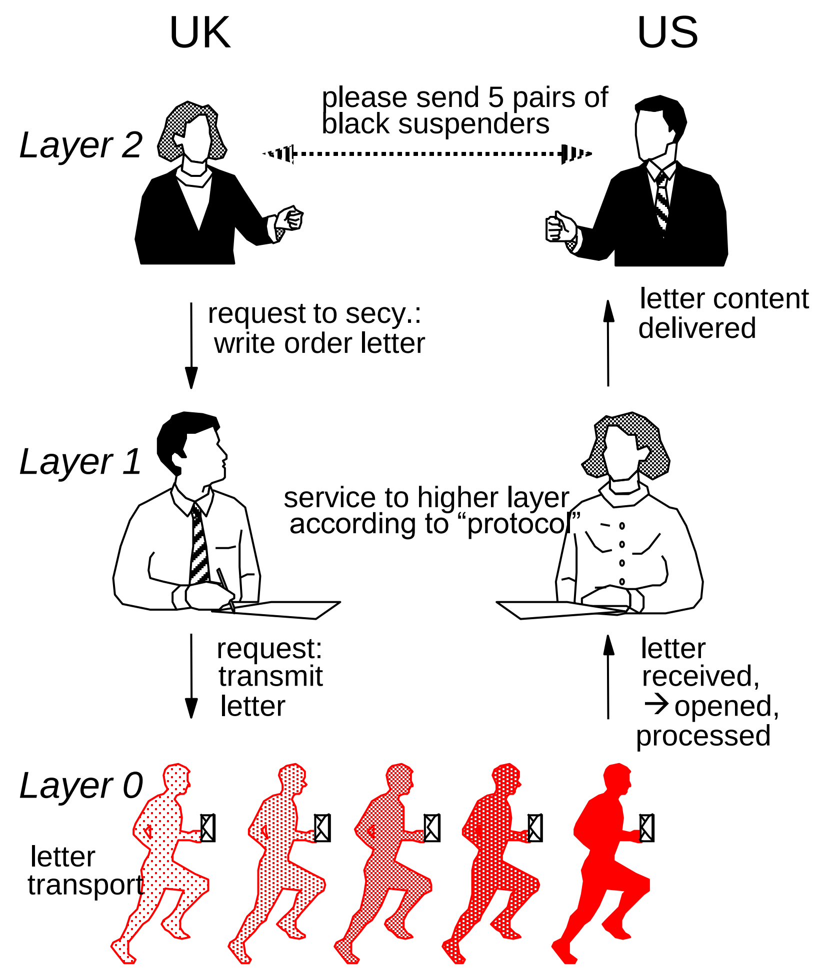
- to ensure peer entities interoperate correctly

Tradeoff:

- overhead (SW/msg) vs. exchangeability, clarity, simplicity

Note:

- open question remains: what is going to happen? (“presentation syntax”)



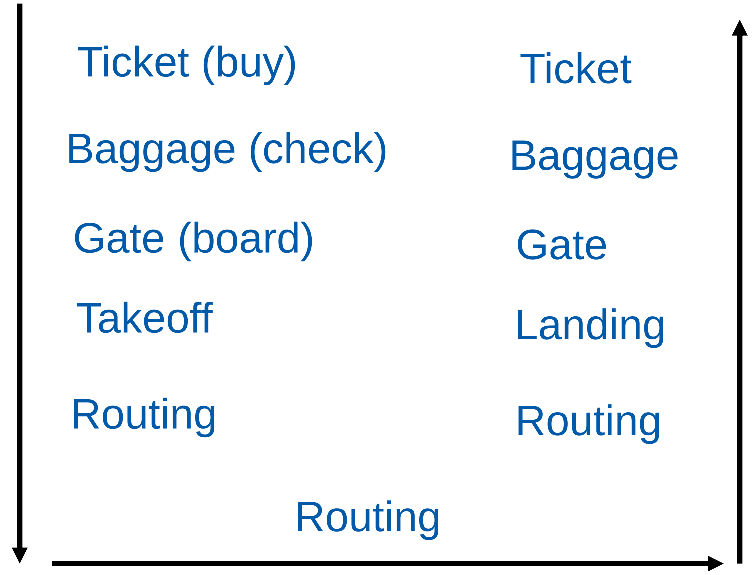
Layered Architecture

How would you describe the airline system?

- Ticketing, baggage, gates, pilots, routing, …

Describe by actions:

- Buy ticket
- Check in with baggage
- Go to gate for boarding
- Plane takes off
- Plane is routed to destination
- Plane lands
- Arrive at gate
- Claim bags
- (Complain to airline)



Layered Architecture

Ticket purchase		Ticket (complain)	Ticketing
Baggage check		Baggage claim	Baggage
Gate (board)		Gate (get off)	Boarding
Takeoff		Landing	TO/Landing
Routing	Routing	Routing	Routing

Layers provide services by:

- Performing actions on its own layer
- Using services from a layer **directly below**
- Realizing a distributed abstract machine

Is above a good example? No!

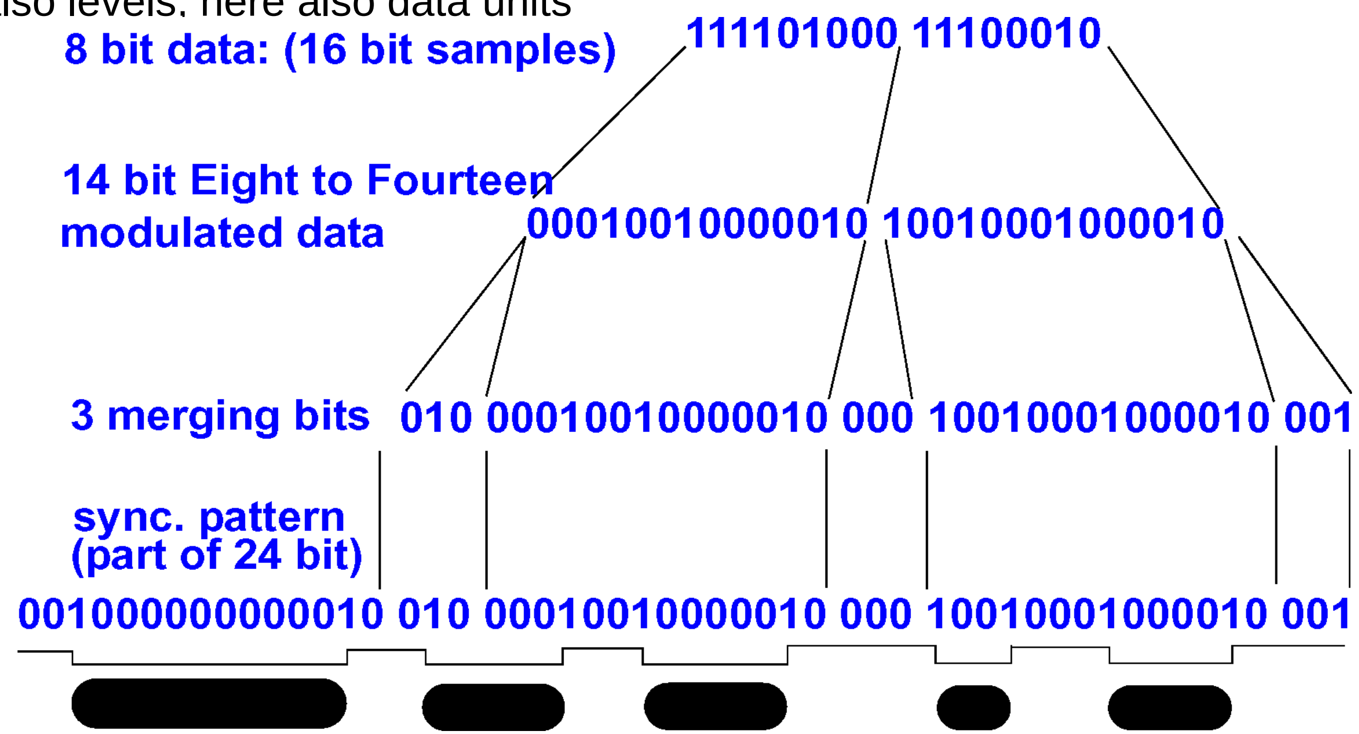
- good layered architectures are great art & science!

(only in communication?) layers exist in various areas

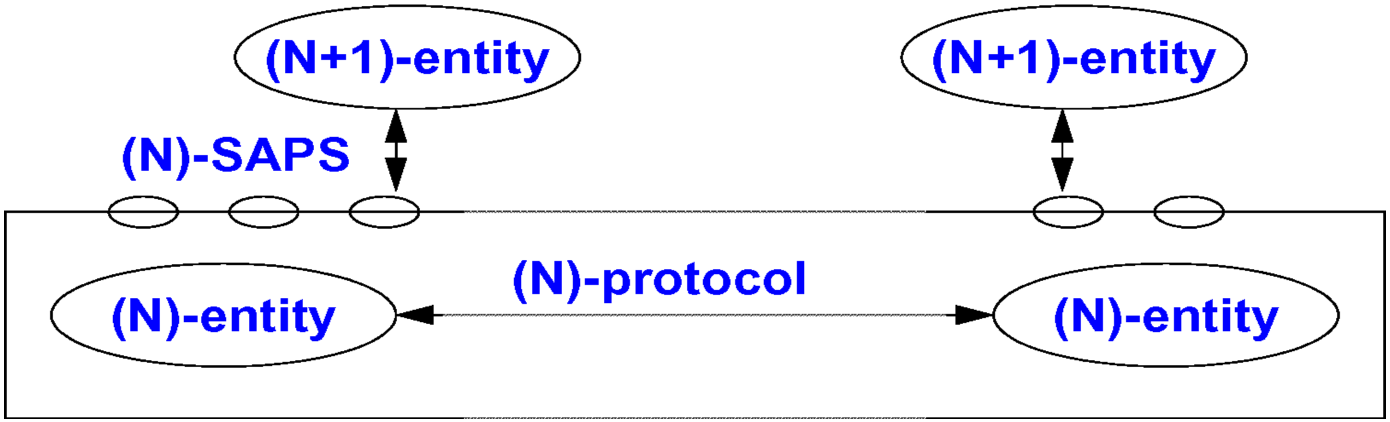
- e. g.
  - compression: MPEG
  - CD technology

Example: CD Digital Audio

- here also levels, here also data units



Layers in General



N-Layer

- abstraction level with defined tasks

N-Entity

- active elements within a layer
- process or intelligent I/O module
- peer entities: corresponding entities on different systems

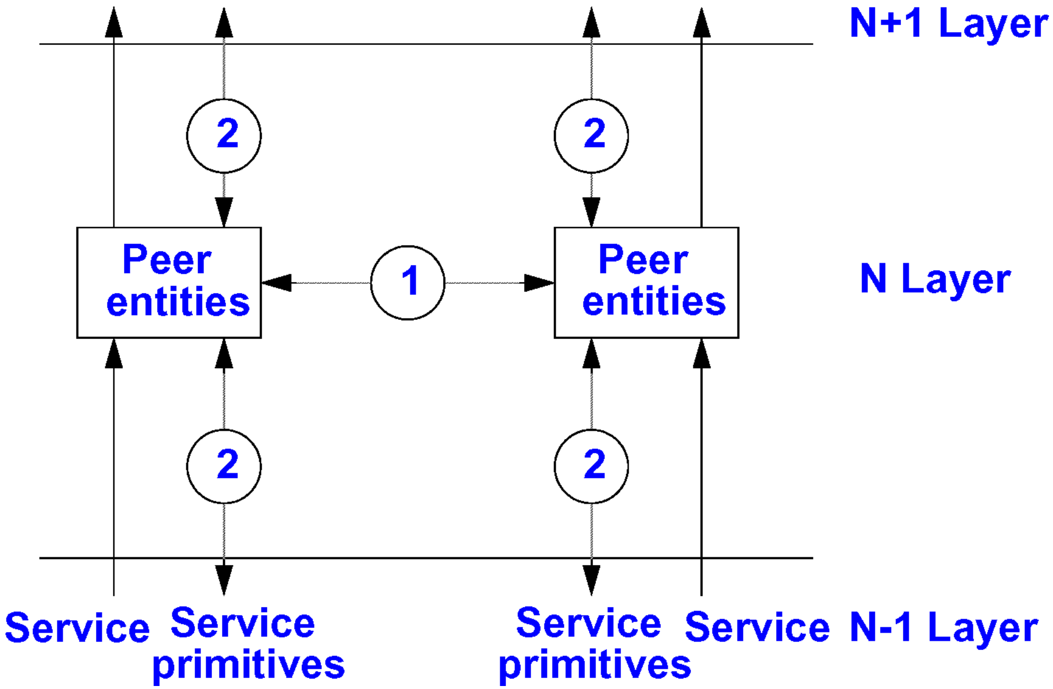
N-Service Access Point, N-SAP

- service identification

N-Protocol:

- a multiple of rules for transferring data between N-entities

9.3 Protocol: Communication between same Layers



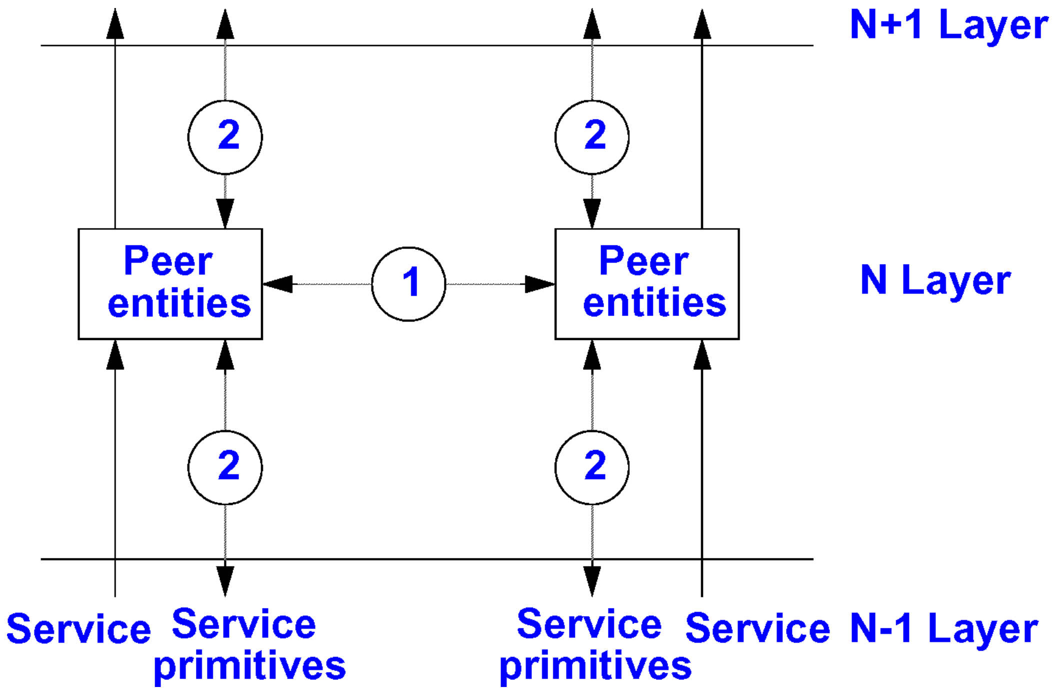
Definition of protocol:

- A protocol defines
  - the format and
  - the order of messages
- exchanged between two or more communicating entities,
- as well as the actions taken on transmission and/or reception of a message or other event

Protocol

- rules for syntax (format) and semantics (contents)
  - of the data transfer (frames, packet, message) occurring
  - between the respective, active peer entities
- analogy: programming, protocol corresponds to
  - realization of the data type (procedures, etc.)
  - the "interior" of the object

Service: Communication between adjacent Layers



Service

- multiple of primitives/operations/functions
  - which one layer offers to the upper next layer
- characterized by the "interface"
- does not reveal anything about the implementation
- analogy: programming, service corresponds to
  - abstract data type
  - object

Fundamental distinction between connection-oriented and connectionless

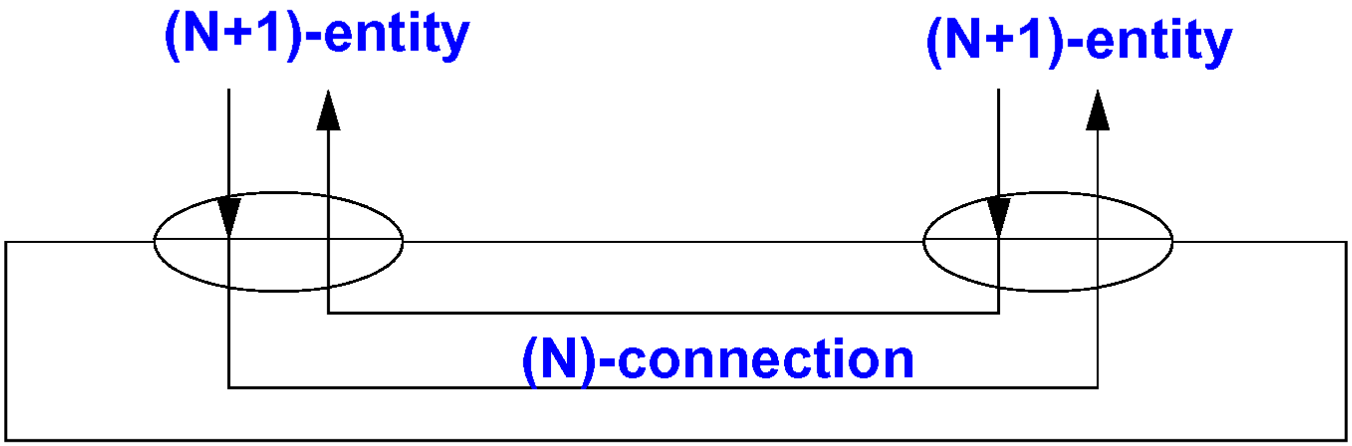
Rough analogies:

- **Connection-oriented ≈ telephone service**
- **Connectionless ≈ postal service**

...how many calls can she handle?

...what kind of guarantee do you get?

Connections: Connection Oriented Service



Connection oriented:

- 3 phases:
  - to connect (also called handshake)
  - to transfer data
  - to disconnect

Note: "Connection-oriented" does not imply any additional properties of the connection

- No reliability, flow control, or congestion control is required
- TCP (Internet's connection-oriented protocol) implements them

BUT: "Connections" are nothing but a distributed "state", held at both end points

- this is the *basis* for almost all additional properties
- … and for overhead (IP golden role: *no* state in routers)

Connectionless Service

Connectionless networks have no connection establishment phase

- transfer of isolated unit data
- Go straight to data transfer phase
- Also, no connection teardown phase

No need to maintain connection state

Communication partner might not be ready for receiving

Connectionless networks do not implement:

- Reliability, flow control, congestion control
- Applies also to UDP (Internet's connectionless protocol)

So, Which Is Better?

Overhead of handshake in connection-oriented

- Can be significant in short communications
- Insignificant in long communications

What happens when network is congested:

- Connection-oriented: Busy, no connection
- Connectionless: Can communicate, but may be stalled

Possible to build connection-oriented service on top of a connectionless service

Pro Connection-oriented: Better service (at cost of state)

Pro Connectionless: Stateless → Scalable

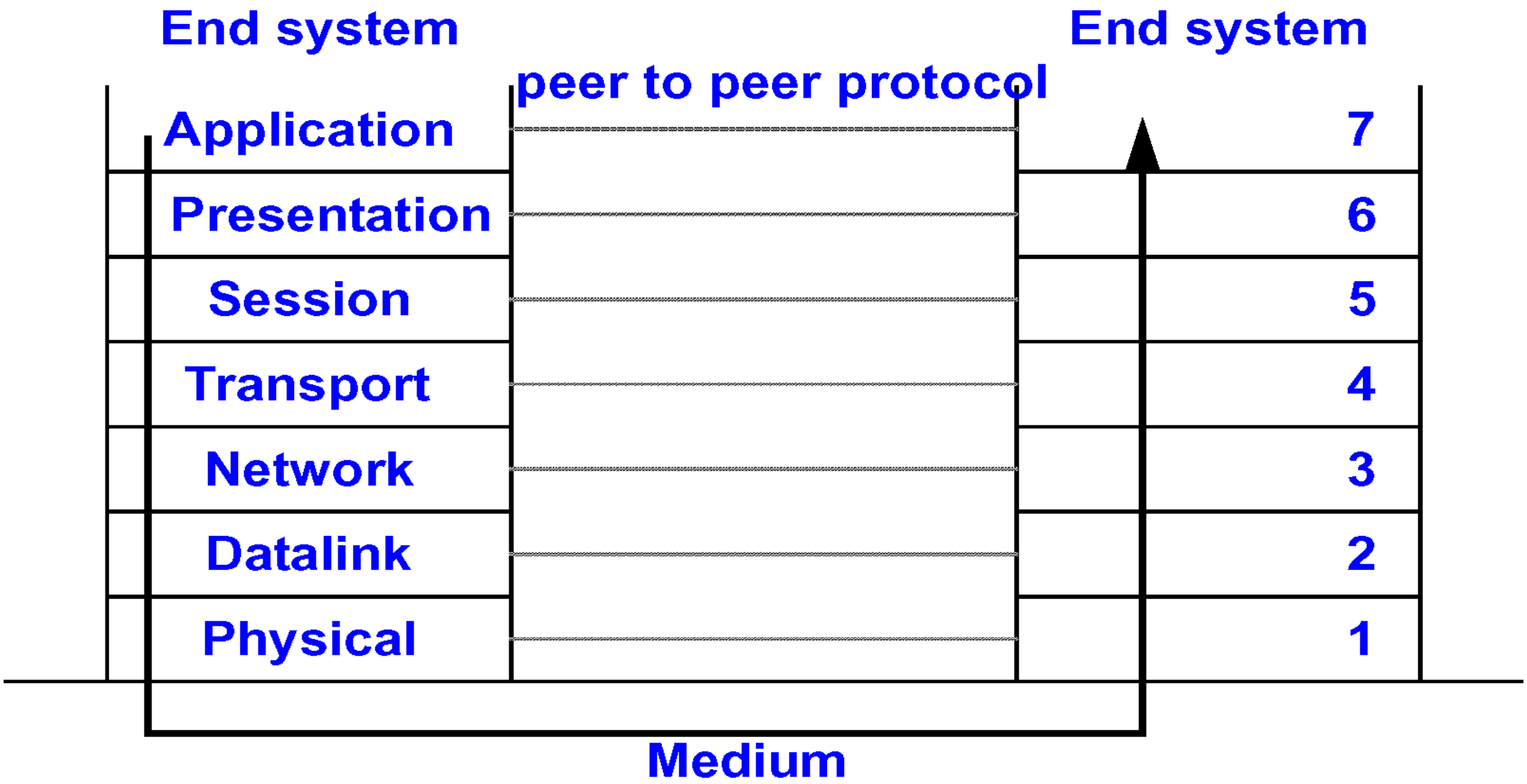
Applications for both types of networks

ISO OSI (Open Systems Interconnection) Reference Model

- model for layered communication systems
- defines fundamental concepts and terminology
- defines 7 layers and their functionalities

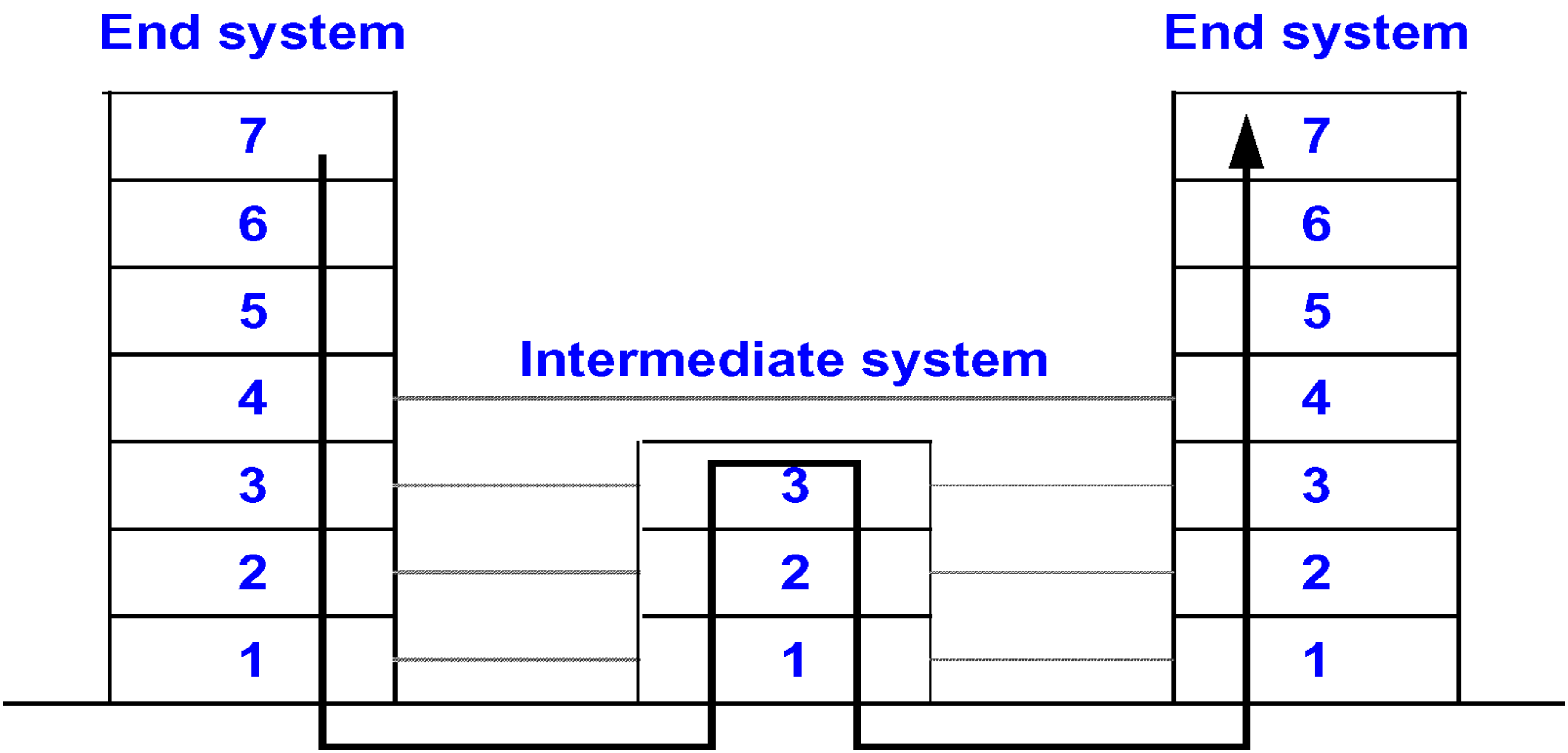
7	**Application Layer**
6	**Presentation Layer**
5	**Session Layer**
4	**Transport Layer**
3	**Network Layer**
2	**Data Link Layer**
1	**Physical Layer**

Actual data flow between two systems:



OSI Architecture

Real data flow with intermediate systems:



11.2 Layers and theirs Functions

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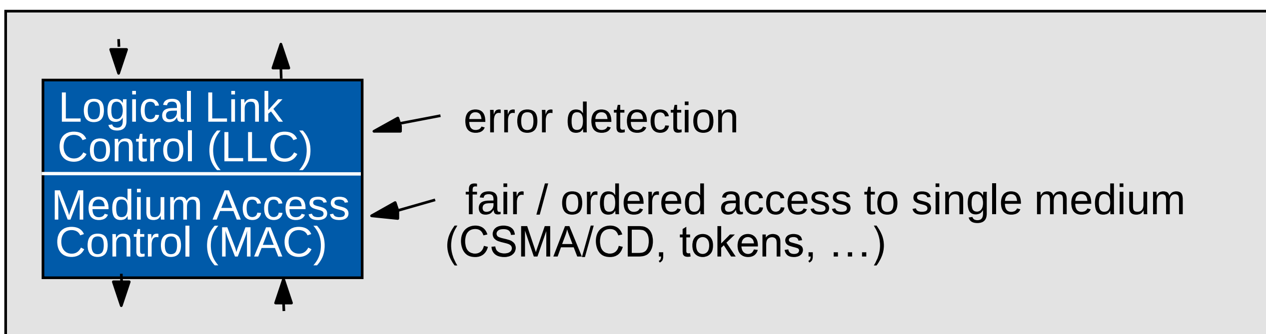
<table>
<tr><th>Layer</th><th>Function</th></tr>
<tr><td>1
Physical</td><td>Signal representation of bits: sending bit 1 is also received as bit 1 (and not as bit 0):
mechanics: connector type, cable/medium,..
electronics: voltage, bit length,..
procedural:
unidirectional or simultaneously bidirectional
initiating and terminating connections
Protocol example: RS232-C = ITU-T V.24; other: ITU-T X.21</td></tr>
<tr><td>2
Data Link</td><td>Reliable data transfer between adjacent stations with frames
introducing data frames and acknowledgement frames
error recognition and correction within the frame:
manipulation, loss, duplication
Residual & “severe” errors deferred to higher layers
fast sender, slow receiver:
flow control
distribution network requires access control:
Medium Access Control (MAC)</td></tr>
</table>

ISO-OSI Layers: Functions

Layer	Function
2 **Data Link**	Layer 2 may already include some flow control Goal: protect slow receiver Flow control can be sophisticated (sliding window protocol), For example, avoid slow stop-and-go for satellite connections Broadcast networks (LAN) often with two sublayers Logical Link Control (LLC) Medium Access Control (MAC)



ISO-OSI Layers: Functions

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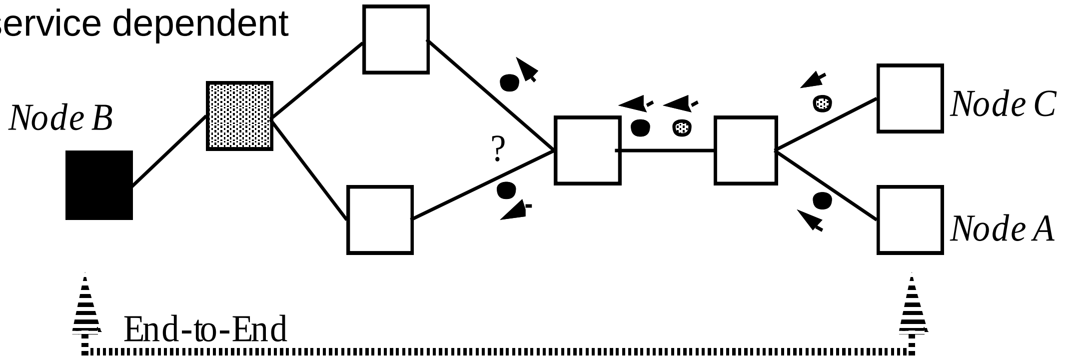
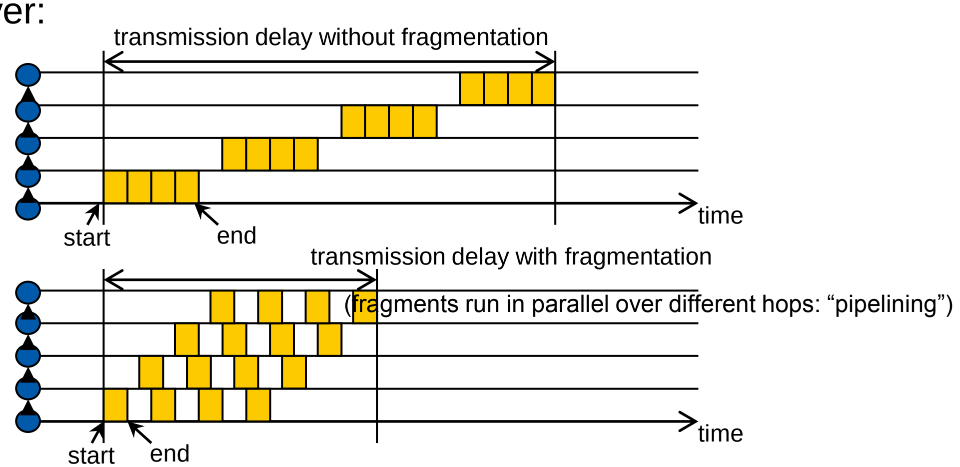
<table>
<tr><th>Layer</th><th>Function</th></tr>
<tr><td>3
Network</td><td>
connection (as relationship between entities)
end system to end system
▪ (subnets) with packets
▪ routing, i. e. among others
  ▪ fixed, defined during connect, dynamic
  ▪ congestion control (too many packets on one path)
  ▪ quality of service dependent


▪ varying subnets, Internetworking,
▪ i. e. among others
  ▪ addressing, packet size
▪ comment: at broadcast networks:
  ▪ routing often simplified or non-existent,
    i. e. this layer does often not exist here
▪ example: IP (connectionless), X.25 (connection-oriented)
</td></tr>
</table>

ISO-OSI Layers: Functions

<table>
<tr><th>Layer</th><th>Function</th></tr>
<tr><td>4
Transport</td><td>Connection (as relationship between entities)
From source (application/process)
to destination (application/process)
▪ optimize required quality of service and costs
  ▪ 1 L4 connection corresponds to 1 L3 connection
▪ increase throughput:
  ▪ 1 L4 connection uses several L3 connections (splitting)
▪ minimize costs:
  ▪ several L4 connections multiplexed onto 1 L3 connection
▪ process addressing, connection management, error correction
▪ fast sender, slow receiver:
  ▪ flow control
▪ protocol example: TCP

</td></tr>
</table>

ISO-OSI Layers: Functions

Layer	Function
5 **Session**	**support a "session" over a longer period** ▪ synchronization (during interrupted connection) ▪ token management (coordinate the simultaneous processing of different applications)

6
Presentation
	data presentation independent from the end system
	▪ negotiating the data structure,
	▪ conversion into a global data structure
	▪ examples:
	  ▪ data types: date, integer, currency,
	  ▪ ASCII, Unicode, …

7
Application
	application related services
	▪ examples:
	  ▪ electronic mail, directory service
	  ▪ file transfer, WWW, P2P, …

Comment:

- layer does not necessarily correspond to the process of the implemented unit
  - otherwise loss of efficiency

OSI 7-Layer Architecture Summary

7. Application Layer A: cooperating entities
6. Presentation Layer P: exchange of data (semantics!)
5. Session Layer S: structured dialogue
4. Transport Layer T: end2end msg. stream betw. individual processes
3. Network Layer N: packet stream between end systems
2. Data Link Layer D: error-recovering frame stream, adjacent sys.
   - LAN comprises
     - L.2b: Logical Link Control
     - L.2a: Media Access Control
1. Physical Layer PH: unsecure bitstream between adjacent systems

Note:

- Many service functions carried out in several layers / services !

→ Overhead, even reversal in part due to net homogeneity

Application level "messages" are processed as data units.

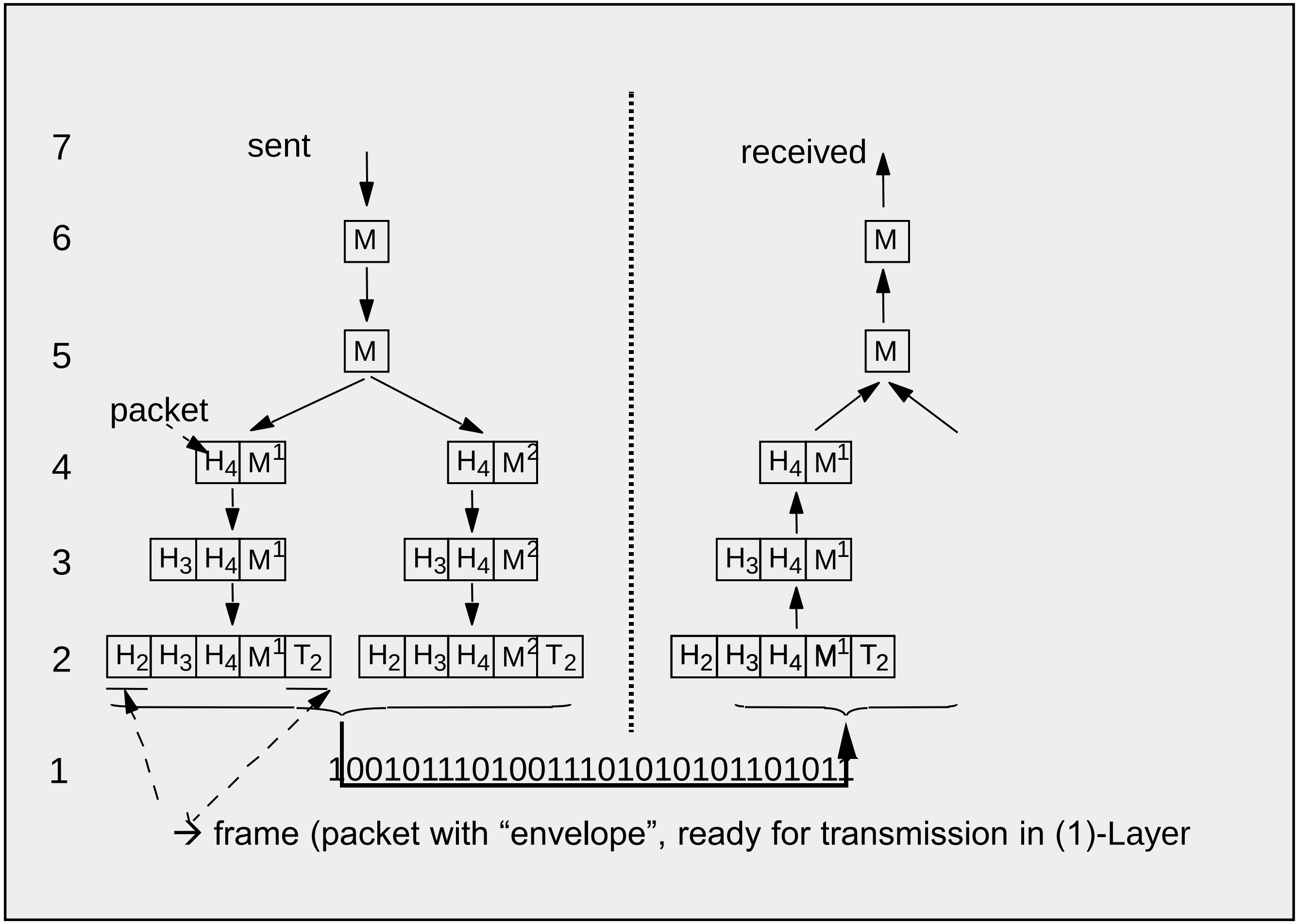
Following notions for data units have become common:

- packet: "unit of transportation" (may contain fragments)
- datagram: instead of packet if sent individually (connectionless)
- frame: with final envelope, ready to send (next to lowest layer)
- cell: small packet of fixed size

OSI terminology: „message" is a PDU

- PDU: Protocol Data Unit
  - (N)-PDU: semantics understood by peer entities of (N)-service
  - (N)-PDU = (N)-PCI plus (N)-SDU; (N)-SDU = (N+1)-PCI plus (N+1)-SDU
- PCI: Protocol Control Information: only used by peers
- SDU: Service Data Unit = payload - optionally carried in PDU for user

OSI Model: Data Units



Header H_n (plus maybe Trailer T_n) in (N)-layer carries (N)-PCI

Protocol Control Information PCI: checksums, msg no., …

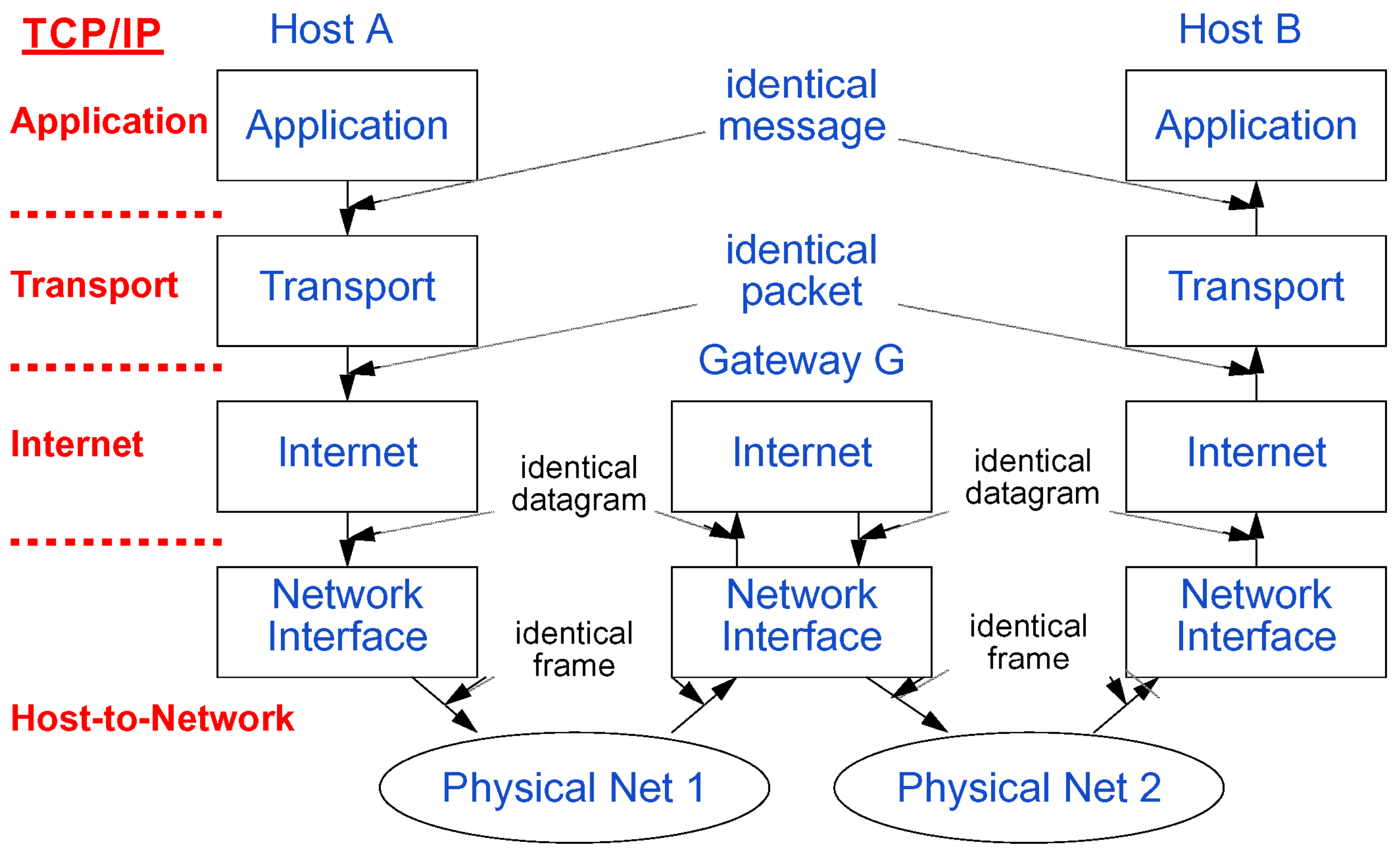
OSI (Open Systems Interconnection) Reference Model

7	Application Layer
6	Presentation Layer
5	Session Layer
4	Transport Layer
3	Network Layer
2	Data Link Layer
1	Physical Layer

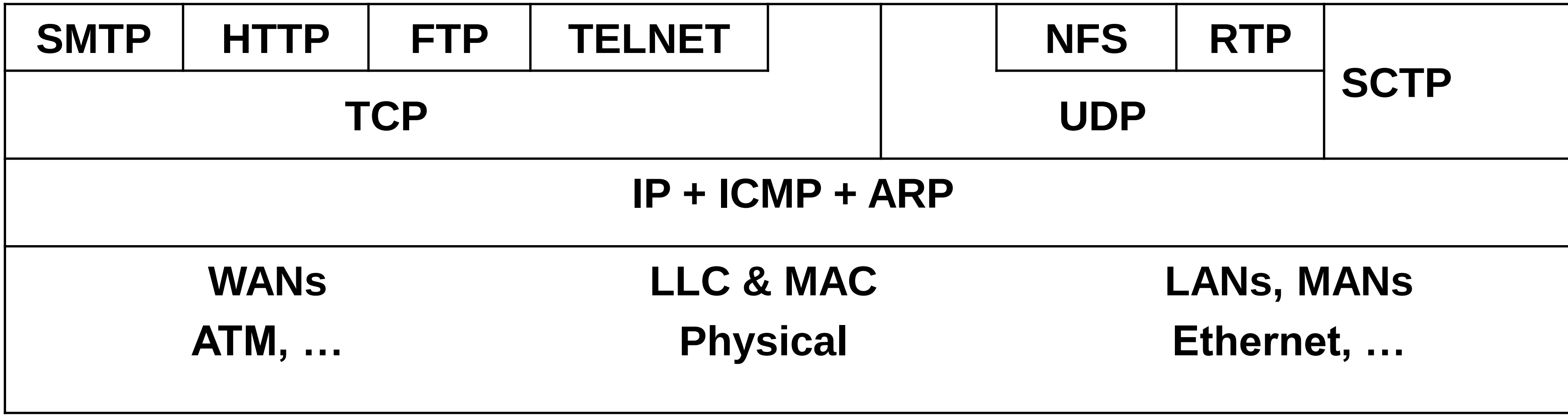
TCP/IP Reference Model Internet Architecture

- ISO-OSI presentation, session and application layer merged
- ISO-OSI data link layer and physical layer merged to form Network Interface

TCP/IP Reference Model: Internet Architecture



Well-Known Internet Protocols



ARP	= Address Resolution Protocol
FTP	= File Transfer Protocol
HTTP	= Hypertext Transfer Protocol
IP	= Internet Protocol
ICMP	= Internet Control Message Protocol
LLC	= Logical Link Control
MAC	= Media Access Control
NFS	= Network File System
SMTP	= Simple Mail Transfer Protocol
TELNET	= Remote Login Protocol
TCP	= Transmission Control Protocol
UDP	= User Datagram Protocol
SCTP	= Stream Control Transmission Protocol

Comparing the Reference Models: 5-Layer Model Used Herein

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ISO-OSI: standardized too late

- implementations usually worse than those of Internet protocols
- in general, however, mainly good concepts

TCP/IP (Internet)

- TCP/IP already prevalent, SMTP too, now e. g. WWW
- integrated into UNIX

Considered here:

Layer		Function
5	Application	application related services incl. ISO-OSI L5 and L6 (as far as necessary)
4	Transport	connection end/source (application/process) to end/destination (application/process)
3	Network	connection end-system to end-system
2	Data Link	reliable data transfer between adjacent stations
1	Physical	sending bit 1 is also received as bit 1

13 Example: Layers in Action

What happens in different layers when you use your browser to access a website?

Remember: Internet has only 5 layers

- Layers 5, 6, and 7 implemented in a single application layer

In Internet, layers 3 and 4 are somewhat confused

- Transport protocol TCP (or UDP) and network protocol IP
- Sometimes hard to draw a clear line where TCP ends and IP begins
- **But:** Basic functionality is clearly separated

So, what happens?

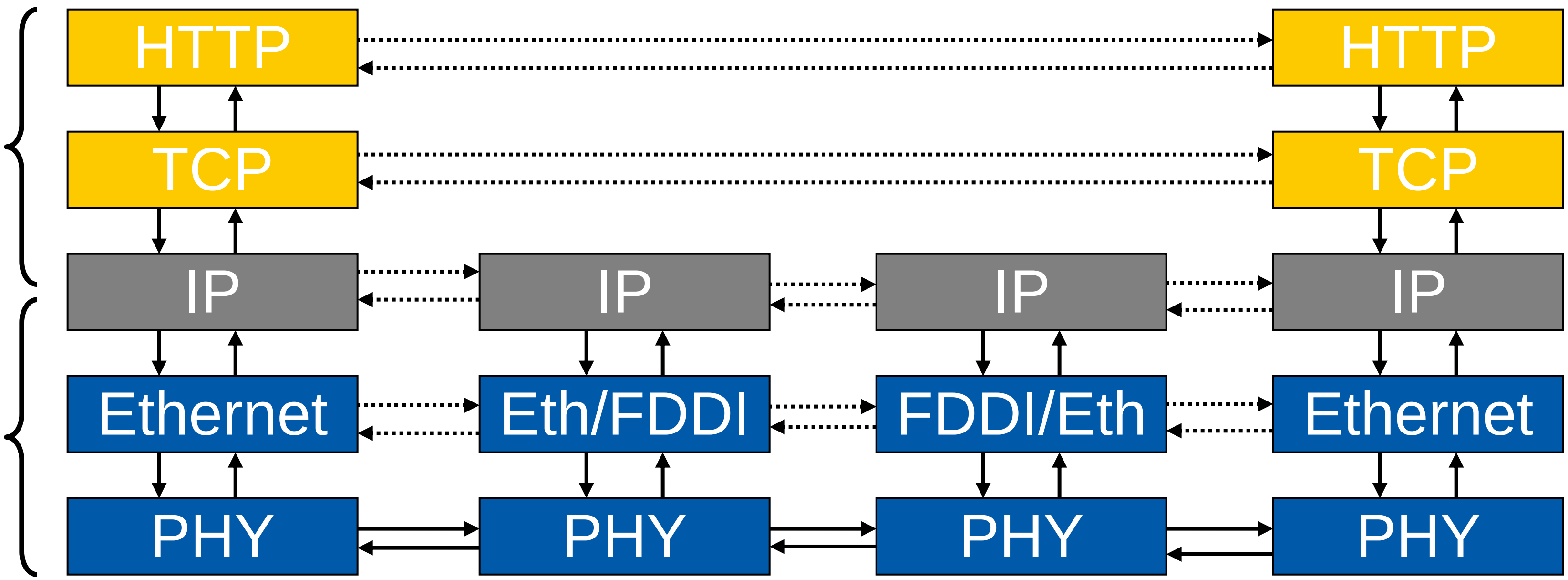
Sidenote: 7-layer model has been extended… :-)

- Layer 8: Financial layer
- Layer 9: Political layer

Layers in Action

Actual communication

(N)-protocol



Request goes down on layers at browser

Physical layer handles actual sending of message to next (neighbor) node

Network protocol (IP) takes care of routing message to destination

- Possibly several hops from one router to another
- At each router, message goes up to IP-layer for processing

Transport and application layers converse end-to-end

Functionality Recap

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Layer 5,6,7

- Create HTTP request
- Invoke layer 4 (= TCP)
- Process reply (= web page)

Layer 4

- Open reliable connection to web server
- Make sure data arrives in the order it was sent
- Do not saturate network
  - Congestion control

Layer 3

- Route message from client to web server
- Message passed from router to router
- Layer 3 provides end-to-end service through hop-by-hop actions

Layer 2

- Put data from layer 3 in frames
- Send frames to immediate neighbor

Layer 1

- Actual transmission of a frame as a bitstream

Each layer performs some critical function

Layering not always “clean”

- Who handles congestion control or reliability?

History

Basic terminology and concepts

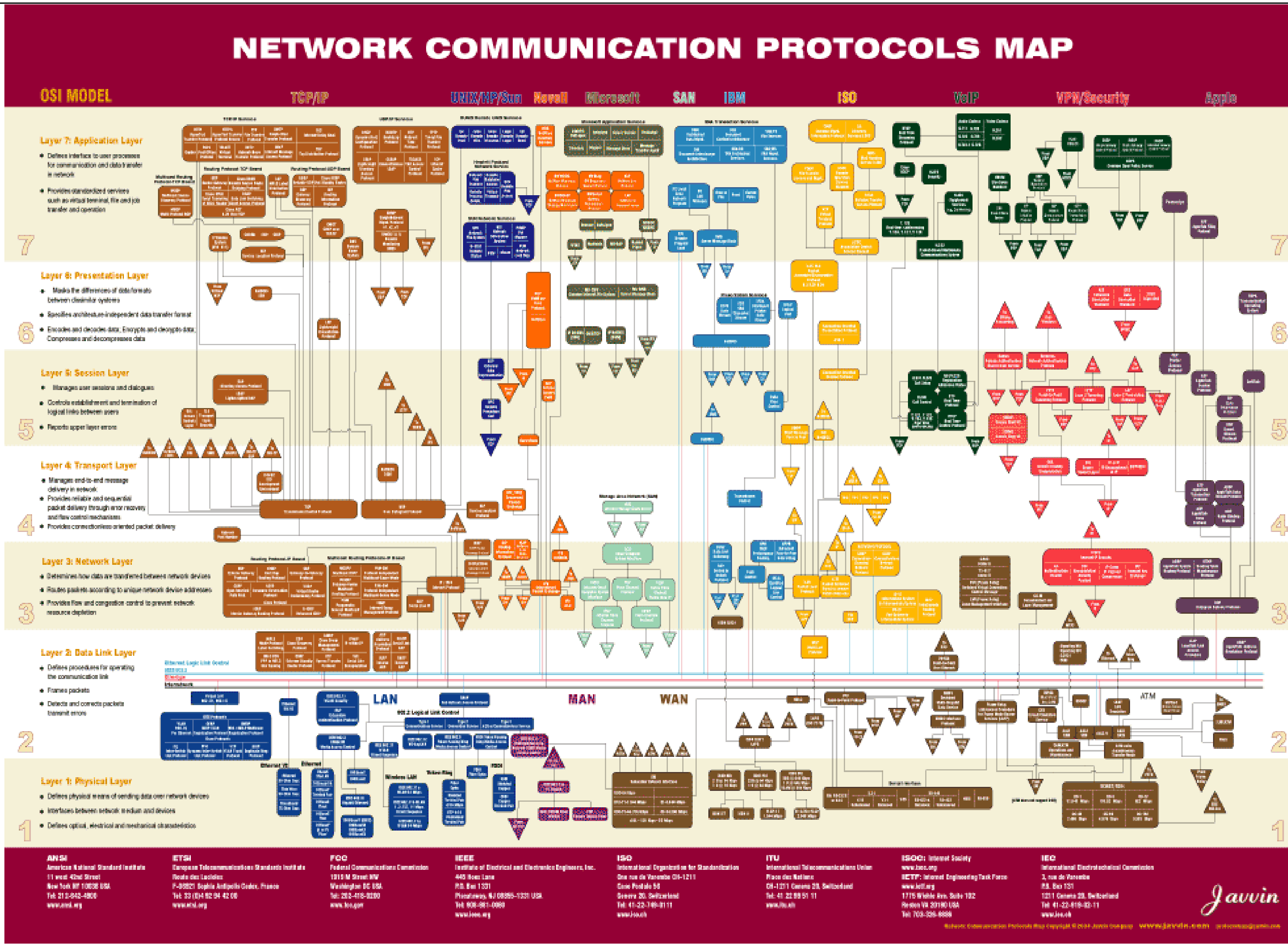
- Protocol
- Service
- Layer

OSI and Internet layer models

Connection-oriented and connectionless networks

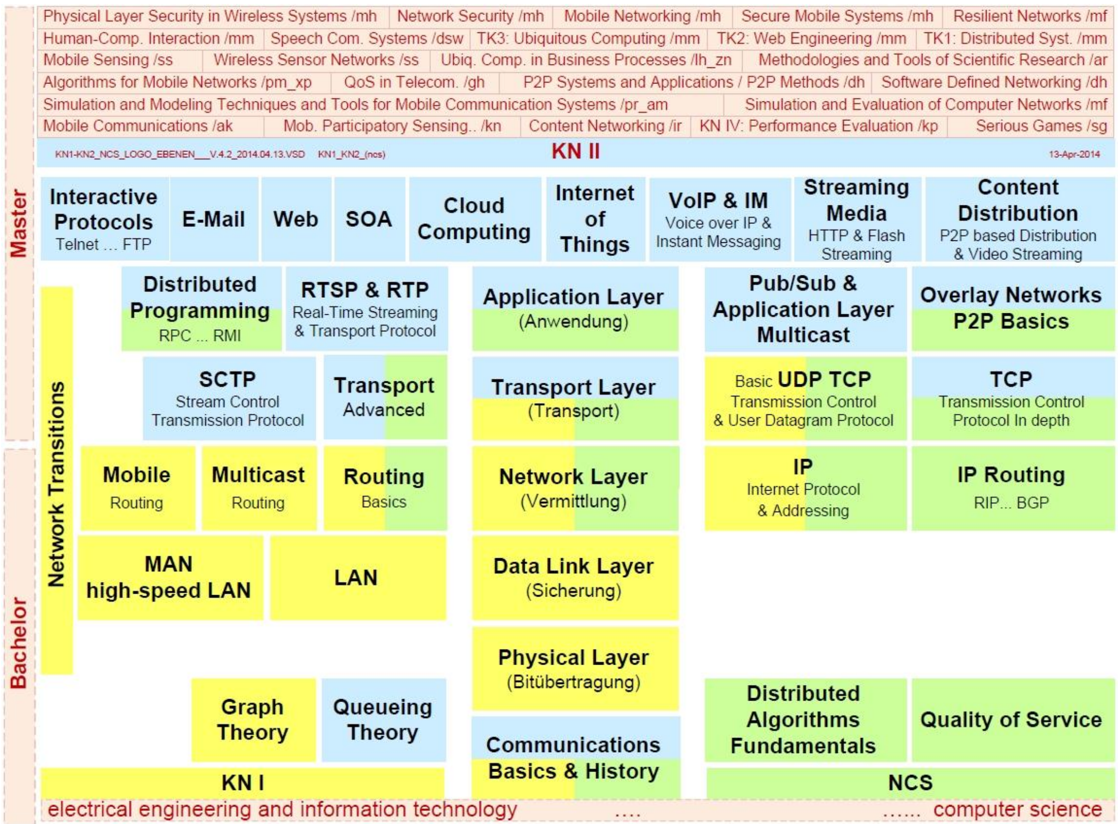
Example of layers in practice

Networking Protocol Map … (Source www.javvin.com)



Communication Networks I

History and Basics



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KOM - Multimedia Communications Lab