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- Introduction
- Application of the Computer Networks
- Network Architecture - hardware and software
- Network Types
Introduction - Terminology

Computer Network:
interconnected autonomous computers
explicit addressing and naming
explicit allocation / reallocation
explicit remote management

Distributed System:
interconnected autonomous computers
transparent addressing
transparent allocation and reallocation
transparent execution
Application of the Computer Networks

- Enterprise Networks (Intranets)
- Public Networks
- Personal Use
- Social Aspects
Enterprise Networks
(“Intranets”)

- **Resource Sharing** - many computers in different places
- **High Reliability** - duplication of data, hardware resources, fault-tolerance
- **Low Cost/Performance Ratio** - cheaper workstations than mainframes; application of the *client-server model*
- **Scalability and Flexibility** - system grows with the enterprise
Public Networks

- 2 preconditions: cheap and compact home computers and communication technologies
- Electronic commercial and banking, entertainment, public and social services, mass media etc.
- Person-to-person communication
- Instances: WWW, E-mail, electronic newspapers, on-line TV/Radio, newsgroups, videoconferencing etc.
Moving all the services at home - shopping, banking, health, TV/radio/cinema/newspapers etc.


Personal contacts and communication.
Social Issues

- Formal (Legislative) Regulation of service providing (incl. taxes, QoS/protection of customer rights, registration of sites/addressing etc.)
- Electronic Payments and Security Issues
- Advertisement (incl. Internet, “spaming”/“bombing”)
- Information Correctness
- Public control (illegal sex, trade, crimes)

*Clinton’s Communication Decency Act - 1996*
Network Hardware

- Main Taxonomy Dimensions:
  - transmission technology
  - network range (scale, size)

- Transmission Technology
  - broadcast networks
  - point-to-point
Broadcast Networks

- Single communication channel shared by all the machines in the network
- Short messages (packets) with addressing field
- Target machine interprets current message; the rest ignore it
- Special bits in the address field indicate the transmission mode: *broadcast* (to all the machines); *multicast* (to group of machines)
Point-to-point Networks

- Many connections between pairs of machines
- Packets visit 0, 1, 2 … intermediate machines reaching the target one
- Alternative routes - routing algorithms
- Basically for large networks
Network Range

- Physical Size
  - fine grain parallel computers; many functional units perform any instruction
  - message passing systems; short and fast communication busses

- Data Flow Machines & Multicomputers are *Distributed Systems* but not *Computer Networks*

- Local Area Networks (LANs)

- Metropolitan Area Networks

- Wide Area Networks (WANs)

- Internetworks (connection of more than one network - The Internet)
Local Area Networks (LANs)

- Up to 1-2 km physical range (room, building, campus)
- Private owned (companies, branches, laboratories, small institutions)
- Connect PCs, workstations, disk stores, printers and other peripherals
- Main characteristics:
  - Size
  - Transmission technology
  - Topology
Size of the LANs

- Small, technologically restricted size
- Bounded and known transmission time
- Simple network management due to the limited transmission time
Transmission Technology of the LANs

- Usually based on a single cable attaching all the components of the network
- Communication speed 10 - 100 Mb/S
- Communication delay 10 - 100 µS (1 µs = 1^{-6} S)
Topology of the LANs

- Topology is the graph of the connectivity of the network components
- Typical topology of LANs is bus or ring
- Bus topology is based on linear cable
- Arbitration management - time-sharing control: 1 master machine at any instant is allowed to transmit; conflict requests resolution
- Centralized or Distributed arbitration
- Ethernet™ (IEEE 802.3) standard: bus-based, distributed arbitration based on collision detection and random delay for next attempt
Topology of the LANs - ring topology

- Network ring forms necklace of the workstations
- Bit-slice propagation of the packets
- IBM Token Ring (IEEE 802.5) standard operates at 4-16 Mb/S
Local area networks

- **Local area networks** (LANs) are physically relatively small. They are usually spanning one km or less.
- Usually, every device on the LAN essentially shares the same transmission cable. This is called **shared media access**.
- **Ethernet** LAN technology (IEEE 802.3) has today the largest installed base. It has several types of cabling - Thick coaxial (10-base-5) with AUI connectors and transceivers, thin coaxial (10-base-2) with BNC connectors, and unshielded twisted pair (UTP or 10-base-T) with RJ-45 jacks.
- Each station on an Ethernet has an Ethernet **network interface card** (NIC), which has a special hardware address, assigned to guarantee link layer uniqueness, even across vendors.
- Ethernet is mostly used with speeds 10 Mbps and 100 Mbps.
Local area networks

- Ethernet **media access control** allows any station on the network try to transmit at any time, which may produce collisions when several stations transmit at one time.
- Media access mechanism identifies collisions and allows each station to have adequate access to common channel.
- In Ethernet this mechanism is called **carrier sense multiple access with collision detection (CSMA/CD)**.
- Another quite a popular LAN technology is the **Token Ring** specified in IEEE 802.5 with basic speed of 4 Mbps.
- The media access in Token Ring is based on **token passing** mechanism.
- Other IEEE 802.x standards are 802.4 **Token Bus** (5 and 10 Mbps) used in **Manufacturing Automation Protocol (MAP)** systems, and 802.6 **Metropolitan Area Network (MAN)**, which is also called **DQDP (Distributed Queue Dual Bus)** and has speed 100 Mbps.
Metropolitan Area Networks

- Bigger version of LANs using similar technology - common broadcast media that connects all the computers
- Options: voice and image communications (incl. cable TV)
- No switching elements; 1 - 2 cables
- DQDB (Distributed Queue Dual Bus - IEEE 802.6) Standard: 2 unidirectional buses with 2 head-ends (for each bus) to initiate the transmission activity in each direction.
Wide Area Networks (WANs)

- WAN covers large geographic area (country, continent)
- Connects different types of machines - "hosts" via communication subnet
- Separation of the services: hosts run application programs and subnet performs the connection tasks
- Subnet consists of transmission lines and switching elements ("routers": specialized in connecting 2 or more switching lines)
Router is specialized switching element in the WAN subnet.

Switching is the process of:
1) receiving data on the incoming channel[s];
2) interpreting it;
3) choosing an outgoing line and
4) forwarding the data on it.

Typical structure of WAN: hosts connected by LANs; LANs connected by the subnet.
WANs & Subnets

- Subnet consists of routers and connection lines
- The subnet lines are based on cables (telephone lines) that connects pairs of routers (point-to-point network) in a connected graph. Exception: wireless/satellite based subnets are of broadcast type (for WANs specialized in broadcasting communication)
- Non connected routers communicate via intermediate routers in store-and-forward mode
- Subnet topology - usually irregular
Wide area networks

- **Wide area network (WAN)** is a concept that is used in context of geographically large networks (1 - 50 km span).
- Generally, WANs consist of site specific LANs and teleoperator backbones which are used to interconnect the LANs.
- This trunk capacity is provided to WANs as:
  - Basic analogue telephone connection with modems
  - Digital ISDN connection with terminal adapters (TA)
  - Connection with direct router support or using Frame Relay (FR)
  - SDH based connection with ATM.
Basic telephone networks support switched 64 kbps connections with either analogue modem or digital ISDN subscriber lines.

- ISDN Basic Rate Interface (BRI) consists of two bearer (B) channels and a 16 Kbps signaling (D) channel (called as 2 B + D).
- ISDN Primary Rate Interface (PRI) is a high-bandwidth version of the BRI, also called as 30 B + D.

Serial Line Internet Protocol (SLIP) and Point-to-Point Protocol (PPP) are used with the basic analogue and digital telephone interfaces as the transport layer for an Internet link.

SLIP/PPP connections are temporary links over standard serial phone links between end user and terminal server.
Preconditions: mobile computers + digital wireless communications

Application: portable office, transportation business, emergency services, police/military, etc.

Features:

- easy installation, portability
- low capacity (1-2 Mb/S), low security, high error rate + radio pollution

Wired-Wireless Networking Convergence

Tendencies
Internetworks

- Internetwork = Communication between LANs, MANs and WANs with different internal standards
- Compatibility requires gateways
- Typical architecture: collection of LANs connected by a WAN: (WAN differs from the subnet just by presence of hosts besides the routers)
- The Internet = biggest internetwork connecting universities, public and private offices, persons etc.
Communication system:

- parallel:
  - DMA to remote shared memory
  - standard common bus
...
- serial:
  - modem connection
  - standard LAN
...
<table>
<thead>
<tr>
<th>Interprocessor distance</th>
<th>Processors located in same</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 m</td>
<td>Circuit board</td>
<td>Data flow machine</td>
</tr>
<tr>
<td>1 m</td>
<td>System</td>
<td>Multicomputer</td>
</tr>
<tr>
<td>10 m</td>
<td>Room</td>
<td>Local area network</td>
</tr>
<tr>
<td>100 m</td>
<td>Building</td>
<td>Metropolitan area network</td>
</tr>
<tr>
<td>1 km</td>
<td>Campus</td>
<td>Wide area network</td>
</tr>
<tr>
<td>10 km</td>
<td>City</td>
<td>The Internet</td>
</tr>
<tr>
<td>100 km</td>
<td>Country</td>
<td></td>
</tr>
<tr>
<td>1,000 km</td>
<td>Continent</td>
<td></td>
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<tr>
<td>10,000 km</td>
<td>Planet</td>
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<tr>
<td>Wireless</td>
<td>Mobile</td>
<td>Applications</td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>Stationary workstations in offices</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>Using a portable in a hotel; train maintenance</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>LANs in older, unwired buildings</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Portable office; PDA for store inventory</td>
</tr>
</tbody>
</table>
Network Software: Characteristics

- Based on structural programming approach
- Network Layers: hierarchy of SW modules providing communication services to the next upper layer
- Transparency of the layered structure: independence of layer $n$ of the implementation of the lower layers
Network Software: Structure

Layered structure:

✓ Protocol - rules and convention of data exchange between layer $n$ of host1 and layer $n$ of host2

✓ Peers - entities that locally implement the functionality of a given layer

✓ Interface - the set of primitive operations and services that lower layer provide to the upper one

✓ Physical media - the signal carrier that is used by the 1st layer for transmission
Network Software

Considerations:

✓ Virtual exchange between the equilevel layers of two hosts according the protocols

✓ Physical exchange between the neighbor layers of one host according to the interface

✓ Portability of the layers: based on clear simple interfaces and well defined set of functions of each layer
Network Architecture

- Network architecture - the set of layers and protocols; ignores the interfaces as the interfaces of the hosts in a network may differ
- Protocol stack - the list of protocol hierarchy in the network; matches the layered structure
- Analogies to the network protocol stack
Example network architecture:

- 5-layer protocol stack
- Layer 5: Application process generates message M and deposit it to Layer 4
- Layer 4: Extends M with the header $H_4$ containing control information (ordering, size, time, etc.) and deposits $H_4M$ to Layer 3
- Layer 3: Brakes $H_4M$ into smaller fixed size packets (e.g. $H_4M_1$ and $M_2$); extends them with its header $H_3$; selects an outgoing line for transmission and passes the packets to Layer 2
- Layer 2: Adds its header and trailer to each packet and deposit them to Layer 1 for physical transmission
Network Architecture

Receiving of the message M at the destination machine consists in:

- moving of its packets upward the layers,
- stripping of control header and trailers,
- merging the packets in a message and
- interpreting the message by the application

- Lower layers have hardware implementation
- Medium layer[s] have firmware implementation
- High layers have software implementation
Layer’s design issues:

- identification mechanism for senders/receivers - process ID, machine ID, net ID, etc.;
- data transfer mode - simplex, half-duplex and full-duplex
- support of multiple logical channels with priority scale
- Application of error-detecting and error-correcting codes and mechanisms for feedback
- ordering protocols for the packets in messages
- buffering between fast and slow processes
Connection-Oriented and Connectionless Services

- **Connection-oriented service**: establishes the connection from point to point; carries the exchange, preserving the order of the bitstream and releases the connection. Analogy to telephone system.

- **Connectionless service**: each message is provided with full destination address and it is routed through the system independently to rest of message stream.

- **QoS (quality of service)** - reliability to losing data
Quality of Services (QoS)

- Implementation of reliability: based on acknowledgment by the receiver - acknowledge receipt for each message
- Acknowledge receipts produce
  - communication overhead and
  - delays
- Application: file transfer
Unreliable Connection-Oriented Service

- Application for systems where delays are unacceptable, e.g. real-time systems for
  - voice communication
  - on-line image transmission
Unreliable Connectionless Service

- Application - all functions where:
  - real-time, interactive or on-line features are not essential but
  - the cost of communications has to be minimized and also
  - reliability is not of crucial importance
- Example: standard e-mail services
- Implementation: datagrams - not acknowledged connectionless service
Reliable Connectionless Service

- Application: non-interactive short messages exchange with guaranteed reliability
- Example: banking, military, remote queries in data bases
- Implementation: acknowledged datagrams
- Variation: Request-Replay services for one-cycle interaction. Mostly in remote database access and another client-server applications
Service Primitives

Set of operations - *primitives* - forms the access language to a service. Primitives:

- request some elementary service action;
- inform the service process for some event in the peer entity
Confirmed and Unconfirmed Services

- **Confirmed Services**: the exchange of primitives between the peer entities follows the pattern:
  - request
  - indication
  - response
  - confirm

- **Application**: basically for connection oriented services

- **Unconfirmed Services**: the exchange of primitives between the peer entities follows the pattern:
  - request
  - indication

- **Application**: basically for connectionless services
<table>
<thead>
<tr>
<th>Service</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliable message stream</td>
<td>Sequence of pages</td>
</tr>
<tr>
<td>Reliable byte stream</td>
<td>Remote login</td>
</tr>
<tr>
<td>Unreliable connection</td>
<td>Digitized voice</td>
</tr>
<tr>
<td>Unreliable datagram</td>
<td>Electronic junk mail</td>
</tr>
<tr>
<td>Acknowledged datagram</td>
<td>Registered mail</td>
</tr>
<tr>
<td>Request-reply</td>
<td>Database query</td>
</tr>
</tbody>
</table>
Reference Models - Basics

- Reference models, ISO
- OSI = open systems interconnection

Layers:

- Perform similar functions
- Process similar data
- Respect internationally standardized protocols
- Minimize the information flow though the interfaces
- Their number is the smallest possible to match all different levels of protocol abstraction

Examples: ISO 7 layers; internet 5 layers
The OSI model:

- 7 layers
- Points out the set of functions of each layer
- Establishes international standard for all of the layers but not protocols
Protocol stacks

- **OSI protocol stack**

  OSI-protocols are specified in seven layers. The lower layers are more hardware and transmission oriented. The upper layers are oriented to presentation and synchronization purposes. The middle layers handle network quality, addressing and routing.

- **Layers with example OSI protocols are:**

<table>
<thead>
<tr>
<th>Layer</th>
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</thead>
<tbody>
<tr>
<td>7</td>
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<tr>
<td>6</td>
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<tr>
<td>5</td>
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<tr>
<td>4</td>
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<tr>
<td>3</td>
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<tr>
<td>2</td>
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<tr>
<td>1</td>
</tr>
</tbody>
</table>

  - Application: FTAM, ACSE, ROSE
  - Presentation: OSI Presentation
  - Session: OSI Session BSS, BSC, BAS
  - Transport: OSI Transport Class 0,...,4
  - Network: OSI Network, X.25
  - Data link: HDLC
  - Physical: Voltages as X.24
# Communication Functions according to the OSI Model

<table>
<thead>
<tr>
<th>Layer</th>
<th>User applications</th>
<th>..</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application layer</td>
<td>Encryption/decryption</td>
<td></td>
</tr>
<tr>
<td></td>
<td>compression/expansion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Choice of syntax</td>
<td></td>
</tr>
<tr>
<td>Presentation layer</td>
<td>Session control</td>
<td></td>
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<tr>
<td></td>
<td>Session synch.</td>
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<tr>
<td></td>
<td>Session to transport mapping</td>
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<tr>
<td></td>
<td>Session management</td>
<td></td>
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<tr>
<td>Session layer</td>
<td>Layer and flow control</td>
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<tr>
<td></td>
<td>Error recovery</td>
<td></td>
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<tr>
<td></td>
<td>Multiplexing</td>
<td></td>
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<tr>
<td>Transport layer</td>
<td>Connection control</td>
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<tr>
<td></td>
<td>Routing</td>
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<tr>
<td></td>
<td>Addressing</td>
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<tr>
<td>Network layer</td>
<td>Data link establishment</td>
<td></td>
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<tr>
<td></td>
<td>Error control</td>
<td></td>
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<tr>
<td></td>
<td>Flow control</td>
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<tr>
<td></td>
<td>Synch</td>
<td></td>
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<tr>
<td></td>
<td>Framing</td>
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<tr>
<td>Link layer</td>
<td>Access to transm. media</td>
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</tr>
<tr>
<td></td>
<td>Physical and electrical interface</td>
<td></td>
</tr>
<tr>
<td>Physical layer</td>
<td>Activation/deactivation of con.</td>
<td></td>
</tr>
</tbody>
</table>
The OSI Model - The Physical Layer

- Bit-slice transmission via some communication channel e.g.
  - Method of bit coding 0/1
  - Physical parameters: voltage/amperage etc.
  - Timing: frequency/period, shape of signal front, etc.
  - Direction[s] of transmission
  - Establishment and canceling of the connection
  - Physical/mechanical interfaces to the connection medium (e.g. RS234 connector)
The OSI Model - The Data Link Layer

Maintains the **error-free** transmission line for **data frames** serving the requests of the upper Network Layer. This includes:

- braking the upper level data into or packing the lower level bit stream into **frames**
- keeping the data **sequence** by exchange of acknowledgement frames
- create or recognize frame boundaries by bit patterns for beginning/end frame boundaries
The OSI Model - The Data Link Layer

- retransmission of corrupted or erroneous frames
- manages problems of duplicate, corrupted or lost frames depending on the service (price/speed) level applied by the upper layers
- low level buffering between upper layers peers of different capacity
- support of bi-directional communication: incoming data frames share the line with outgoing acknowledgement frames
- for broadcast networks: medium access sublayer for shared channel control
The OSI Model - The Network Layer

- **Subnet** control layer i.e. **routing** of the Data Link Layer packets from source to destination. Routing might be:
  - **Static** - based on static tables
  - **Dynamic** - new route for each session
  - **Turbo** - new revision of the route for each packet

- Routing trends to solve problems with temporarily bottlenecks

- Network layer also does the following:
The OSI Model - The Network Layer

- Counts (on demand of the upper layers) the number of packets/B/b produced by customer/network etc.
- Interprets addresses from another conventions
- Adjusts the packet size according to the size of peer network
The OSI Model - The Transport Layer

Exchange ("transport") of data "point-to-point" providing the upper (session) layer with error-free data messages. It cares for:

- effective communication - for high throughput it might open >1 network connections - "multiplexing"
- fault tolerance
- opening/closing the connections with named parties in the network + support of naming mechanism needed - "flow control"
- different types of services: point-to-point channel; isolated messages; broadcasting.
The OSI Model - The Session Layer

Establishes sessions between network machines. The sessions are extensions over the transport layer communication, that support:

- remote login
- file transfer
- interactive exchange (dialogue):
  - bi-directional simultaneous
  - bi-directional alternative
  - uni-directional
- dialogue synchronization - by session brakes
The OSI Model - The Presentation Layer

- Interprets the exchanged data as information considering its syntax and semantics. This includes:
  - security coding/decoding
  - presenting data as **text strings**, **formatted numbers** (integers, fixed, floating, double, etc.) according different formatting codes in both directions:
    - local computer standard
    - network standard
The OSI Model - The Application Layer

- Set of protocols providing network-wide compatibility of the user programs including:
  - full-screen terminal compatibility
  - file- and directory- structure compatibility
  - remote procedure calls/remote evaluation
  - electronic mail
  - ...............

- Solution: network virtual standard to which to translate local structures/objects
The OSI Model - example Data Transmission

- Sender transmits Data to Receiver
- The protocols implementing each OSI layer add special header to the Data (header might be null)
- The lower level deals with extended Data (Data+Header) as a whole
Reference Models - the TCP/IP Model

- Developed for ARPANET (70ties US national military network) and inherited in the Internet

- Features:
  - flexible routing - tolerant to loss of network nodes, subnets, route[r]s, connections, etc.
  - flexible architecture - tolerant to different throughput and application services (off-line, on-line, real-time)

- 4-layer structure
**Protocol stacks**

**TCP/IP stack**

- Internet networks are based on TCP/IP protocols, so the TCP/IP model and protocol stack have a growing importance.
- TCP/IP is based on **five** protocol layers instead of seven. The OSI model session and presentation layers can be considered empty in TCP/IP context.
- TCP/IP stack with example protocols is shown below:

<table>
<thead>
<tr>
<th>Layer</th>
<th>Protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Application</td>
</tr>
<tr>
<td>4</td>
<td>Transport</td>
</tr>
<tr>
<td>3</td>
<td>Network</td>
</tr>
<tr>
<td>2</td>
<td>Data link</td>
</tr>
<tr>
<td>1</td>
<td>Physical</td>
</tr>
<tr>
<td></td>
<td>Telnet, FTP, SMTP, SNMP, HTTP</td>
</tr>
<tr>
<td></td>
<td>TCP, UDP</td>
</tr>
<tr>
<td></td>
<td>IP</td>
</tr>
<tr>
<td></td>
<td>HDLC or LAN frames</td>
</tr>
<tr>
<td></td>
<td>Voltage levels</td>
</tr>
</tbody>
</table>
TCP/IP Layered communication

Client

- Telnet request
- TCP segment
- IP datagram
- Ethernet frame
- Voltage

Router

- IP datagram
- Ethernet frame
- Voltage

Server

- Telnet request
- TCP segment
- IP datagram
- Ethernet frame
- Voltage
The TCP/IP Model - The “Host/Network Layer”

- Corresponds to OSI Physical+Data Link Layers
- Unspecified strictly as protocol
- Implementations vary in different networks and even hosts
- Only restriction: serving upper (internet) layer in transmission of data packets
The TCP/IP Model - The Internet Layer

- Connectionless layer (in order to provide the flexibility needed)
- Implementation: IP
- free independent exchange of packets (IP datagrams) transparently to the sender and receiver
  - routing is a key issue in IP
- standard packet format (strictly supported) for proper routing
- corresponds to OSI Network Layer
The TCP/IP Model - The Transport Layer

- Supports “point-to-point” connectivity between the source and destination (like OSI transport layer)
- Implemented by two protocols:
  - **TCP** (Transmission Control Protocol) - connection oriented, delivers the byte stream from source to destination by fragmentation into discrete messages for transmission by IP. Receiving TCP assembles the incoming messages to output stream
  - **UDP** (User Datagram Protocol) - connectionless, unreliable, non-sequential, for prompt delivery (multimedia applications)
The TCP/IP Model - The Application Layer

- Top level protocols (session and presentation layer functions are performed by the application when needed) like:
  - TELNET
  - FTP
  - SMTP
  - DNS
  - HTTP
Reference Models - OSI vs. TCP/IP

Similarities:
- **structure**: stack of protocols
- **functionality**: routing + point-to-point connectivity + application supporting functions

Dissimilarities (OSI)/(TCP):
- conceptuality/applicability
- hidden, transparent, replaceable protocols / conservative, non-conceptual approach
- mostly connection oriented / pure connectionless oriented
- 7 layers / 4 layers
Example Networks - The ARPANET

- [Defense] Advance Research Project Agency - consists of subnet and hosts
- Subnet is based Interface Message Processors (IMP) connected by communication lines.
  - Software: IMP/IMP- Host/IMP- and Host/Host- protocols
- Development - chiefly US universities: 1969, 70, 72, 73
- Extensions: Terminal Interface Processors (TIP) (Terminal Complexes), LANs, TCP/IP (protocol stack and model -1974), DNS (1981)
Example Networks - The ARPANET

- multiple routes rise fault-tolerance (dated)
- dense communication channels (actual)

Structure: **subnet** and **hosts**

Subnet structure: Interface Message Processors (IMP) connected by communication lines;
Alternative connections for each IMP

Software: IMP/IMP- Host/IMP- and Host/Host-
protocols based on datagram exchange; rerouting algorithms for lost datagrams.
Example Networks - The ARPANET

- Development - chiefly US universities: 1969, 70, 72, 73
- Extensions:
  - Terminal Interface Processors (TIP) (Terminal Complexes) - multiple host per TIP, multiplexed access of one host to several TIPs
  - LANs
  - TCP/IP (protocol stack and model -1974) suitable for mobile networks where a host can be switched to different networks of the subnet; since 1983 the only protocol stack of ARPANET
  - DNS (1981) organization of host domains, naming all the hosts and mapping onto list of IP addresses
- Early 90’s ARPANET melted in arising Internet space
The Internet arises on base of ARPANET after joining of another regional networks - NSFNET, BITNET, EARN, …, thousands of LANs; early 90’s the term “internet” widely accepted as net name “The Internet”

Internet machine is each machine that (1) inter-communicates with others under TCP/IP and (2) has a specific IP address

Classic applications: mail, news, remote login and file transfer

“New wave” applications: from gophers to WWW surfing
Example Networks - Gigabit Implementations

- Next step after 10^2 Mb Internet backbones
- Specific Applications: Teleservices (online transmission of huge data arrays) especially televideoservices, cable TV to net, etc.
- Note: not always faster, but better bandwidth - for mass communications
- Implementations: mainly Ethernet LANs and ATM switches: 3Com® (1000 megabits per second (Mbps) Gigabit Ethernet networking infrastructure around eleven 3Com CoreBuilder 9000 enterprise switches).
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