

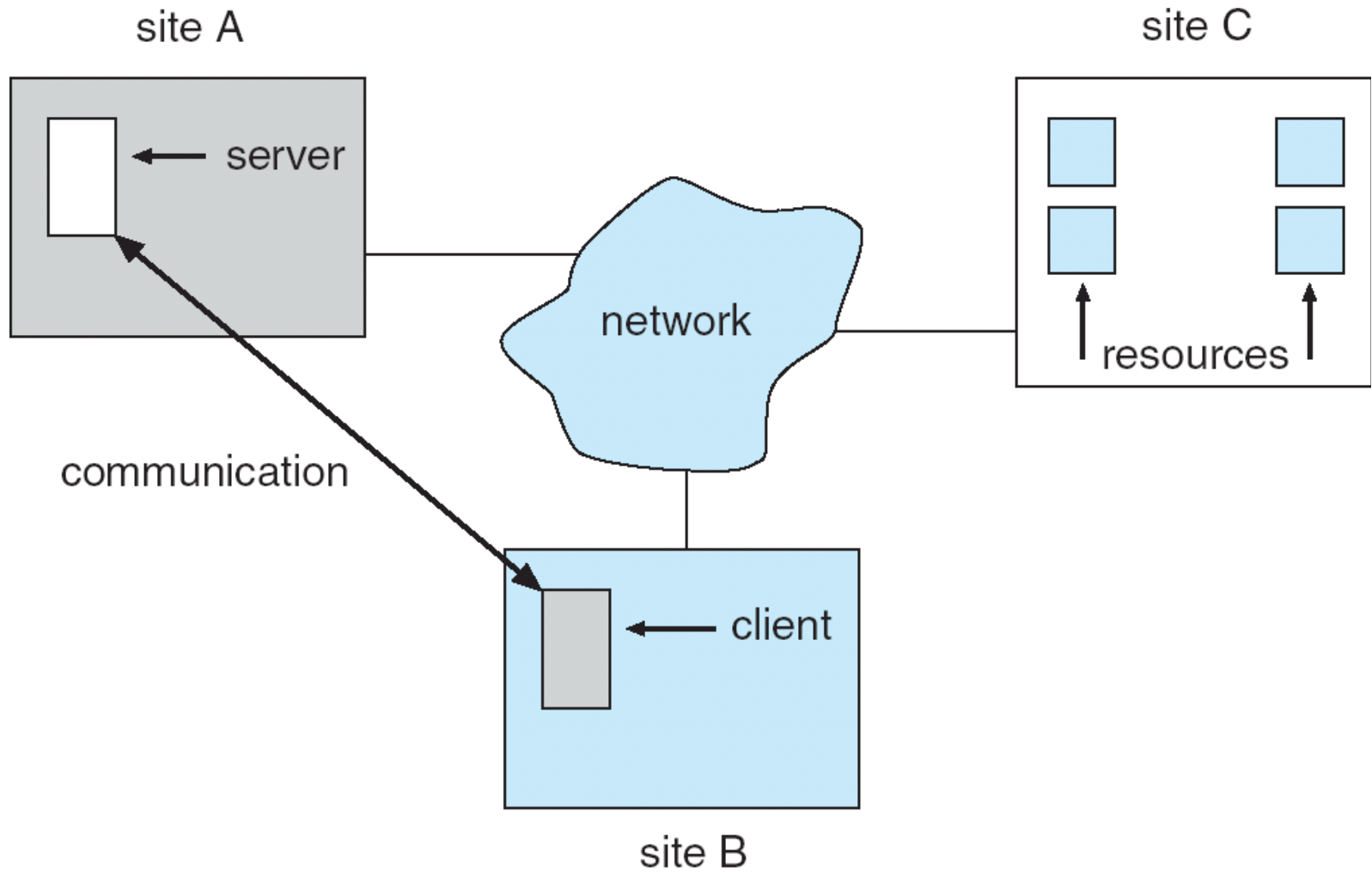
# Lecture 11: Networks & Networking



# Motivation

- **Distributed system** is a collection of loosely coupled processors interconnected by a communications network
- Processors variously called *nodes*, *computers*, *machines*, *hosts*
  - *Site* is the location of the processor
- **Reasons for distributed systems**
  - Resource sharing
    - ▶ sharing and printing files at remote sites
    - ▶ processing information in a distributed database
    - ▶ using remote specialized hardware devices
  - Computation speedup – **load sharing**
  - Reliability – detect and recover from site failure, function transfer, reintegrate failed site
  - Communication by message passing

# A Distributed System

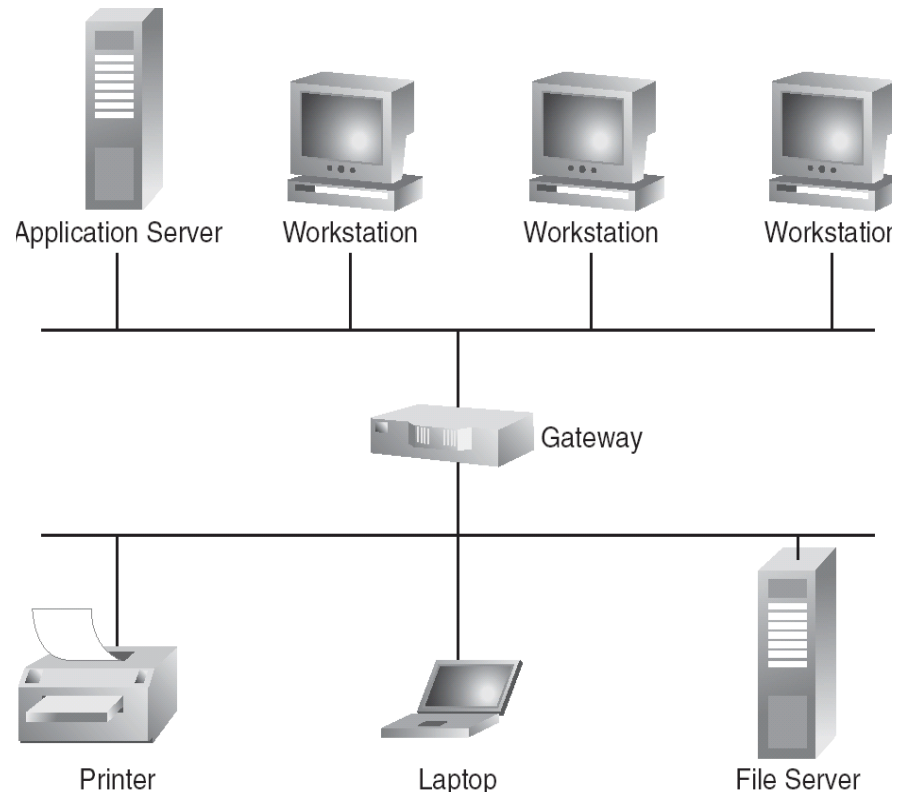


# Network history

- 1950 computers are connected
- 1960 development of packet – packet switching
- 1969 – ARPANET – DARPA (Defense Advance Research Projects Agency) project of MIT, Univ of California, Stanford Research Institute
- 1974 – first specification of TCP/IP
- 1981 – CESNET – Computer Science Network
- 1982 – TCP/IP standard
- 1982 – SMTP – Simple Mail Transfer Protocol
- 1983 – DNS – Domain Name Server
- 1991 – www and first web server
- 1995 – sugestion of IPv6

# Network Structure - LAN

- Local-Area Network (LAN) – designed to cover small geographical area.
  - Multiaccess bus, ring, or star network
  - Speed  $\approx$  100 megabits/second, or higher
  - Broadcast is fast and cheap
  - Nodes:
    - ▶ usually workstations and/or personal computers
    - ▶ a few (usually one or two) mainframes



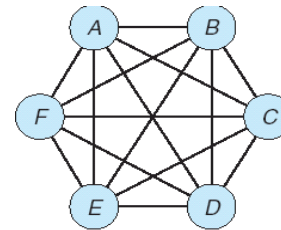
# Network Topology

- Sites in the system can be physically connected in a variety of ways; they are compared with respect to the following criteria:

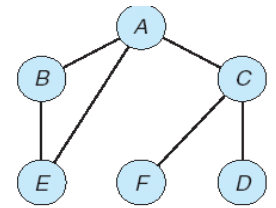
- **Basic cost** – How expensive is it to link various sites in the system?
- **Communication cost** – How long does it take to send a message from site *A* to site *B*?
- **Reliability** – If a link or a site in the system fails, can the remaining sites still communicate with each other?

- The various topologies are depicted as graphs whose nodes correspond to sites

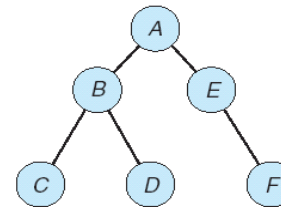
- An edge from node *A* to node *B* corresponds to a direct connection between the two sites



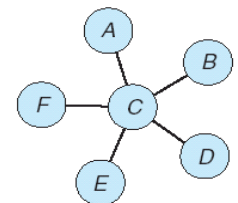
fully connected network



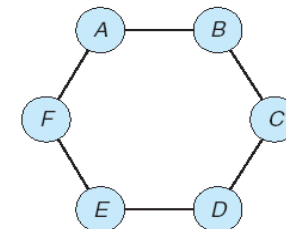
partially connected network



tree-structured network



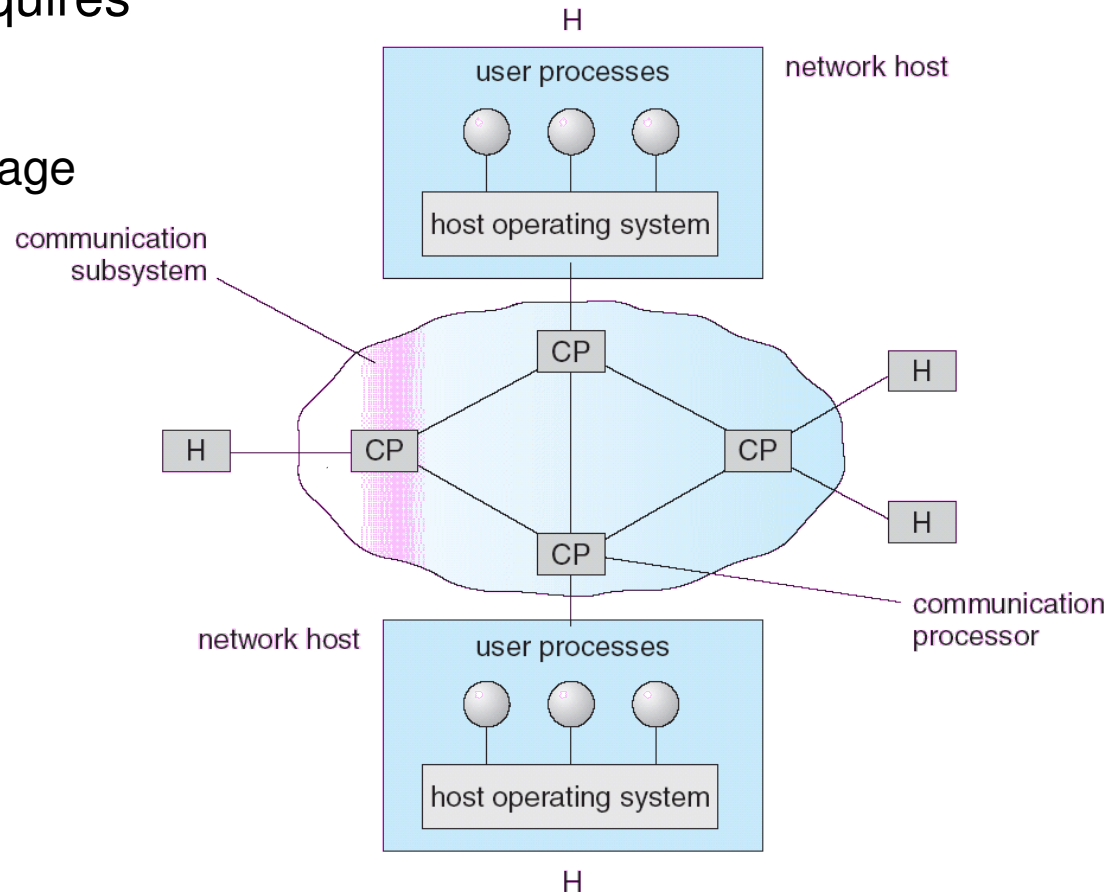
star network



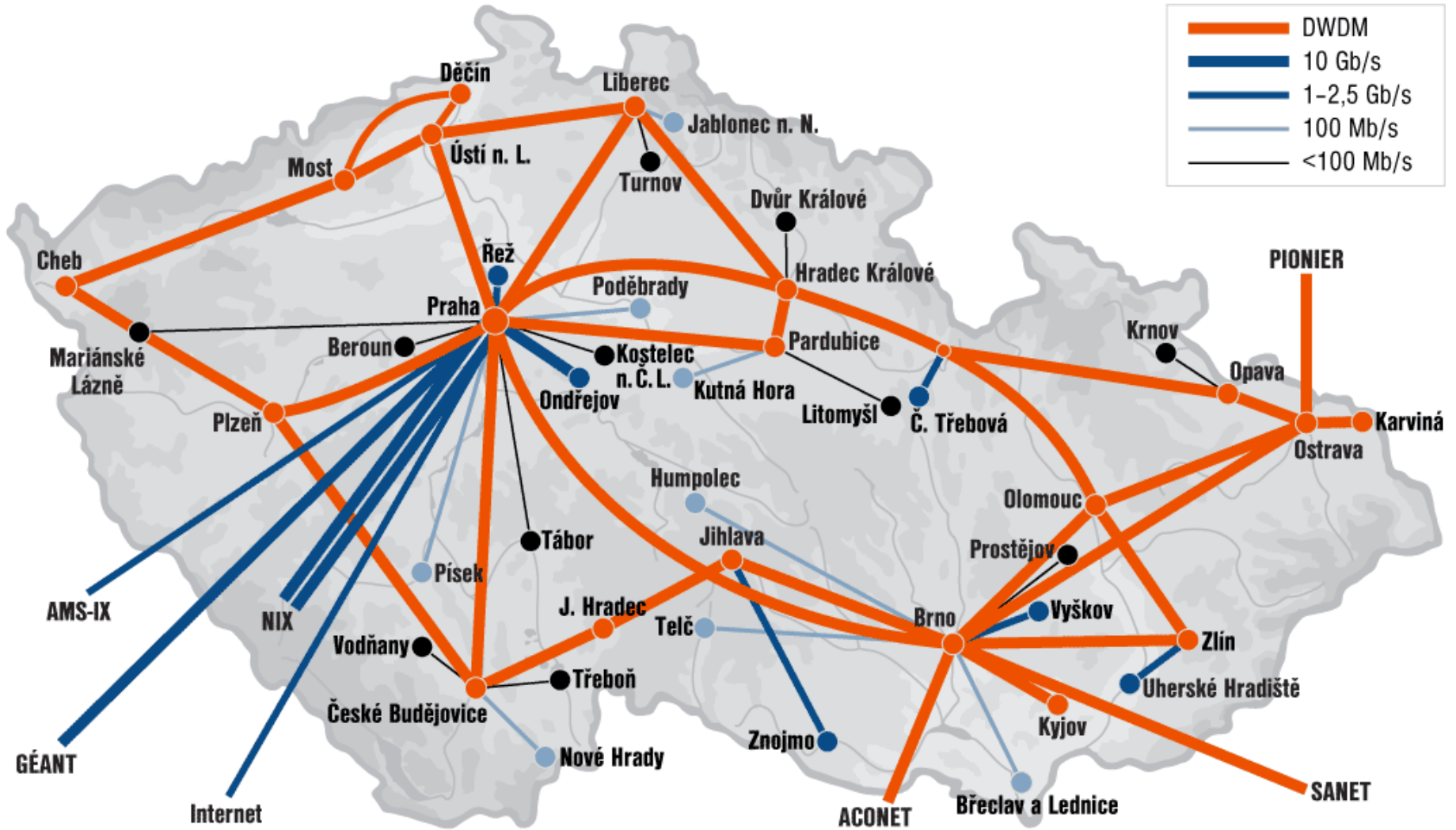
ring network

# Network Structure - WAN

- Wide-Area Network (WAN) – links geographically separated sites
  - Point-to-point connections over long-haul lines (often leased from a phone company)
  - Broadcast usually requires multiple messages
  - Nodes:
    - ▶ often a high percentage of mainframes

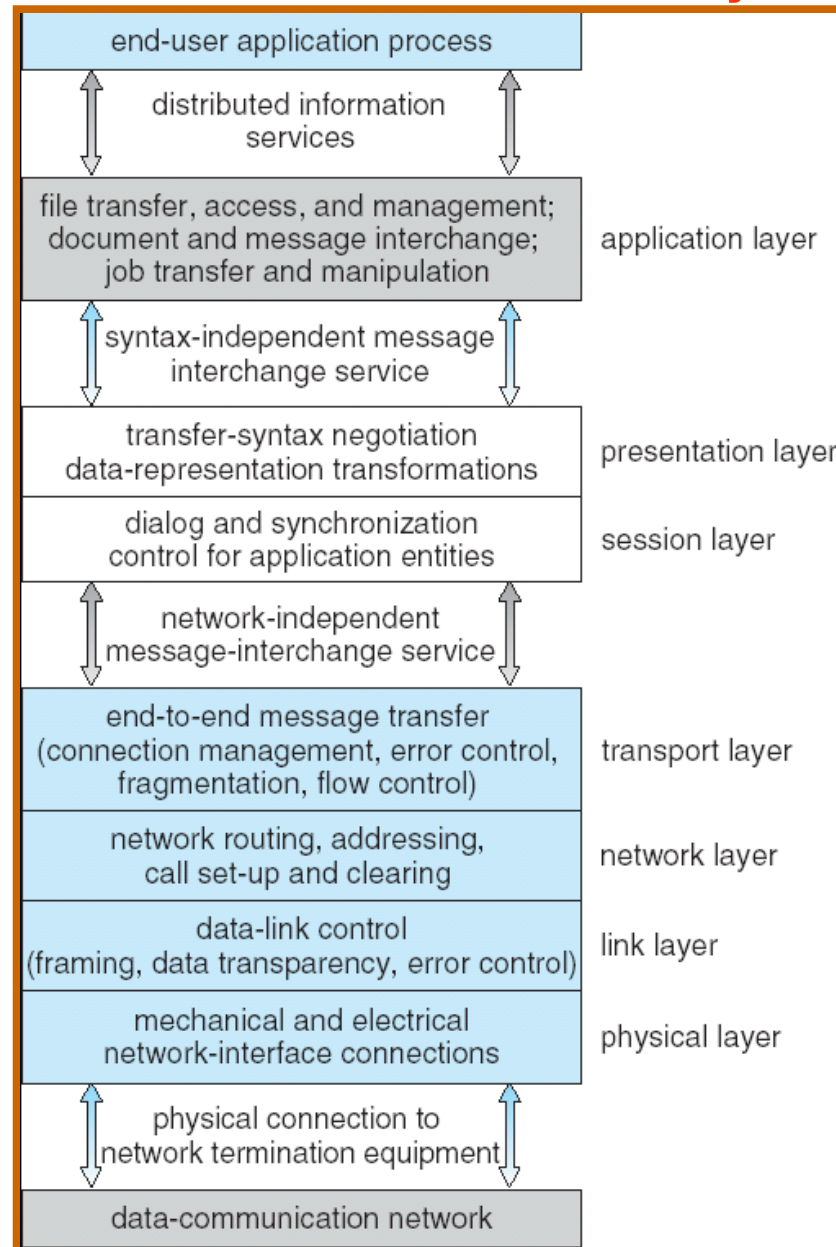


# CESNET structure





# The ISO/OSI Protocol Layers



# Open Systems Interconnection (OSI)

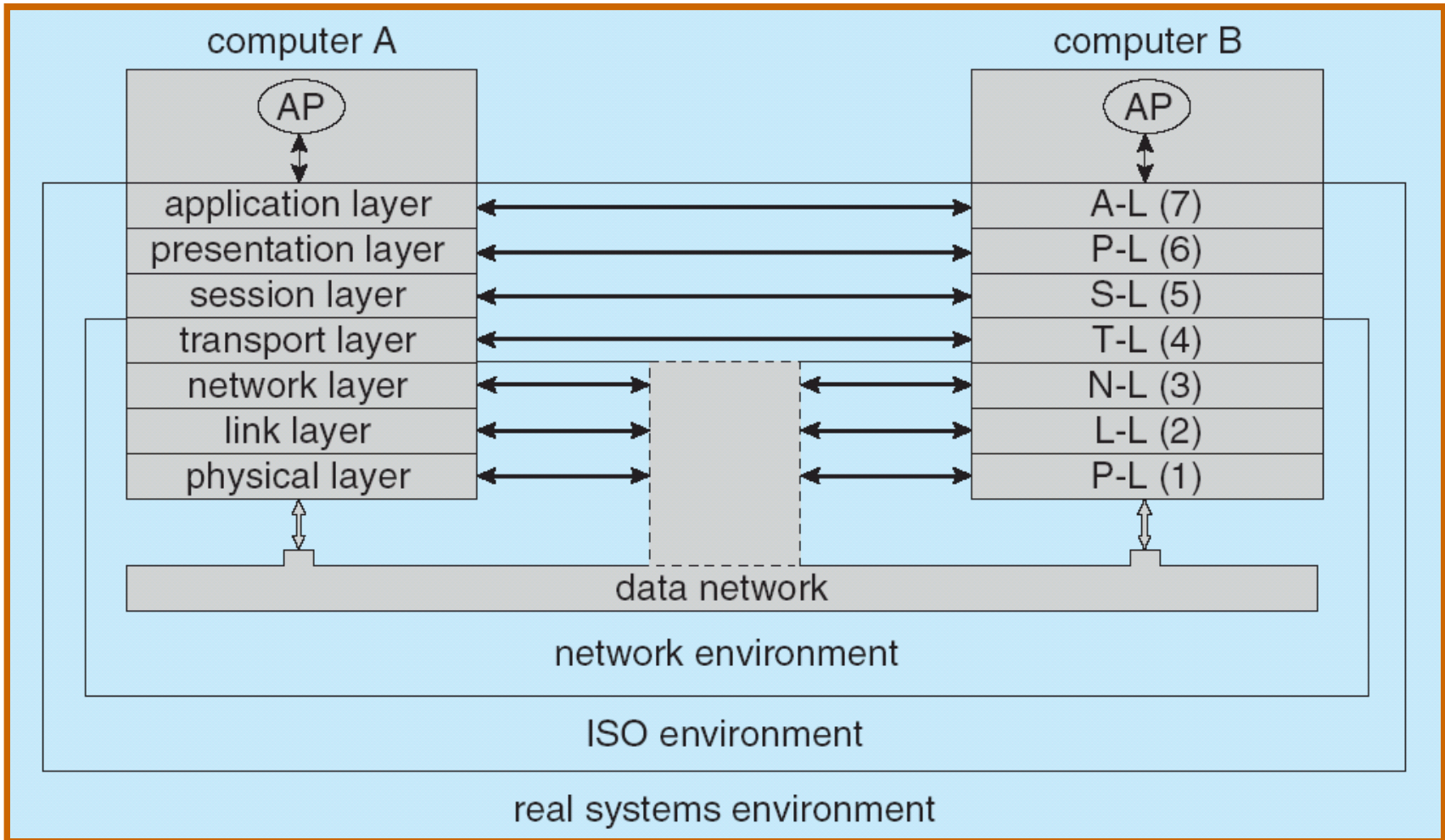
The communication network is partitioned into the following multiple layers:

- **Physical layer** – handles the mechanical and electrical details of the physical transmission of a bit stream, voltages, layout of pins, line impedance, cable specification, Token ring, FDDI, IEEE 802.11, Bluetooth
- **Data-link layer** – handles the *frames*, or fixed-length parts of packets, including any error detection and recovery that occurred in the physical layer, Ethernet IEEE 802.3
- **Network layer** – provides connections and routes packets in the communication network, including handling the address of outgoing packets, decoding the address of incoming packets, and maintaining routing information for proper response to changing load levels

# Communication Protocol (Cont.)

- **Transport layer** – responsible for low-level network access and for message transfer between clients, including partitioning messages into packets, maintaining packet order, controlling flow, and generating physical addresses
- **Session layer** – implements sessions, or process-to-process communications protocols
- **Presentation layer** – resolves the differences in formats among the various sites in the network, including character conversions, and half duplex/full duplex (echoing)
- **Application layer** – interacts directly with the users' deals with file transfer, remote-login protocols and electronic mail, as well as schema for distributed databases, etc.

# Communication Via ISO/OSI Network Model



# Connection Strategies

- **Circuit switching** - A permanent physical link is established for the duration of the communication (i.e., telephone system)
- **Message switching** - A temporary link is established for the duration of one message transfer (i.e., post-office mailing system)
- **Packet switching** - Messages of variable length are divided into fixed-length packets which are sent to the destination
  - Each packet may take a different path through the network
  - The packets must be reassembled into messages as they arrive
- Circuit switching requires setup time, but incurs less overhead for shipping each message, and may waste network bandwidth
  - Message and packet switching require less setup time, but incur more overhead per message

# Contention

- **Token passing** - A unique message type, known as a token, continuously circulates in the system (usually a ring structure)
  - A site that wants to transmit information must wait until the token arrives
  - When the site completes its round of message passing, it retransmits the token
  - A token-passing scheme is used by some IBM and HP/Apollo systems
- **Message slots** - A number of fixed-length message slots continuously circulate in the system (usually a ring structure)
  - Since a slot can contain only fixed-sized messages, a single logical message may have to be broken down into a number of smaller packets, each of which is sent in a separate slot
  - This scheme has been adopted in the experimental Cambridge Digital Communication Ring
- **General problem with the ring structure**
  - Ring break

# Contention

Several sites may want to transmit information over a link simultaneously. Techniques to avoid repeated collisions include:

- **CSMA/CD** - Carrier sense with multiple access (CSMA); collision detection (CD)
  - A site determines whether another message is currently being transmitted over that link. If two or more sites begin transmitting at exactly the same time, then they will register a CD and will stop transmitting
  - When the system is very busy, many collisions may occur, and thus performance may be degraded
- CSMA/CD is used successfully in the Ethernet system, the most common network system

# An Ethernet Packet

Preamble	Destination address	Source address	Frame type	Message data	Checksum
64 bits	48 bits	48 bits	16 bits	368-12000 bits	32 bits

## ■ Preamble:

- 7 bytes [10101010] + 1 byte [10101011] used to synchronize the transfer rate

## ■ 6 byte addresses (MAC addresses)

- World unique addresses
- If destination address = 0xFF-FF-FF-FF-FF-FF then broadcast

## ■ Frame type – indicates different standards:

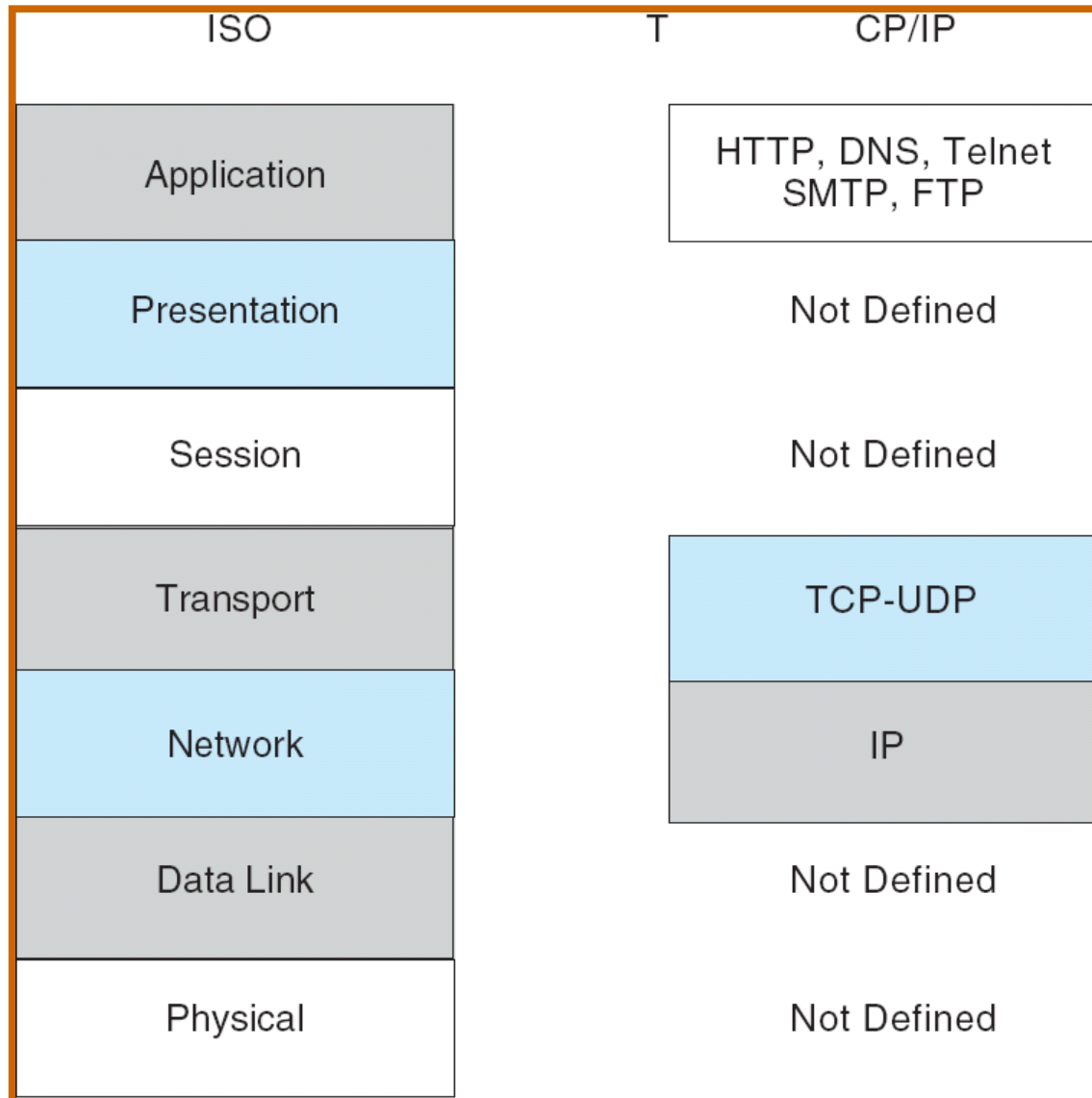
- 0x0800 = the packet contains an IPv4 datagram
- 0x86DD indicates an IPv6 frame
- 0x0806 indicates an ARP frame

## ■ Message data usually 1500 bytes

- Encapsulates packet with the transferred data



# The TCP/IP Protocol Layers



# Example: Networking

- Link layer - the transmission of a network packet between hosts on an Ethernet network
- For link layer you can use alternative protocols – for example PPP – Point to Point protocol for connection of two nodes using HDLC frames
- Every host has a unique IP address and a corresponding Ethernet (MAC) address
- Communication requires both addresses
- Domain Name Service (DNS) can be used to acquire IP addresses
- Address Resolution Protocol (ARP) is used to map MAC addresses to IP addresses
- If the hosts are on the same network, ARP can be used
  - If the hosts are on different networks, the sending host will send the packet to a *router* which routes the packet to the destination network

# Internet Architecture

## ■ Basic Internet properties

- Each host has its unique identification: the **IP address**
  - ▶ IP address is composed by the network address and the host address within the network
- The applications and the network API behavior is independent of the LAN technology

## ■ Basic architecture of the Internet (and general internetworking)



- **Gateways** and **routers** connect LAN's
  - ▶ LAN's may be based on different technologies
- Gateways keep info on hosts belonging to LAN's they connect
- Routers maintain knowledge about networks
  - ▶ Routers forward packets based on the network part of the IP address (the host part is ignored when forwarding)
- Units connecting LAN's usually merge gateway and router functionality
- IP protocols consider all LAN's as equivalent regardless of the technology

# Internet addresses

- Current Internet – v. 4 uses 32 bits addresses
  - Convention: decimal numbers per 8 bits each – 147.32.85.1
- Internet v. 6 uses 128 bits addresses
  - More details next lesson
  - Not easy to switch from v4 to v6
  - Tunneling v6 through v4
  - World IPv6 day was 8 June 2011
  - You can test your IPv6 configuration on [test-ipv6.com](http://test-ipv6.com)
- IP address
  - Identifies each single network adaptor
    - ▶ Host can have several adaptors („*multi-homed*“ *host*)
    - ▶ One adaptor can even have more addresses
  - Is composed of two parts
    - ▶ Identification (address) of the network – *netid* (leftmost bits)
    - ▶ Identification (address) of the host within the network – *hostid* (rightmost bits)

# Internet addresses (2)

## Primary IP address classes

	0 1 2 3 4	8	16	24	31	Net Mask	Address range
Class A	0	netid	hostid			255.0.0.0	0.0.0.0 – 127.255.255.255
Class B	1 0	netid	hostid			255.255.0.0	128.0.0.0 – 191.255.255.255
Class C	1 1 0	netid		hostid		255.255.255.0	192.0.0.0 – 255.255.255.255

## Reserved ranges:

- In A      0.0.0.0 – 0.255.255.255,      127.0.0.0 – 127.255.255.255,
- In B      128.0.0.0 – 128.0.255.255,      191.255.0.0 – 191.255.255.255,
- In C      192.0.0.0 – 192.0.0.255,      255.255.255.0 – 255.255.255.255

# Internet addresses (3)

## ■ Convention:

- Network address *netid* is the full IP address with *hostid* = 0
- Address composed by *netid* and the *hostid* part is full of "1" serves for addressing all hosts in the network (*network broadcast address*)

## ■ Net mask:

- Address „arithmetic“  
 $IP\_Address \wedge NetMask = netid$   
 $IP\_Address \wedge \neg(NetMask) = hostid$

## ■ Special addresses

- 127.0.0.1 – loopback address – a host speaks to itself
- Private addresses – may not spread over Internet – routers must not forward datagrams containing these addresses
  - ▶ 1 class A network: 10.0.0.0 – 10.255.255.255
  - ▶ 16 class B networks: 172.16.0.0 – 172.31.255.255
  - ▶ 256 class C networks: 192.168.0.0 – 192.168.255.255
- Multicast addresses – one host sends info to many “subscribed” hosts (e.g. Internet TV)
  - ▶ range 224.0.0.0 – 238.255.255.255

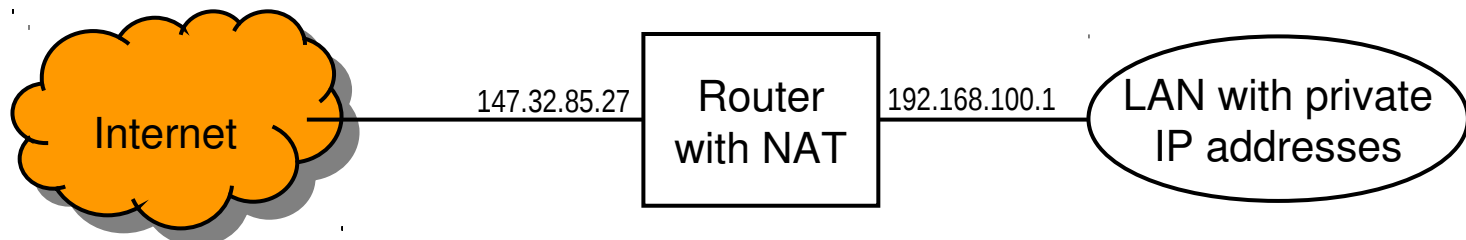
# Internet addresses (4)

## ■ CIDR addressing (= *Classless Inter-Domain Routing*)

- Address arithmetic enables for more efficient splitting *netid|hostid* – the border between *netid* and *hostid* may be anywhere
- Net mask may be any number composed of  $n$  ( $n=0 \dots 32$ ) leftmost “1” bits
- CIDR notation:
  - ▶ IP\_Address/ $n$ ; e.g.: 147.32.85.128 – 147.32.85.191 = 147.32.85.128/26
  - ▶ Reserved ranges in CIDR notation:  
0.0.0.0/8,                    127.0.0.0 /8,                    128.0.0.0/16,                    191.255.0.0/16,  
192.0.0.0/24,                    255.255.255.0/24
  - ▶ LAN 192.168.200.64/30 contains 4 addresses: 192.168.200.64 = netid, 192.168.200.65=host<sub>1</sub>, 192.168.200.66=host<sub>2</sub>, 192.168.200.67 = LAN broadcast

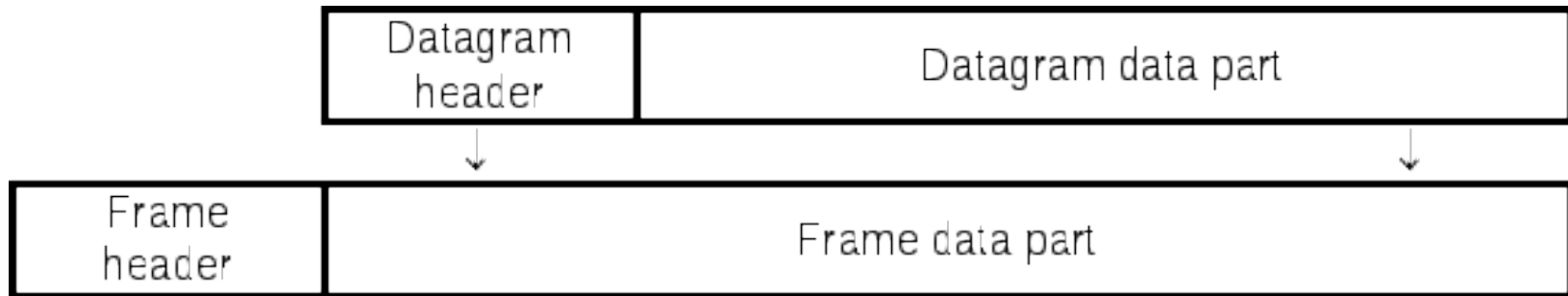
## ■ Saving IP addresses

- Using private addresses and their translation to “public” addresses (**NAT** = *Network Address Translation*)
  - ▶ Many private addresses is translated into 1 public
  - ▶ Problem with publicly available servers on the private address LAN (behind the NAT router)
  - ▶ The principle of NAT is connected to IP protocols



# Internet datagrams

- Internet creates a virtual network and carries **IP datagrams**
  - The network is a *best effort delivery* system
  - Datagrams travel through Internet over different physicals LAN's
  - Datagrams may not depend on the LAN technology
- Format of an IP datagram

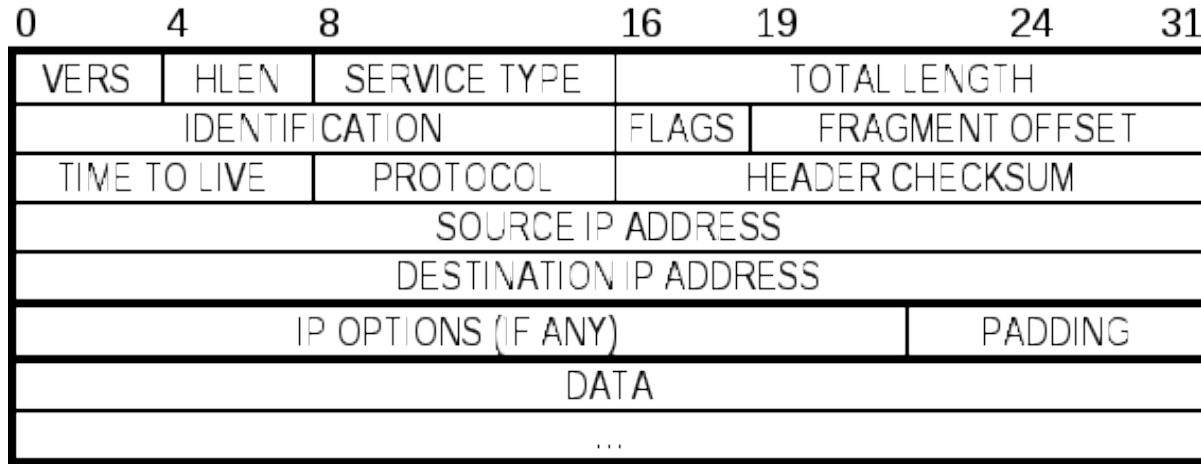


Encapsulating IP datagram into physical network frame



# IP datagram header

- Every IP datagram has a header carrying information necessary for datagram delivery



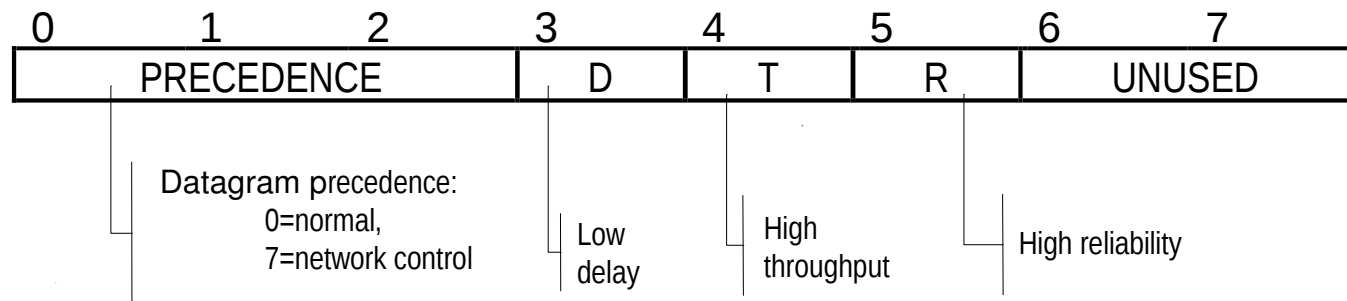
IP datagram format

## ■ Fields

- VERS: IP protocol version – for IP v. 4 VERS = 4
- HLEN: Header length in 32-bit words (standard 5)
- TOTAL LENGTH: of the datagram in bytes (header+data) – max. 64 kB
- SOURCE IP ADDRESS: sender's IP address
- DESTINATION IP ADDRESS: IP address where to deliver
- IDENTIFICATION: usually sequential or a random number generated by the datagram sender

# IP datagram header (cont.)

- **PROTOCOL:** Identification of the protocol carried in the IP datagram (UDP=17, ICMP=1, TCP=6, ...). Defined in RFC 1060
- **FLAGS, FRAGMENT OFFSET:** Information on datagram fragmentation
- **TIME TO LIVE (TTL):** Determines how long the datagram may travel through Internet. Every router decrements this value; if TTL==0 the datagram is discarded and the router sends an ICMP message to the sender
- **SERVICE TYPE:** 8-bit field commanding the datagram routing

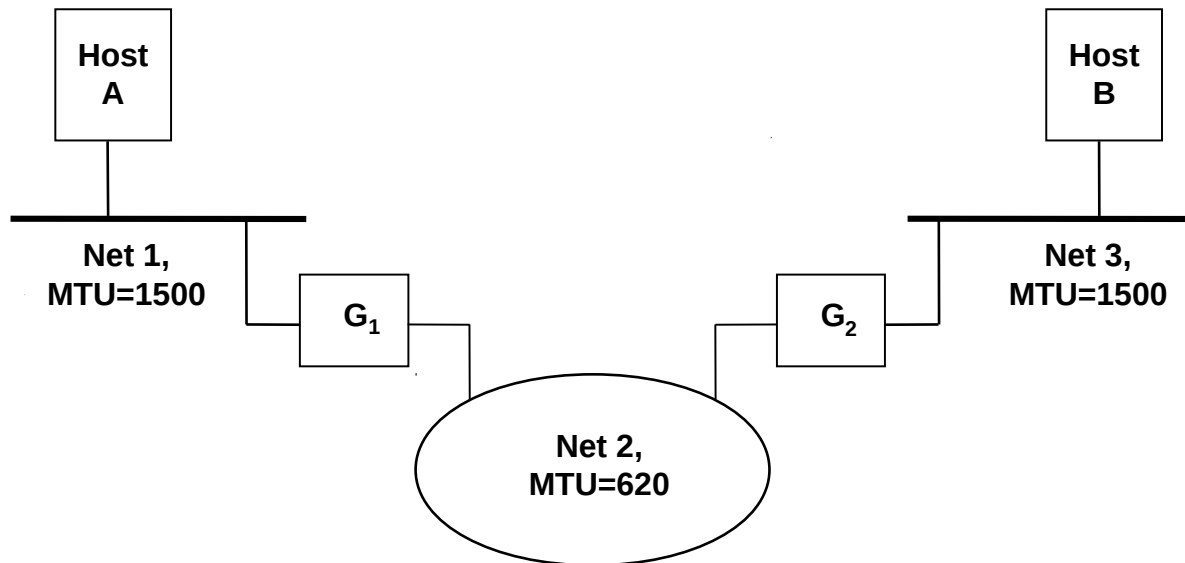


# Datagram fragmentation (1)

- **MTU**: (*Maximum Transmission Unit*) defines the maximum datagram size that can be transferred in a LAN

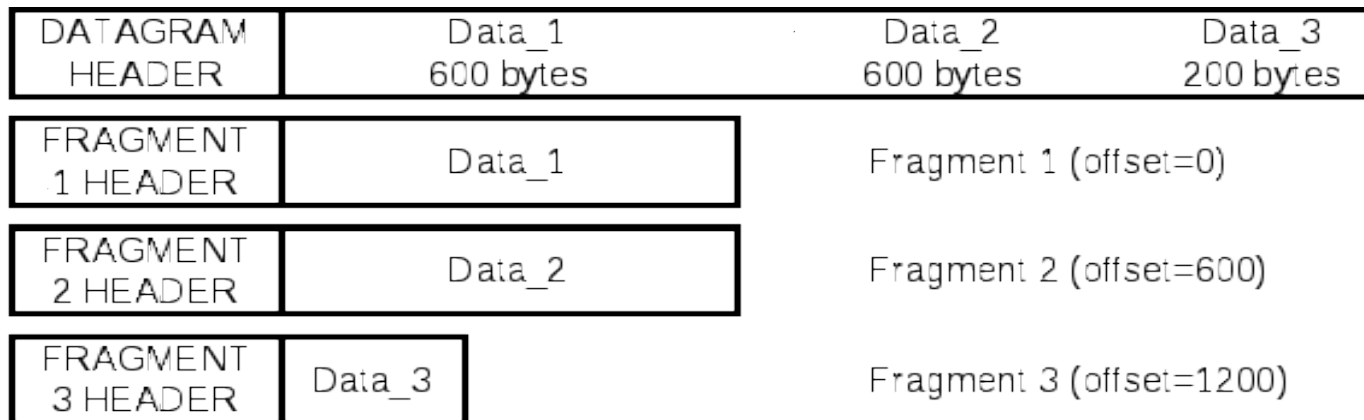
Net type	Implicit MTU	Net type	Implicit MTU
PPP	296	X.25	576
Ethernet	1 500	FDDI	4 352
TokenRing 4Mb	4 464	TokenRing 16Mb	17 914

- Internet – a set of LAN's with different MTU's
  - Whenever the datagram is larger than MTU it must be **fragmented**



## Datagram fragmentation (2)

- Fragmentation occurs anywhere during the datagram travel
  - If the datagram is fragmented it is not defragmented on the way and the reconstruction is the task of the destination host
  - Every fragment travels as a separate datagram:
    - ▶ The following fields are copied from the original datagram header: VERS, HLEN, SERVICE TYPE, IDENTIFICATION, PROTOCOL, SOURCE IP ADDRESS, DESTINATION IP ADDRESS
    - ▶ TOTAL LENGTH is changed to the fragment size and the field FRAGMENT OFFSET determines the offset of the fragment in the original datagram
    - ▶ Field FLAGS contains a bit *more fragments*. If this bit is 0 then the target host knows that the last fragment has been obtained. The target host reconstructs the original datagram using the FRAGMENT OFFSET and TOTAL LENGTH fields

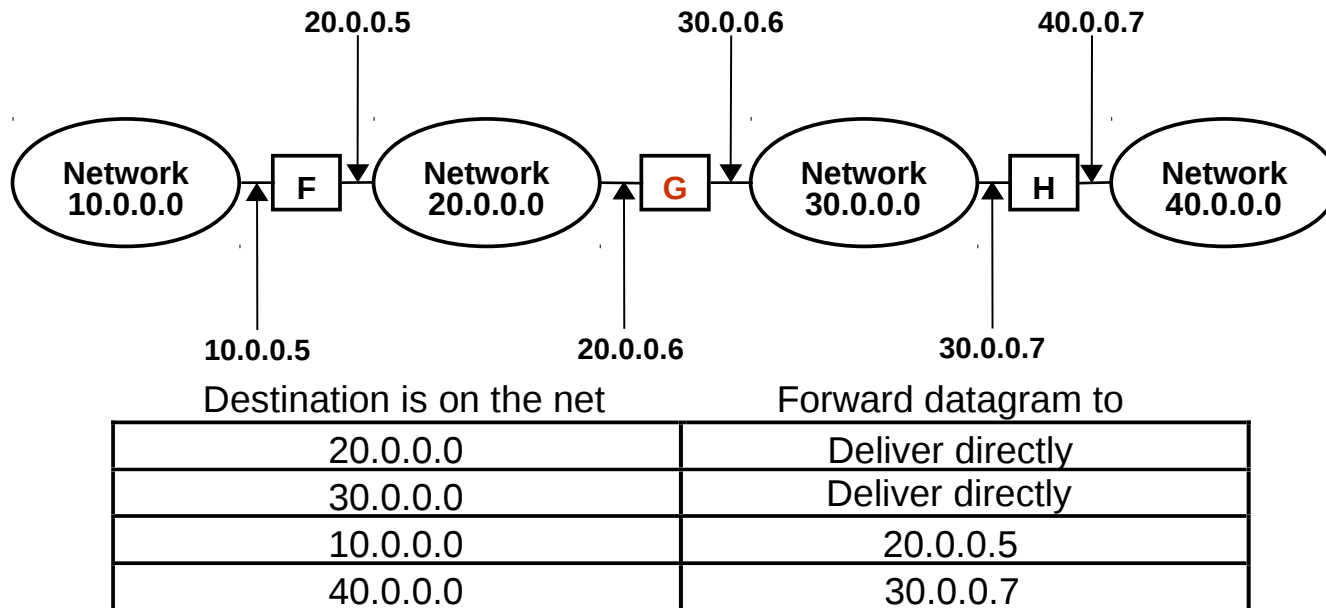


1400 bytes datagram fragmentation

# Datagram routing (1)

- Routing is a **decision making** process on where to forward the datagram (or its fragment).
  - Any device making such decision is called router
  - Routing can be **direct** or **indirect**
    - ▶ **Direct** routing occurs when the destination host is a part of the LAN directly connected to the router so that the datagram can be delivered directly to the destination.
    - ▶ All other cases represent **indirect** routing
  - Routers in the Internet form a cooperative interconnected structure. Datagrams pass from router to router until they reach a router capable to deliver directly (locally) to the destination
  - Table driven routing
    - ▶ Every router maintains a **routing table** with entries in the form of pairs  $(N, G)$ , where  $N$  is *netid* of the destination network and  $G$  is the IP address of the “next router” along the path to the destination network  $N$ . The “next router” must be reachable directly so that the datagram can be forwarded there without further routing

# Datagram routing (2)



Routing table of G

## ■ Default routes

- Often LAN's are connected to the "rest of world" through a single router. Such router is called **default gateway**, i.e. the address where all host on the LAN send datagrams with the destination outside the LAN

## ■ Host-Specific Routes

- Sometimes it may be reasonable to assign a special routing information for administrative, security, or technical reasons (e.g., dedicated serial line connection)

# Datagram routing (3)

## ■ Routing algorithm

- Extract the destination IP address  $DA$  from the datagram and using the netmask determine the  $netid$  of the destination network
  1. If  $DA$  corresponds to a *host-specific route* send the datagram directly to the destination host
  2. If  $netid$  is equal to the  $netid$  of a directly connected LAN then deliver directly (locally)
  3. If  $netid$  can be found in the routing table send the datagram to the corresponding “next router”
  4. If the *default route* is specified send the datagram to the *default gateway*
  5. Otherwise send a ICMP “*Destination unreachable*” message to the datagram sender

# Local datagram delivery

- Direct routing must assure local datagram delivery
  - The same has to be done when forwarding to a router directly connected on the LAN (not through *point-to-point* link)
  - Datagram contains the destination IP address but the delivery must be accomplished using a LAN specific physical address
- Mapping IP addresses to physical addresses
  - *Address Resolution Protocol* (ARP) – dynamic mapping
  - Ethernet case example solution: datagram sent by host  $A$  to host  $B$ 
    - ▶ The sender has IP address  $I_A$  and physical address  $P_A$  needs to learn the physical address  $P_B$  but knows only the IP address  $I_B$ .
    - ▶ Host  $A$  sends an **ARP ethernet broadcast** frame and in its data part will contain both  $I_A$  and  $I_B$  (*Who-has ARP request*). This frame get all hosts on the LAN.
    - ▶ Host which recognizes its IP address  $I_B$  responds to this broadcast (*ARP reply*) and tells the requestor its physical address  $P_B$ .
    - ▶ The ethernet broadcast makes a big load for the LAN host; so the requestor caches  $P_B$  for some time (5 minutes as standard)
    - ▶ Host  $B$  has learnt from ARP request also addresses  $I_A$  a  $P_A$  so it caches it, too (an early datagram from  $B$  to  $A$  can be expected).

A real network capture:

```
12:32:35.363 arp who-has 147.32.85.117 tell 147.32.85.8
```

```
12:32:35.696 arp reply 147.32.85.117 is-at 00:1a:80:d9:27:64
```



End of Lecture 11

# Questions?

