Reti di Calcolatori I

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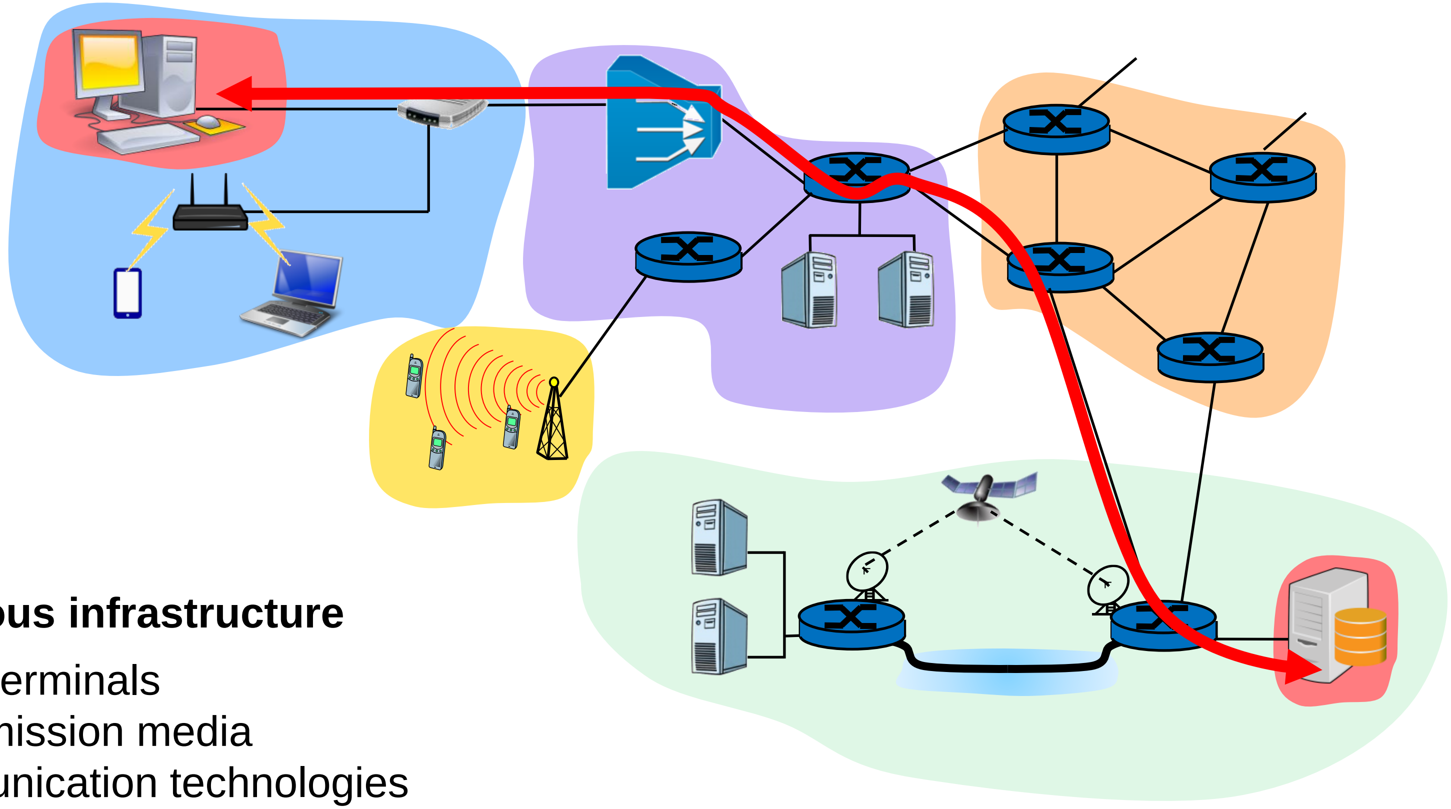
Corso di Laurea in Ingegneria Informatica

Introduction to Computer Networks

What is a computer network ?

A collection of **computing devices** connected in various ways
in order to communicate and share resources



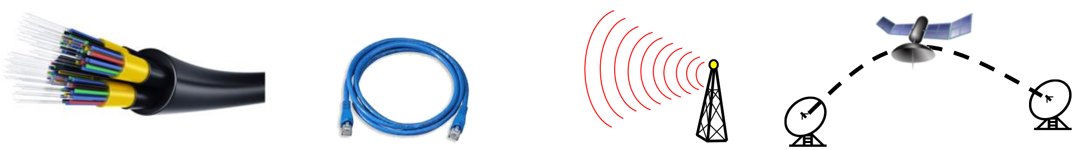
Heterogeneous infrastructure

- Many kinds of terminals
- Different transmission media
- Multiple communication technologies
- Several owners
- A number of different services

Computer network components

- **Terminals (*a.k.a. hosts or end-systems*)**
  - personal computers, servers, computer peripherals (printers, scanners, …), smartphones, sensors, “connected things”, …

- **Intermediate devices**
  - perform various communication tasks and are placed “in the middle” while terminals are “at the edges” of the network
  - take different names according to the main function they perform
    - hub, switches, routers, modems, access points, firewalls, …



- **Connections (*a.k.a. links*)**
  - ***physical wires*** or cables
  - ***wireless connections***, using radio waves or infrared signals

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Digital transmission basics: bit rate

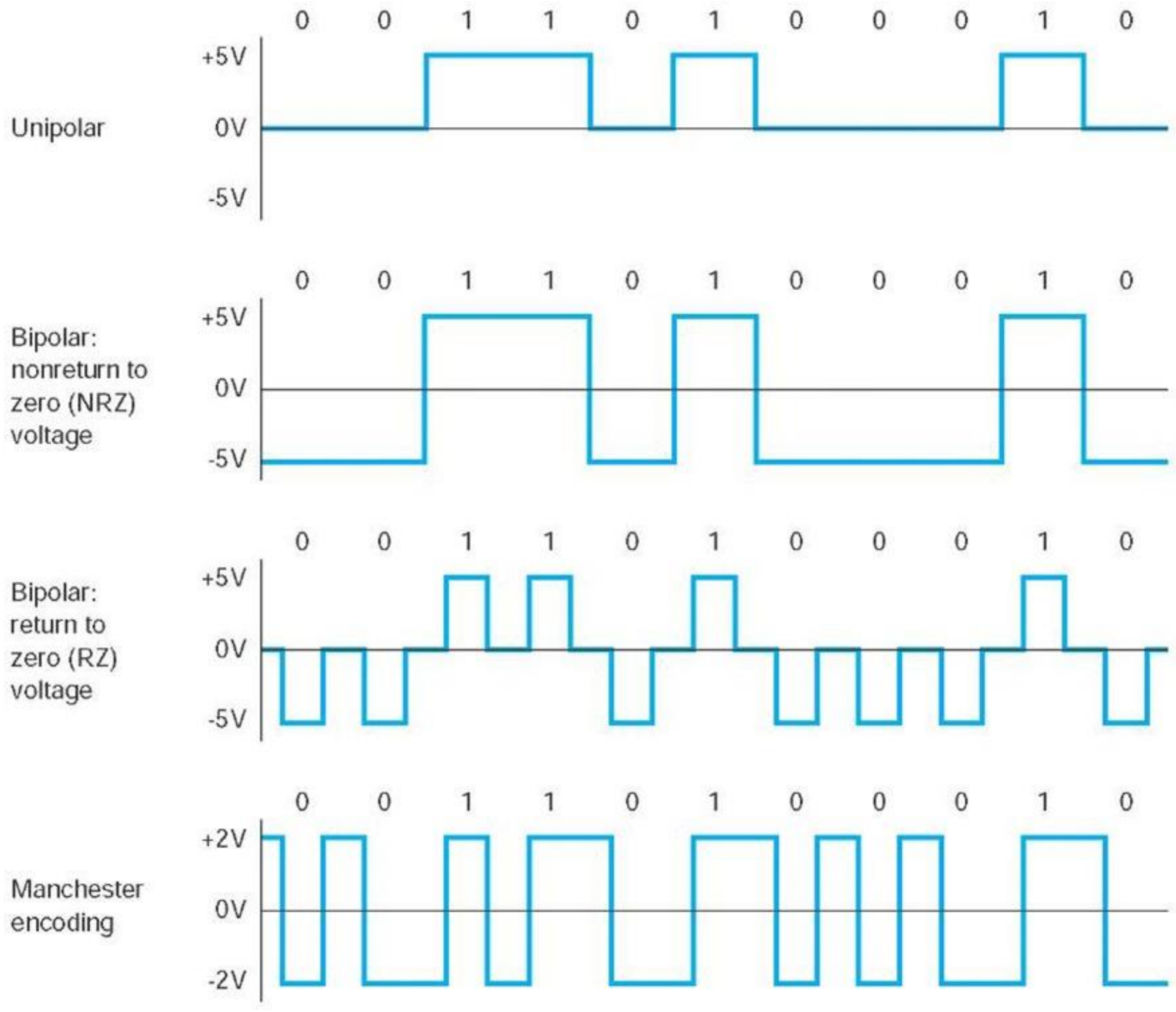
- Computers are complex programmable digital systems
- Computer networks use digital transmission techniques to let computers send and receive sequence of bits (0 and 1) over digital links
- A **digital transmission technique** allows sequence of binary symbols (**bits**) to be transmitted and received on a communication channel
- Different ***modulation techniques*** are possible to transmit a binary symbol (0 or 1) by associating its value to a signal level or to a variation (edge) of a signal level

- A digital transmission is characterized by the **bit rate** (or **data rate**), i.e. the number of bits that can be transmitted in a time unit (1 second)

- Early days' links had a data rate of 56-64 kbps
- Today's links have a data rate in the order of:
  - 1 Mb/s = 10^6 bits per second
  - 1 Gb/s = 10^9 bits per second
  - 1 Tb/s = 10^{12} bits per second

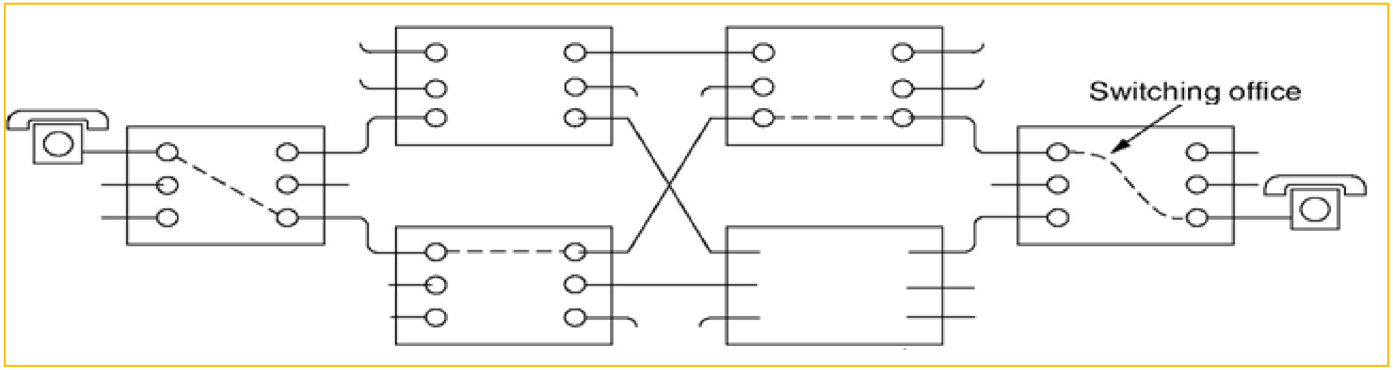
- **Time needed to transmit L bits at data rate R =** $\dfrac{L \text{ (bits)}}{R \text{ (bits/sec)}}$

Digital transmission basics: digital modulation



PSTN and circuit switching (1/2)

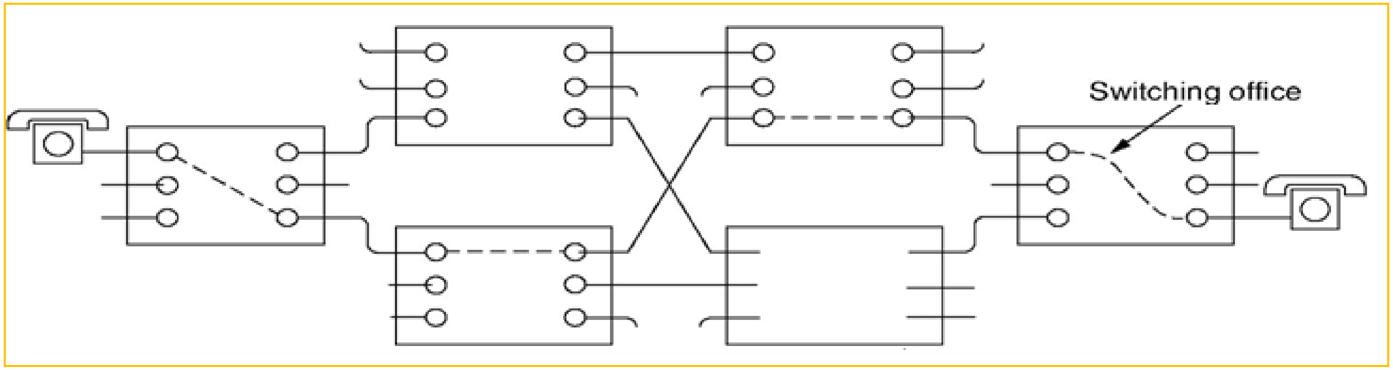
- Computer networks operate according to the ***packet switching model***, while the traditional telephone system operates according to the ***circuit switching model***
- In the PSTN (*Public Switched Telephone Network*), communicating terminals (*phones*) are connected through switching offices
  - The PSTN service is also referred to as POTS (*Plain Old Telephone System*)
- When a phone call is made, a ***circuit*** is established between the two phones as a concatenation of links along a fixed path
  - A circuit is dedicated to a single phone call, i.e. its transmission capacity is assigned to a call even when none of the two communicating persons is talking



PSTN and circuit switching (2/2)

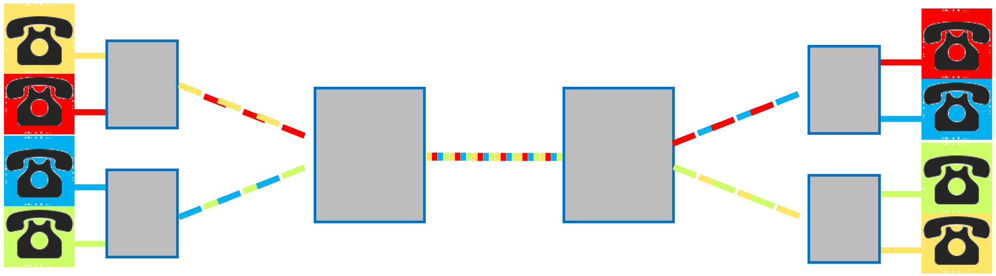
- Establishing a communication in a circuit switching network involves 3 phases:
  1) Circuit establishment
     - Route selection and link by link resource allocation
  2) Call or data transfer
  3) Circuit tear-down
     - Resource deallocation

- Phases 1) and 3) involve exchange of ***signalling*** information both
  - between terminals and switching offices
  - and between switching offices among themselves



Link multiplexing in PSTN

- Switching offices in the PSTN network are hierarchically organized
- Links connecting switches need to carry several phone calls at the same time
- The transmission capacity of such links must be split in multiple ***channels*** to accommodate this ***aggregate traffic***
- Different multiplexing techniques may be adopted
  - time-division multiplexing (TDM) vs. frequency-division multiplexing (FDM)



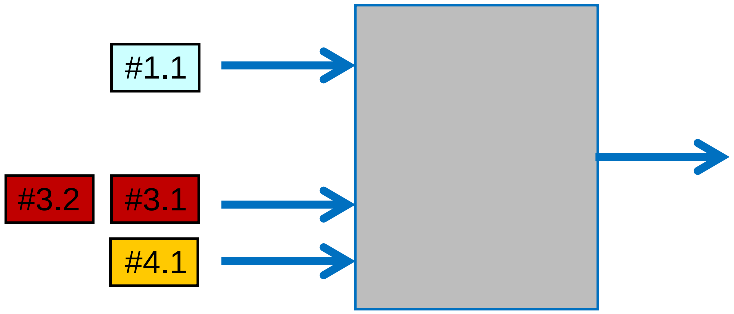
- Both TDM and FDM partition a link capacity in channels of fixed capacity
  - A single phone call is typically transmitted over a 64 kb/s channel
  - A channel is associated to a specific call during the circuit establishment phase

Computer networks and packet switching

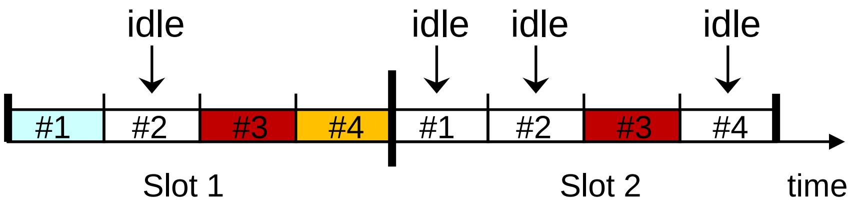
- Computer networks operate according to the ***packet switching model***
- In a packet switched network, information is transmitted in ***packets*** formed by a ***header*** and a ***payload***
  - the header contains control information including a destination ***address*** identifying the terminal to which the information must be delivered

- Intermediate systems typically operate in a way called ***store-and-forward***
  - each packet is received in its entirety, inspected for errors, and retransmitted along the path to the destination
  - this implies buffering and enqueueing of packets at these intermediate systems
  - a channel is occupied only during the transmission of a packet, and upon completion of the transmission the channel is made available for the transfer of other traffic

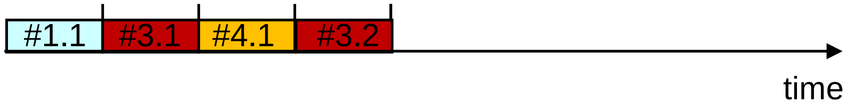
Packet switching and statistical multiplexing



Circuit switching with TDM: each slot may be uniquely assigned to a flow



Packet switching: packets are transmitted as soon as it is possible

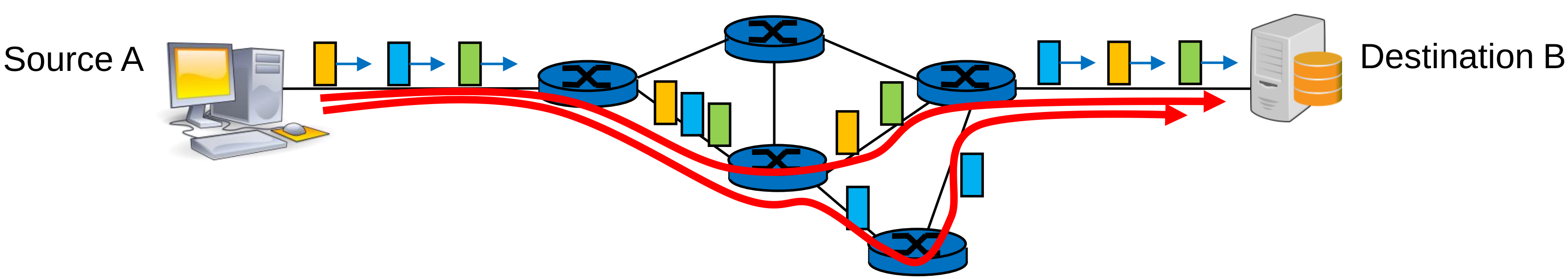


Packet switching allows ***statistical multiplexing*** of packets

Packet switching: datagram networks

The packet switching model has two possible incarnations:
- Datagram networks
- Virtual circuit networks

- In a ***datagram network***, each packet is independently routed toward its destination
  - Packets ***do not*** follow a pre-established route
  - Each time a packet arrives to an intermediate device operating at network layer (i.e. a ***router***), the device decides what is next hop device to which the packet is to be transmitted
  - Subsequent packets sent from the same source A to the same destination B may be routed along different paths
  - Packets may arrive to destination with a different order
  - No need for connection setup

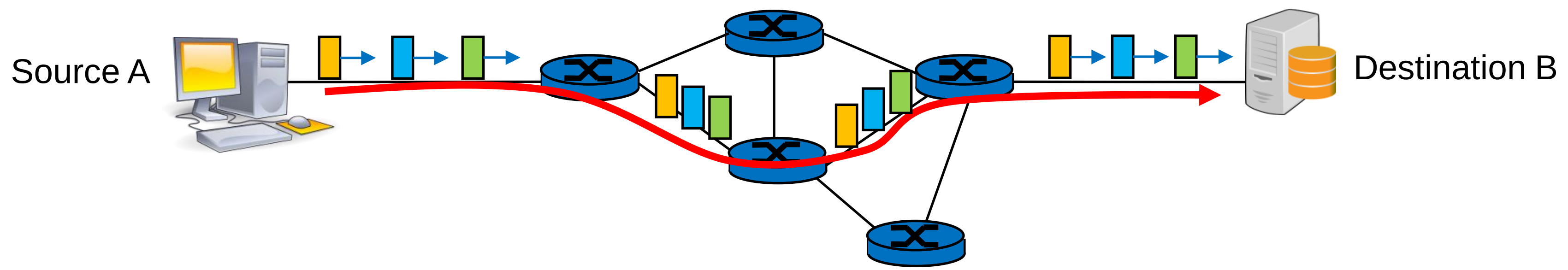


Beware: packets may get lost during their journey from A to B

Packet switching: virtual circuit networks

The packet switching model has two possible incarnations:
- Datagram networks
- Virtual circuit networks

- In a ***virtual circuit network***, a path from source A to destination B is computed and pinned down before communication begins
  - Packets from A to B follow a pre-established route
  - Packets arrive in the same order in which they have been transmitted
  - A connection setup phase is needed (***signalling***)
  - Resources may be set aside for the A→B stream in each intermediate device



Analogies with circuit switching (<u>but this is packet switching</u>!)

Beware: packets may get lost during their journey from A to B

Type of networks by geographic extension

Local-area network (LAN)
Connects a relatively small number of terminals in a relatively close geographical area

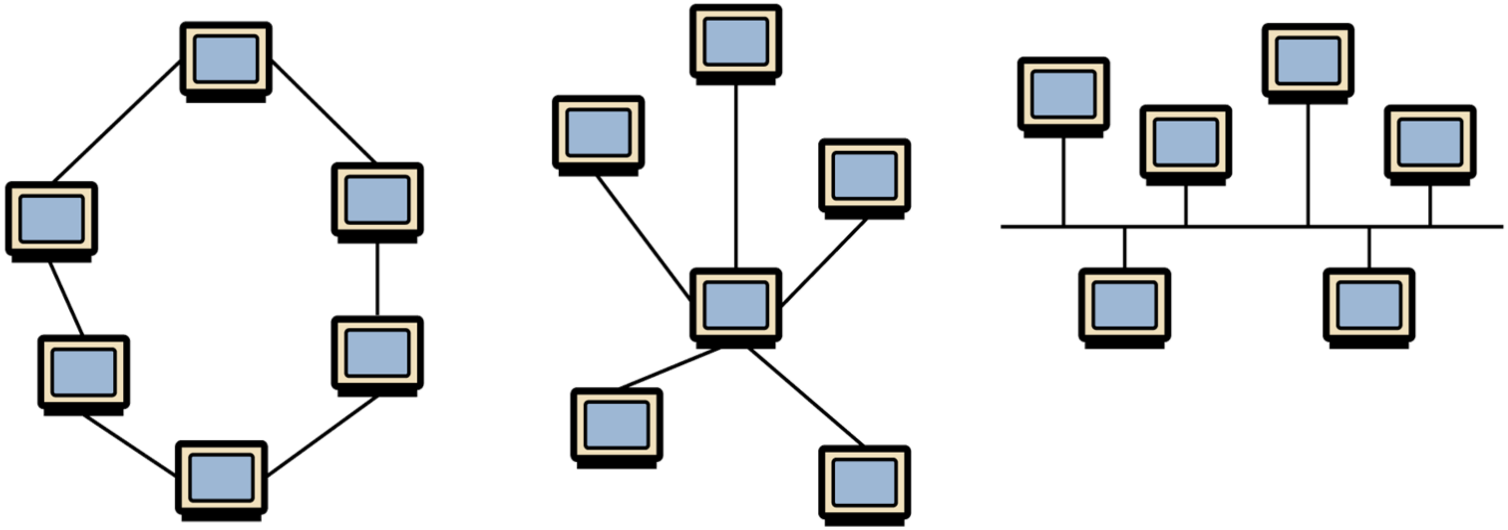
Wide-area network (WAN)
Connects two or more local-area networks over a potentially large geographic distance

Metropolitan-area network (MAN)
Communication infrastructures spanning large cities

The Internet, as we know it today, is essentially the ultimate wide-area network, spanning the entire globe

WANs are typically created by LAN interconnections
Communication between networks is called ***internetworking***

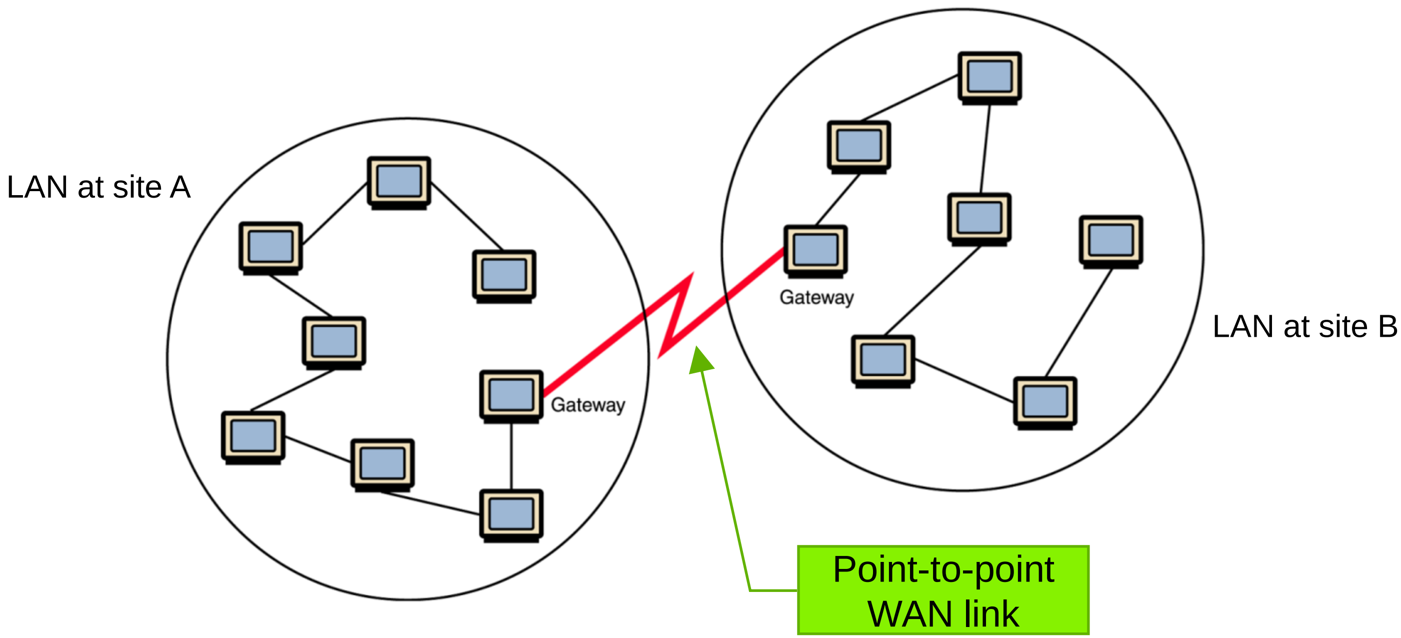
LAN topologies



Ring topology Star topology Bus topology

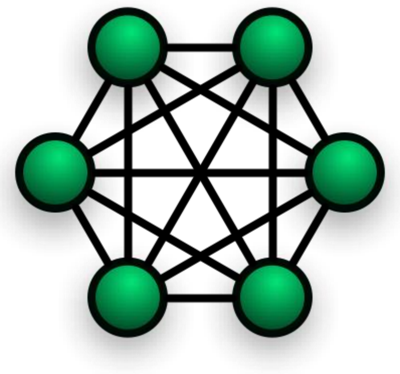
Internetworking

- When two or more LANs, located at different sites, are to be interconnected, a particular node at each LAN is set up to serve as a ***gateway*** to handle all communication going between that LAN and other networks
- In the Internet, gateways are also referred to as ***routers***



Full mesh topology

- Consider an internetwork of N sites in which any site is connected to all other N-1 sites according to a full mesh topology
- Number of bidirectional links is N*(N-1)/2

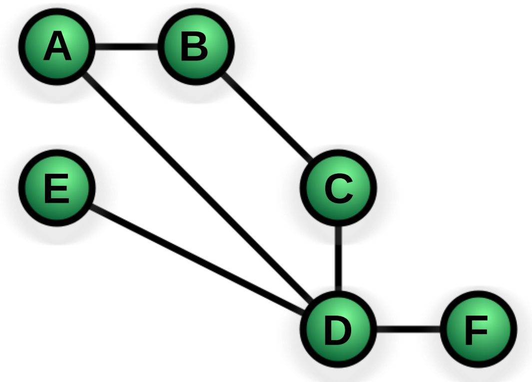


- Large scale internetworks (such as the Internet) cannot have a full mesh topology for scalability reasons
  - Most of the links would be rarely used anyway

Typical WAN topologies

- Large scale WAN internetworks (such as the Internet) typically have a partially connected mesh topology
- Not all the links are equal: some have great ***capacity*** than others, i.e. are able to carry a larger amount of information per time unit

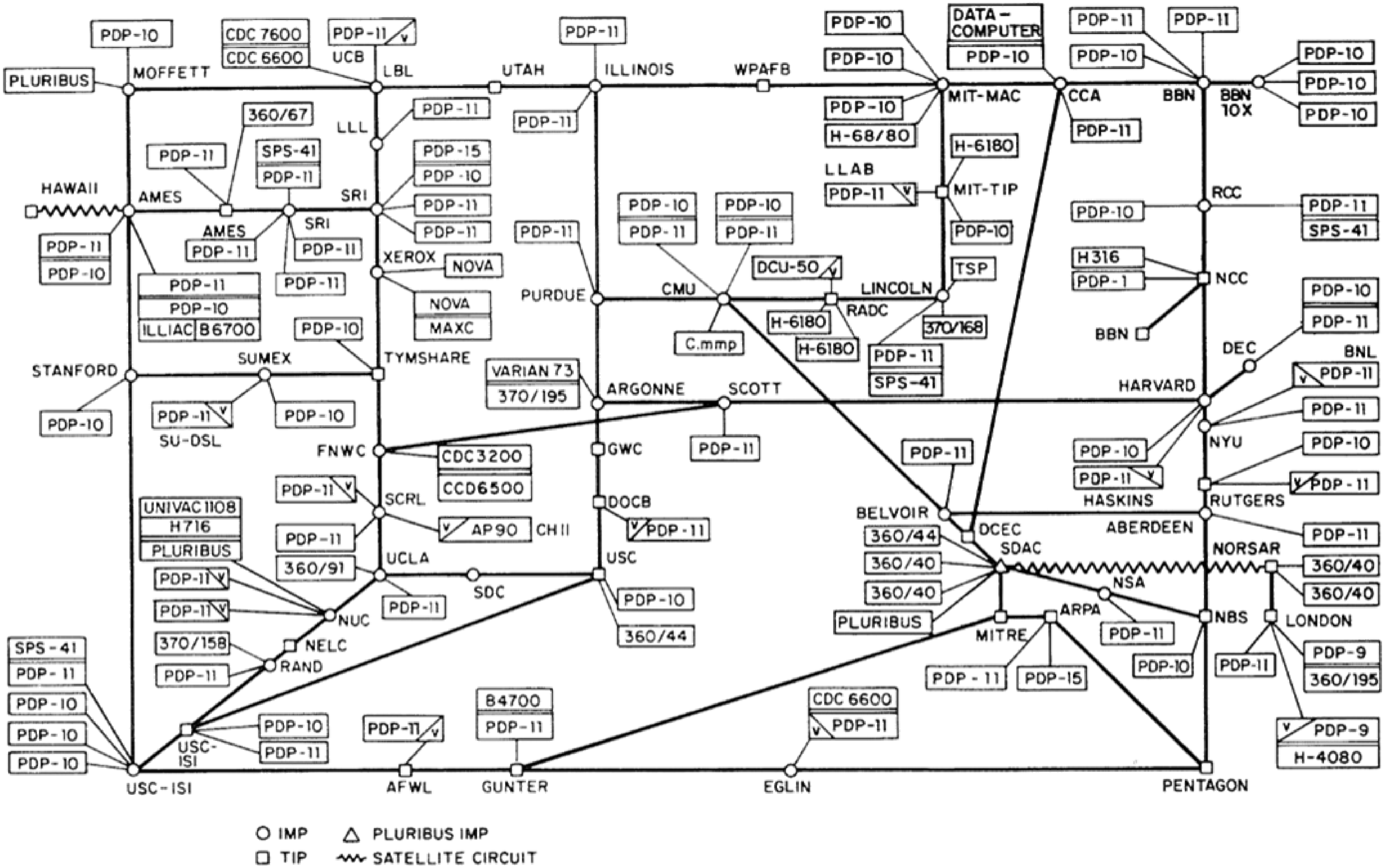
If not directly connected, two nodes may communicate along a **path** traversing other intermediate nodes



A may communicate with F along the paths:

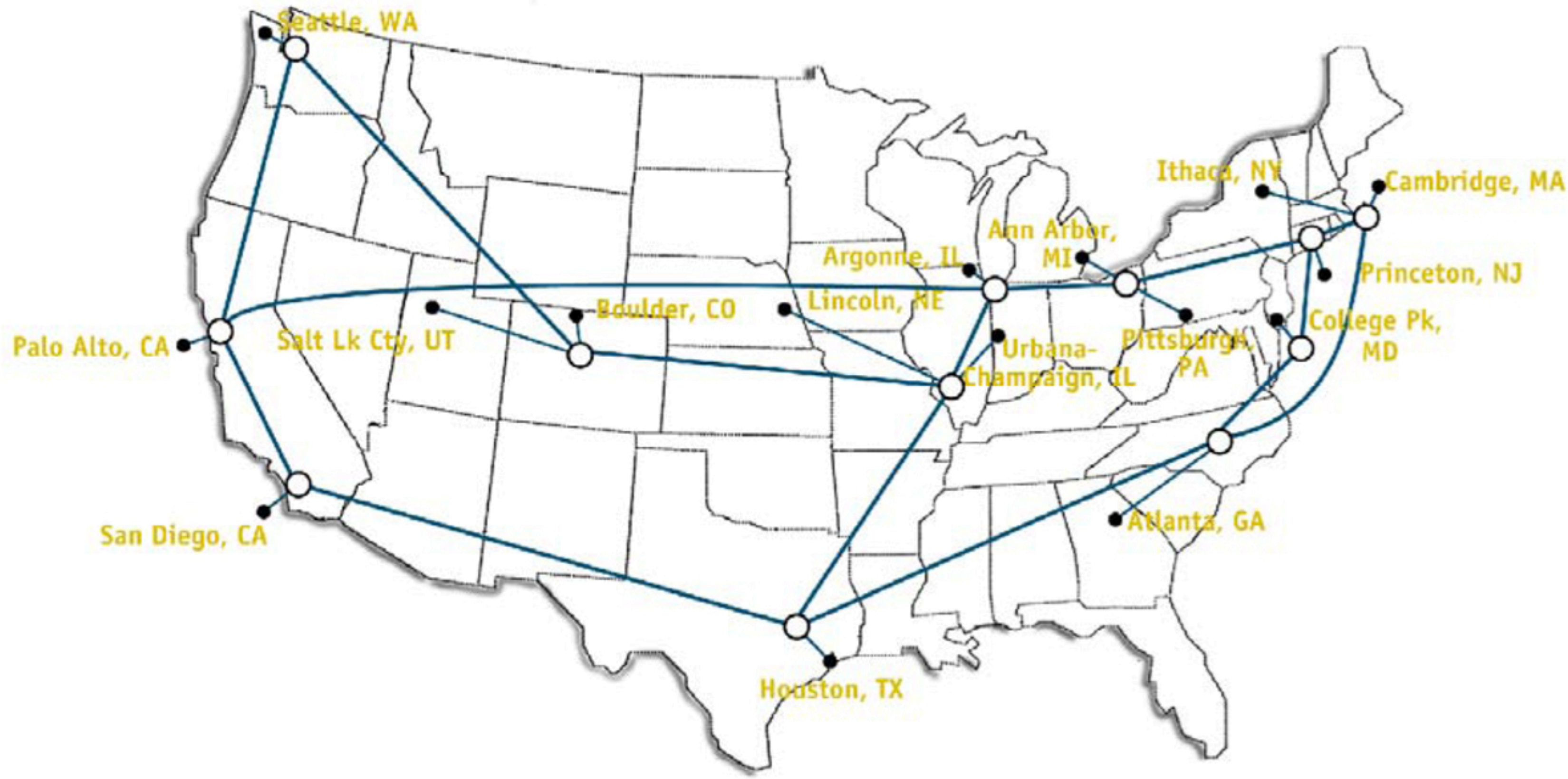
a) A ↔ D ↔ F
b) A ↔ B ↔ C ↔ D ↔ F

Arpanet – August 1976



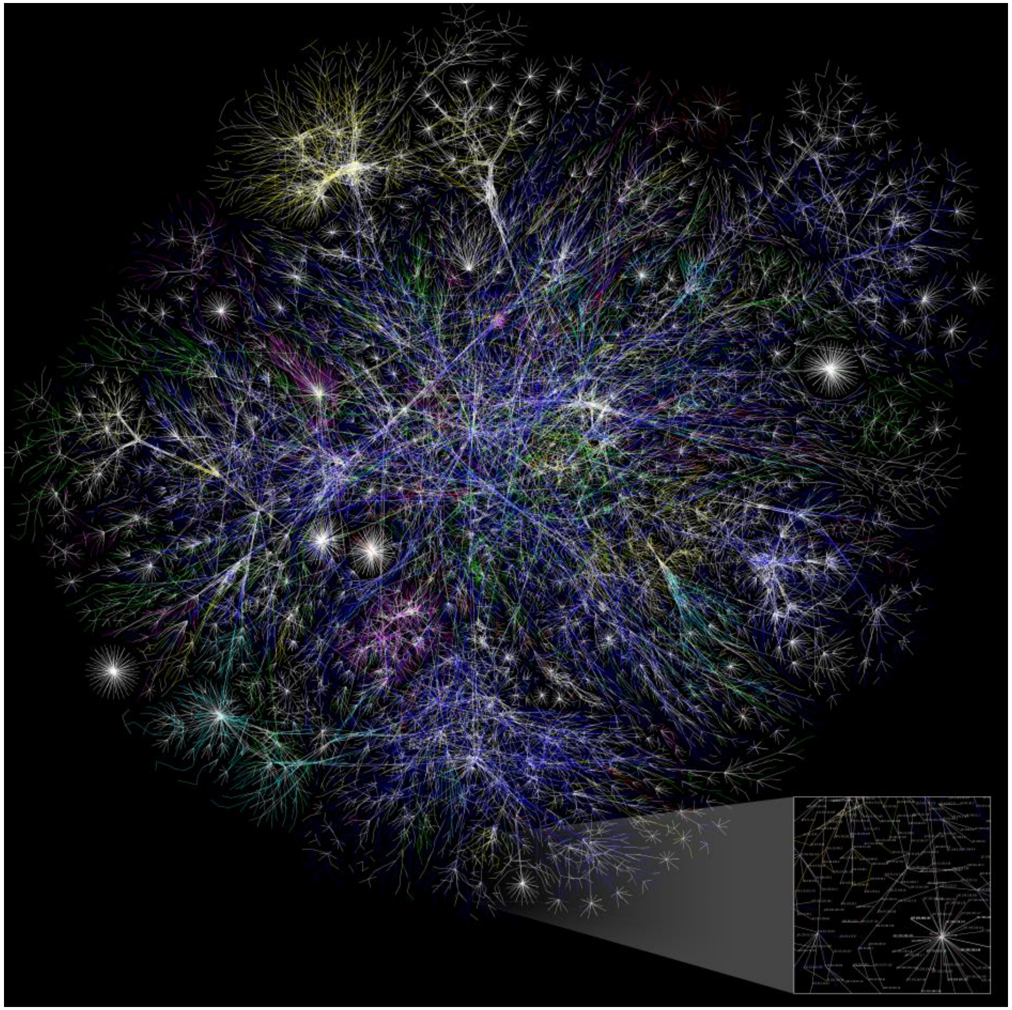
(PLEASE NOTE THAT WHILE THIS MAP SHOWS THE HOST POPULATION OF THE NETWORK ACCORDING TO THE BEST INFORMATION OBTAINABLE, NO CLAIM CAN BE MADE FOR ITS ACCURACY)

NSFNET T3 Network 1992



An Internet map

- Partial map of the Internet based on the January 15, 2005 data found on http://www.opte.org/maps/ opte.org



Layered models of computer networks

- Computer networks are engineered according to layered conceptual models
  - Each layer deals with a particular aspect of network communication
- *Fundamental Truths of Networking* (RFC 1925): ***It is always possible to aglutenate multiple separate problems into a single complex interdependent solution.***

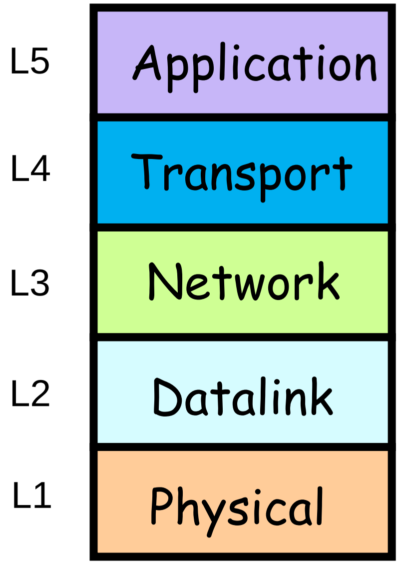
  In most cases this is a bad idea. ☺
- Historically, the **International Organization for Standardization** (ISO) established the **Open Systems Interconnection** (OSI) Reference Model, based on seven layers
  - Today used almost exclusively for teaching purposes
  - Layers 1 to 3 are implemented in both terminals and gateways
  - Layers 4 to 7 are implemented in end systems (terminals)

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

Names of the seven layers in the ISO-OSI reference model

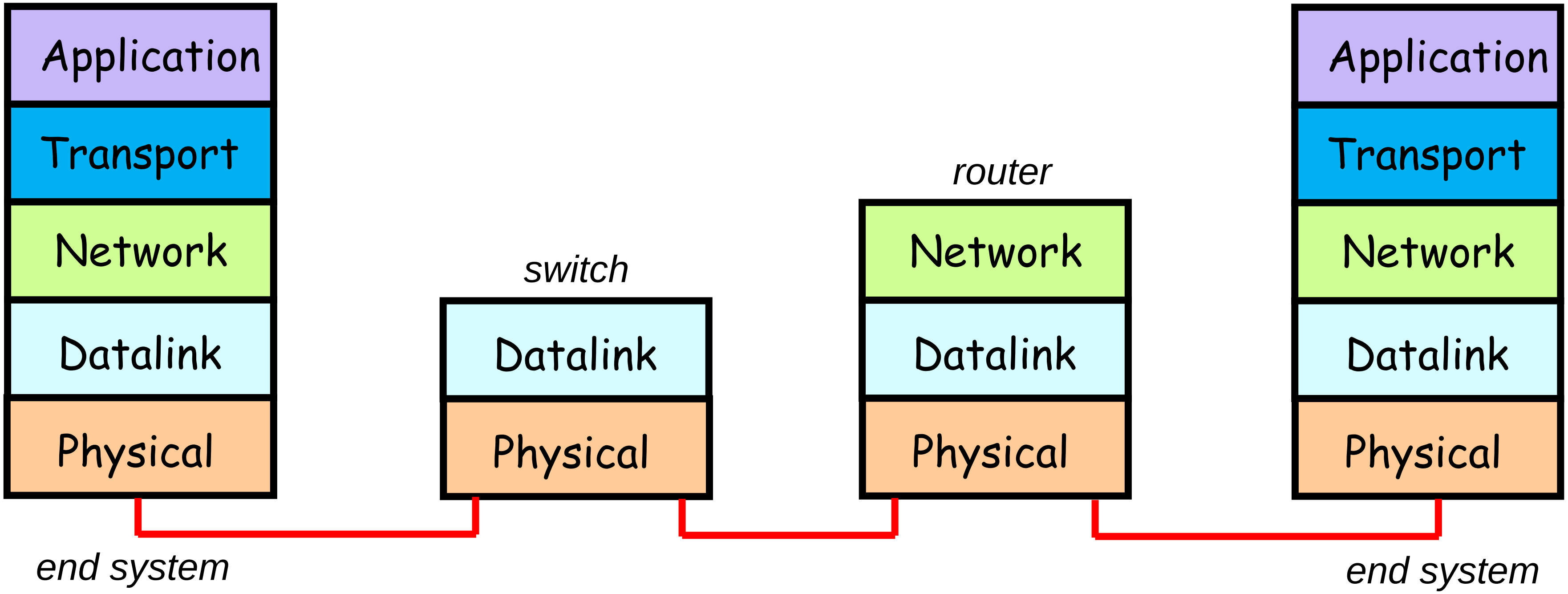
Five layers model of the Internet

- The Internet has been designed according to a five layers stack model
- With respect to the ISO/OSI model, L5 and L6 functions have not been explicitly assigned to specific layers
  - If needed, they are implemented at the upmost level, the Application layer
  - The Application layer is sometimes still referred to as L7, as in OSI/ISO



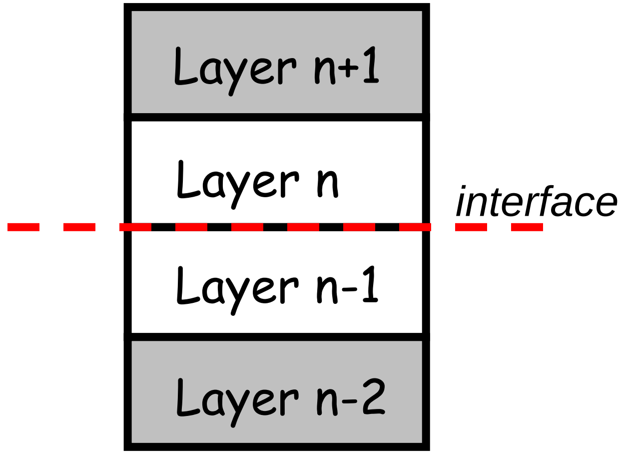
Layers and intermediate devices

- In most networks, two interacting end systems (terminals) are interconnected by a number of ***intermediate devices***
- An intermediate device implements only the lowest layers
- The upmost layer implemented in a device is related to the device specific function
  - ***Repeaters*** and hubs implement only L1
  - ***Switches*** implement layers up to L2
  - ***Routers*** implement layers up to L3



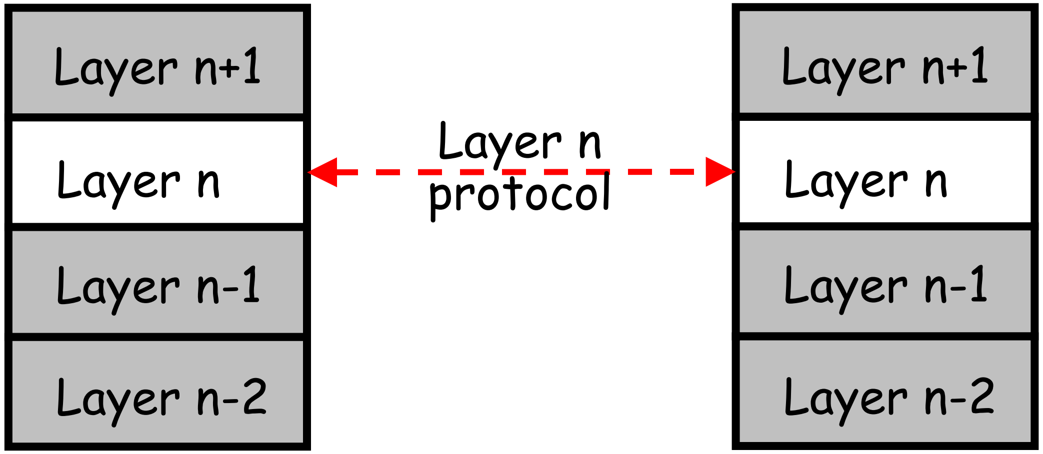
Layers: roles and interactions

- A ***layer located*** is responsible of performing specific tasks
- In a layered model, each layer is located at a level identified by an integer number
- Layer 1 is the lowest
  - L1 usually referred to as the **physical layer**
  - **L1** responsible of transmitting sequence of bits on a digital link
- Lower layers are implemented in hardware, upper layers in software
- Layer *n* provides a ***service*** to layer *n+1*
- Layer *n* (for *n* > 1) uses services provided by layer *n-1*
- The service provided by a layer to the upper layer is accessed through an ***interface***
- Each layer should interact only with adjacent layers

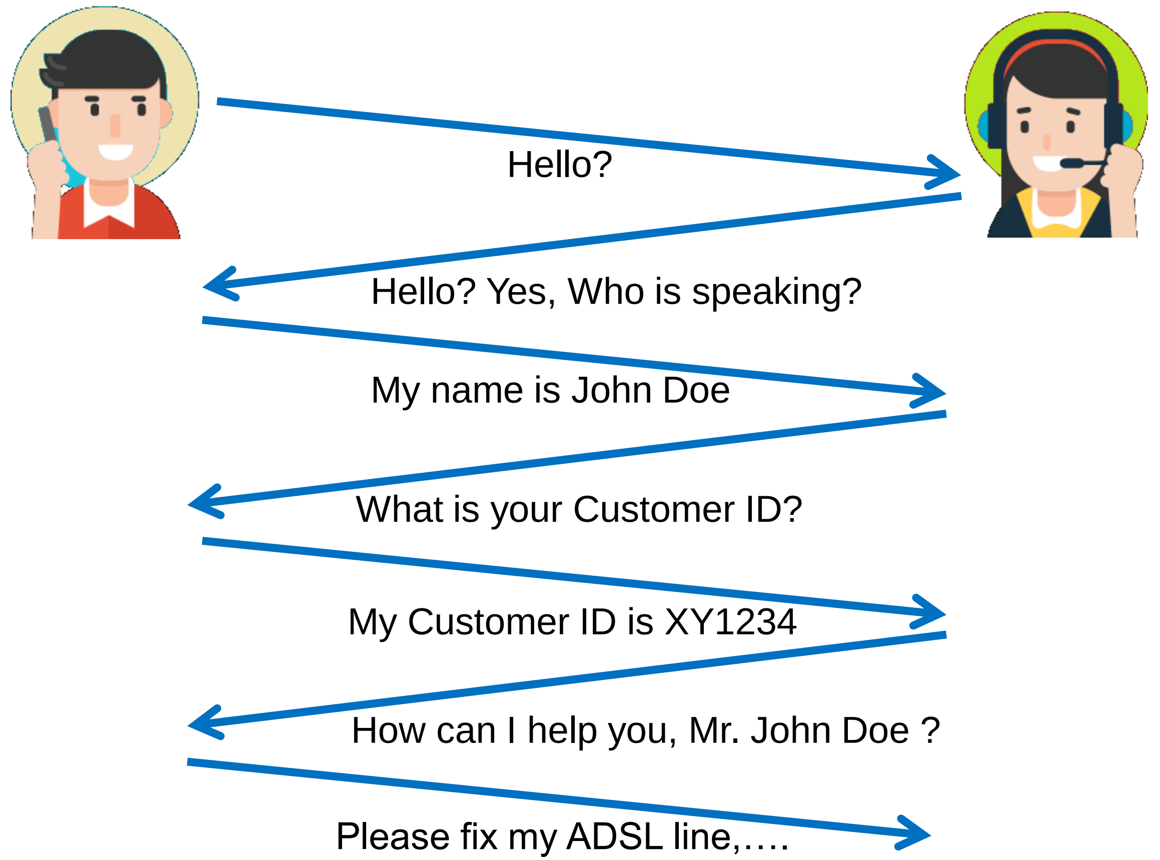


Protocols

- A ***network protocol*** is a set of rules and formats that govern the communication between communicating peers operating at the same layer
- It specifies:
  - format and order of messages sent and received among communicating entities
  - actions to be taken on message transmission or receipt
- Since each layer has its own protocol(s), the term ***protocol stack*** is often used

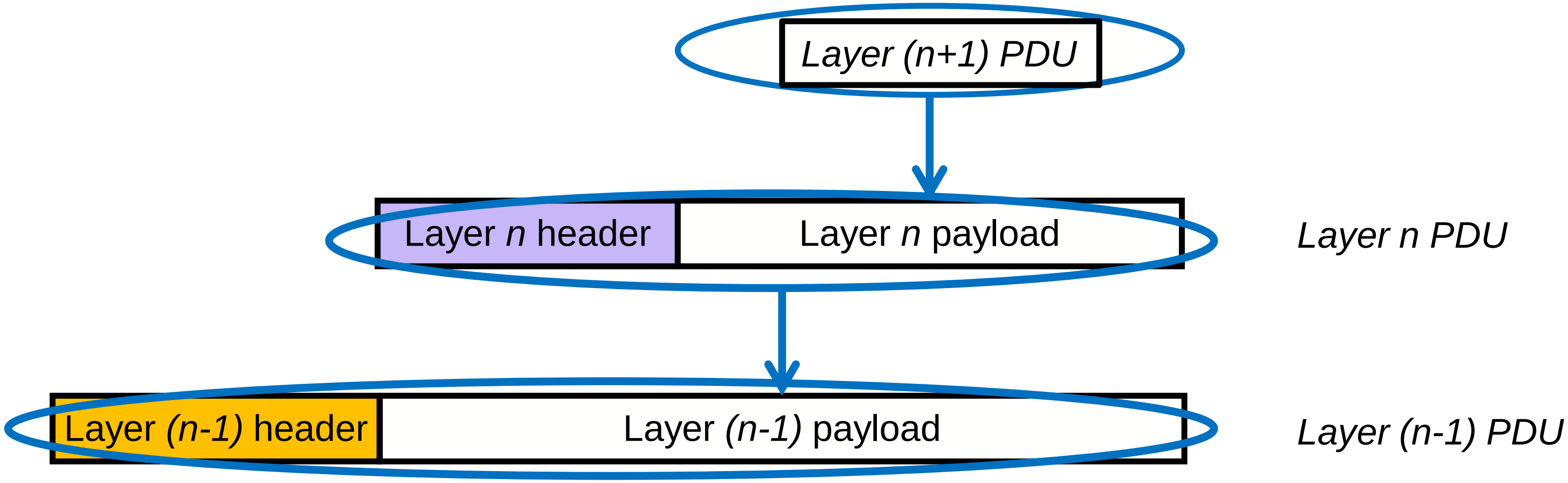


Protocols in real life



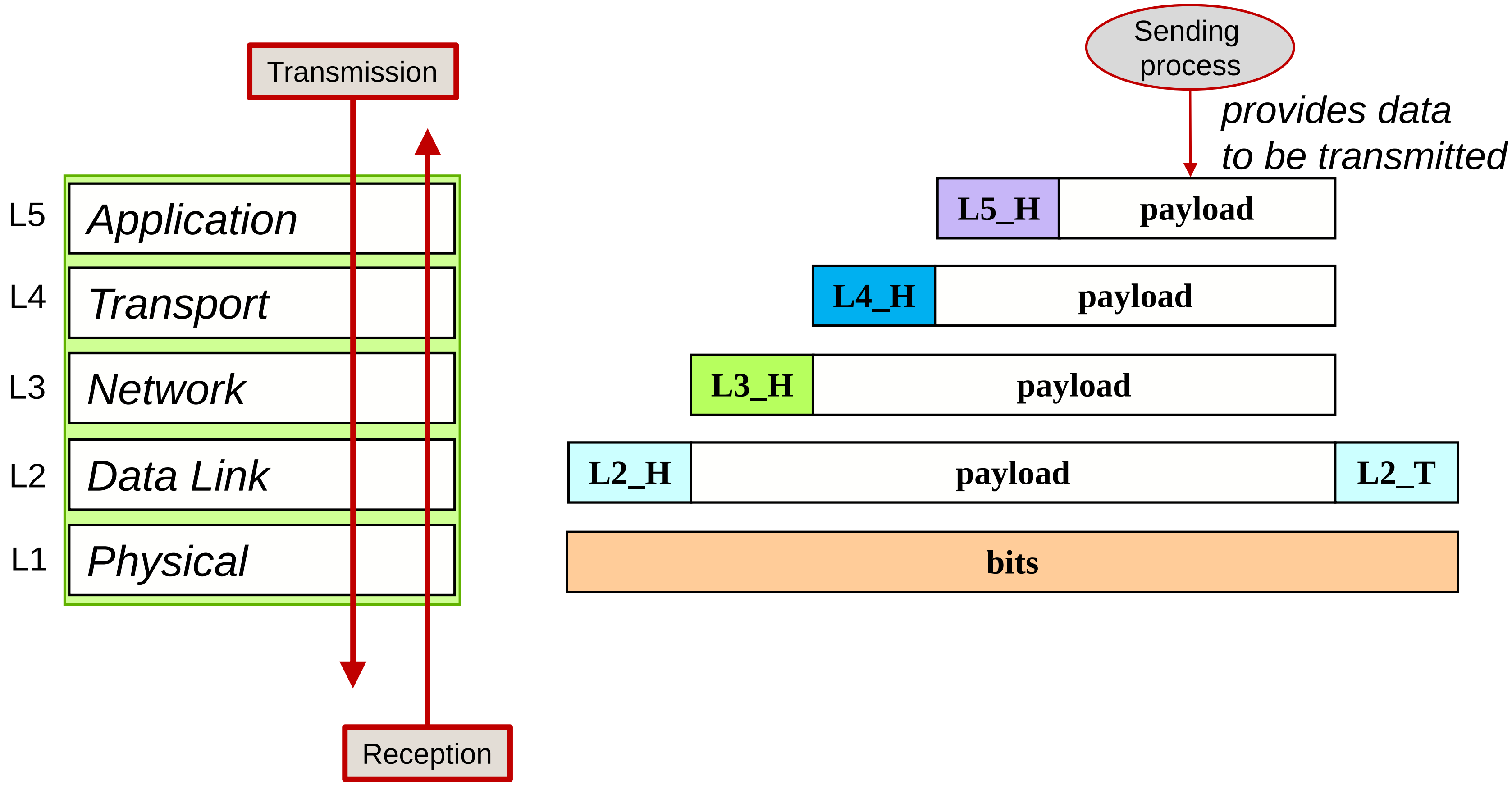
Protocols: PDUs handling (1/2)

- In a layered stack of protocols, each layer receives a payload from the upper layer and forms a ***Protocol Data Unit*** (PDU) made of a ***header*** and a ***payload***



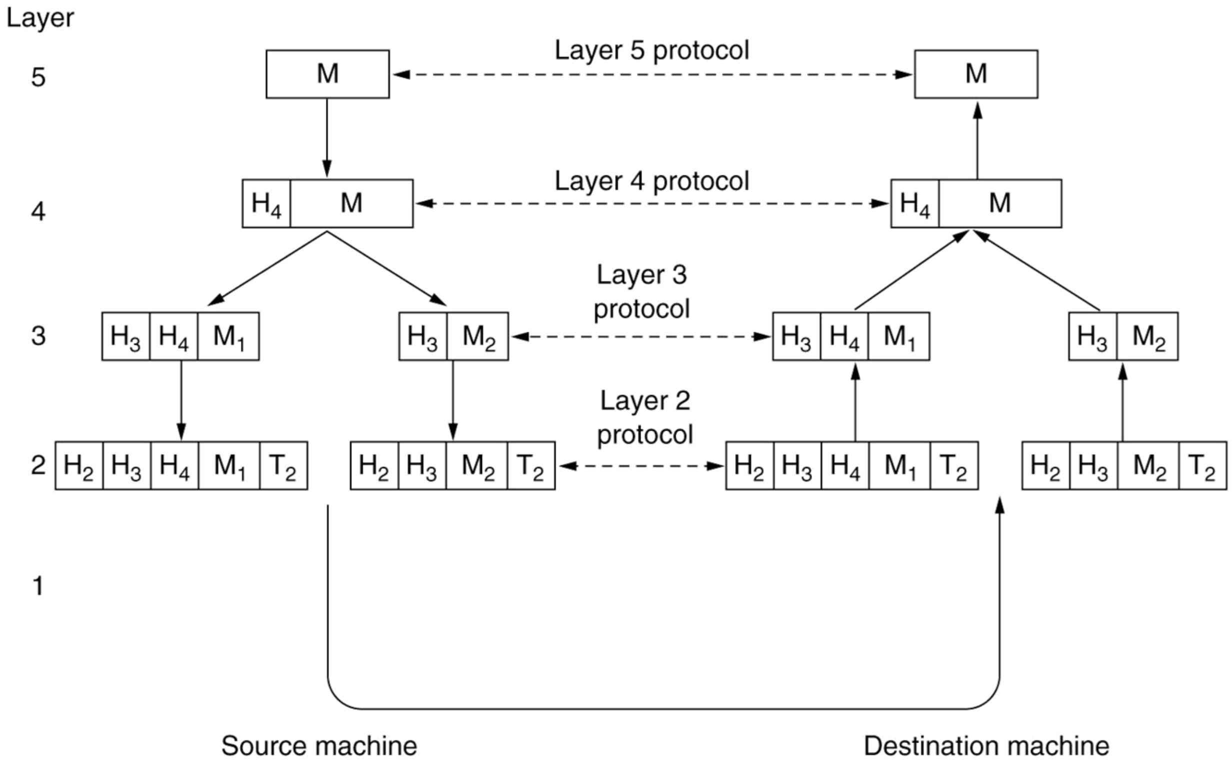
- Such PDU, in turn, is passed to the lower layer as a payload
- Just as with the postal system, the “content” to be sent must be put into an envelope and the envelope must be addressed
  - The PDU header contains control information such as the destination address
- When a PDU is received, the payload is extracted and passed to the upper layer

Protocols: PDUs handling (2/2)



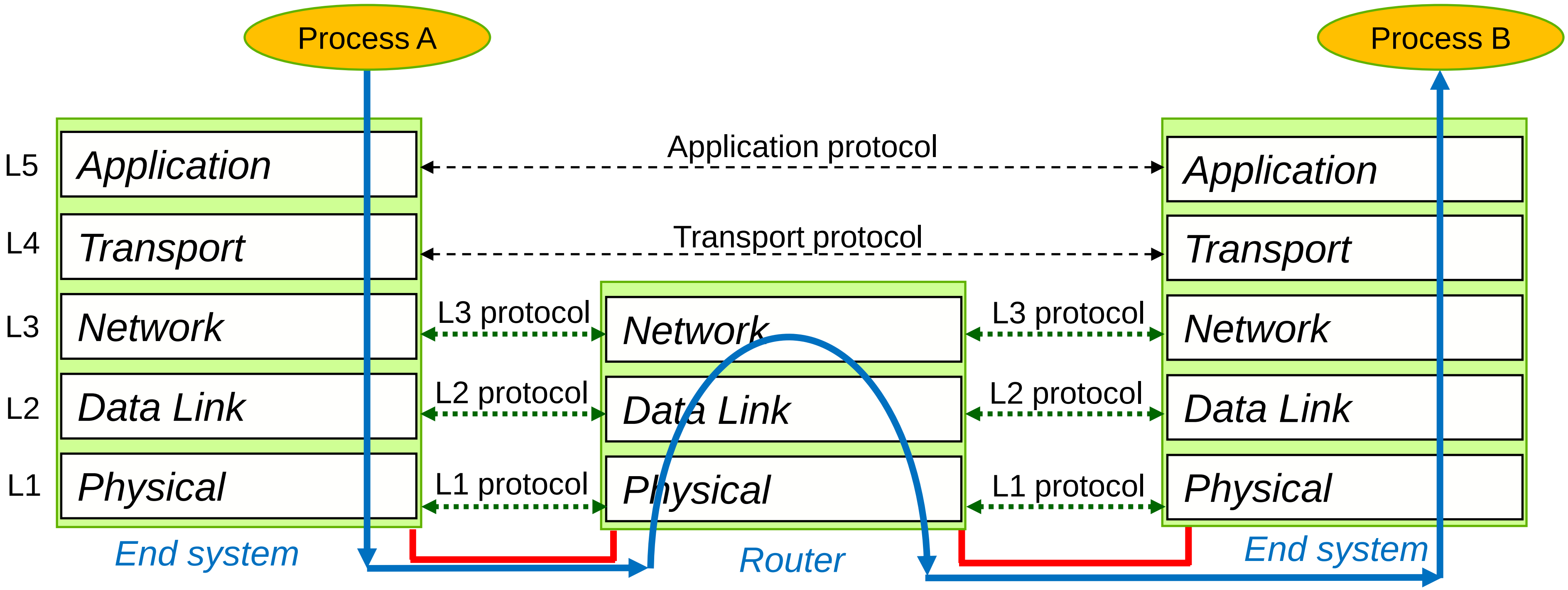
Message fragmentation

- At any layer of a stack it may occur that the payload is too large to fit in a single PDU
- In this event, the payload is split into a sequence of packets → ***fragmentation***
- The original payload is reconstructed at the receiving entity → ***reassembly***



Source: A. S. Tanenbaum. Computer Networks (4 ed.). Prentice Hall, 2003. (Chapter 1, Figure 1.15)

End-to-end communication through an intermediate system

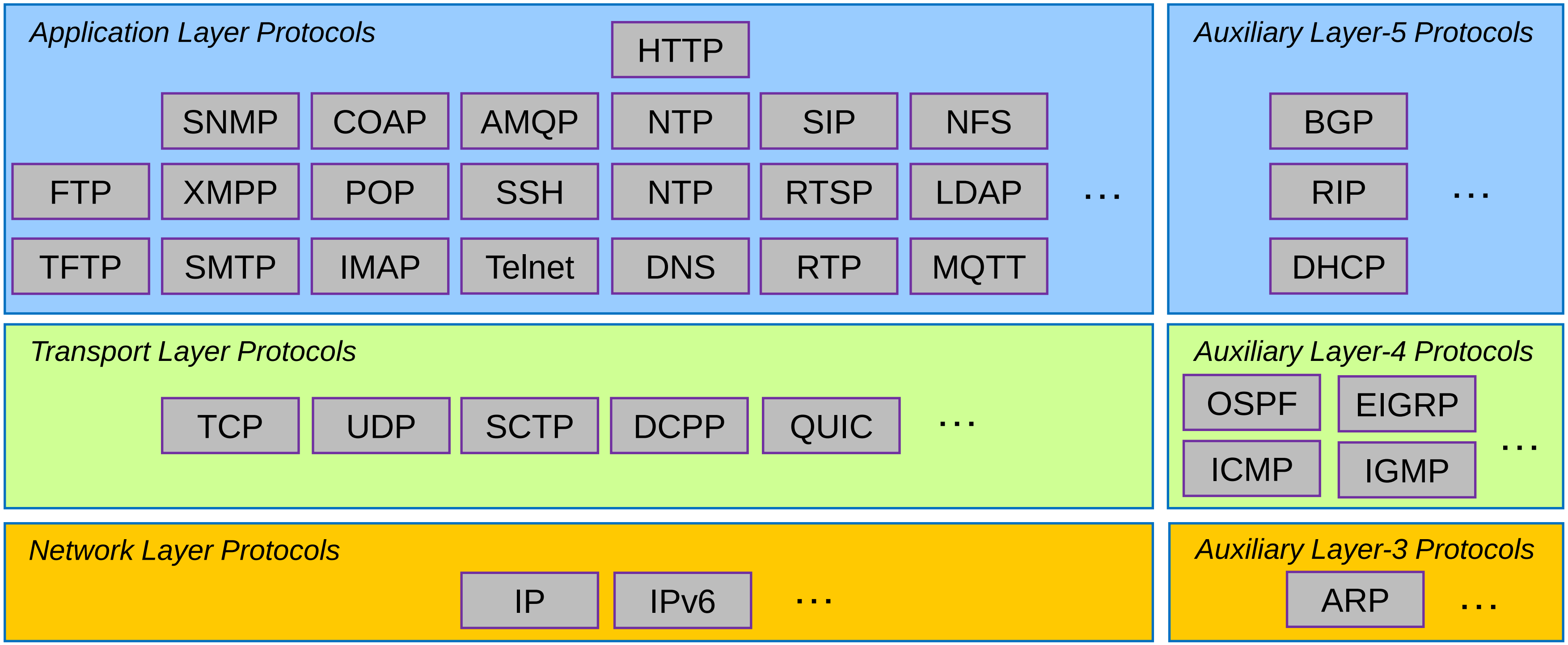


PDU names according to layers

- Generally speaking, a PDU is a ***packet***, made of a ***header***, a ***payload*** and, optionally, of a ***trailer***
- PDUs are usually referred to with different names according to the layer

Layer	**PDU name**
Application	Message
Transport	Segment
Network	Datagram
Data Link	Frame
Physical	Bit

Internet Protocol suite



- The Internet Protocol Suite is the term used to refer to the whole set of protocols today used in the Internet
- Also known as the *TCP/IP protocol stack*
- Most of these protocols are defined by the ***Internet Engineering Task Force*** (IETF)
- These protocols are "*open standards*"
- The Internet Protocol Suite does not consider layers below the Network layer
  - This is because the IP protocol may be adapted to any layer 2 technology

IETF mission

- The **Internet Engineering Task Force (IETF)** is an open standards organization, which develops and promotes voluntary Internet standards, in particular the standards that comprise the Internet protocol suite (TCP/IP)
- The IETF started out in January 1986 as an activity supported by the federal government of the United States
- Since 1993, the IETF operates as a standards-development function under the auspices of the **Internet Society (ISOC)**, an international membership-based non-profit organization
- The primary mission of IETF is to produce high quality, relevant technical documents, called ***Request for Comments*** **(*RFC*)**, that influence the way people design, use, and manage the Internet in such a way as to make the Internet work better
    - RFC 3935: *A Mission Statement for the IETF* (October 2004)
- More specifically, the IETF mission includes:
    - Identifying and proposing solutions to pressing operational and technical problems in the Internet
    - Specifying the development or usage of protocols and the near-term architecture, to solve technical problems for the Internet
    - Facilitating technology transfer from the *Internet Research Task Force* (IRTF) to the wider Internet community
    - Providing a forum for the exchange of relevant information within the Internet community between vendors, users, researchers, agency contractors, and network managers

IETF organization

- Participation to the IETF does not require the payment of membership fees
- IETF takes decisions “***by rough consensus and running code***” rather than by either individual or organization voting
- Technical activities in the IETF are addressed within **working groups**
  - All working groups are organized roughly by function into **seven areas**
  - Each area is led by one or more Area Directors who have primary responsibility for that area of IETF activity
  - Together with the Chair of the IETF/IESG, these Area Directors comprise the *Internet Engineering Steering Group* (IESG)
- The working groups conduct their business during the tri-annual **IETF meetings**, at interim working group meetings, and via electronic mail on mailing lists established for each group
  - The tri-annual IETF meetings are 4.5 days in duration, and consist of working group sessions, training sessions, and plenary sessions
  - Following each meeting, the IETF Secretariat publishes meeting proceedings, which contain reports from all of the groups that met, as well as presentation slides, where available
  - The proceedings also include a summary of the standards-related activities that took place since the previous IETF meeting
- Meeting minutes, working group charters (including information about the working group mailing lists), and general information on current IETF activities are available on the IETF Web site at https://www.ietf.org

The importance of standards for ICT

- A **standard** is a framework of specifications that:
  - either has been approved by a recognized organization (*de-jure*),
  - or is generally accepted and widely used throughout by the industry (*de-facto*)

- Following standard specifications is required to obtain **interoperability** between products of different producers
  - *This practice fosters global competition and drives innovation which, in turn, contributes to the creation of new markets and the growth and expansion of existing markets*

- A particular relevance for the development of ICT has been played by ***open standards***
  - There are a number of definitions of open standards which emphasize different aspects of openness
  - Non-open standards are also referred to as ***closed standards***

- In general, it is widely agreed that an ***open standard*** must satisfy at least the following characteristics:
  - easy accessibility for all readers and users
  - developed by a collaborative open process

- It is not generally agreed whether a truly open standard should be royalty-free or not
  - A *royalty* is a sum to be paid to a patent holder for using it in a product

Open standards

- A definition of Open Standards given by Bruce Perens can be found here in
  - Open Standards: Principles and Practice

- The process of creating RFCs in the IETF is described in RFC 2026
  - RFC 2026: *The Internet Standards Process -- Revision 3*
  - In RFC 2026, the IETF classifies specifications that have been developed in a manner similar to that of the IETF itself as being "open standards" and lists the standards produced by ANSI, ISO, IEEE, and ITU-T as examples

- In August 2012, the leaders of the IETF, the *Institute of Electrical and Electronics Engineers* Standards Association (IEEE), the *Internet Architecture Board* (IAB), the *Internet Society* (ISOC), and the *World Wide Web Consortium* (W3C), signed a statement affirming the importance of a jointly developed set of principles establishing a modern paradigm for global open standards
  - These principles have become known as the "OpenStand" principles
    - https://open-stand.org/about-us/principles/
  - The IETF published the OpenStand declaration in the form of RFC 6852 in January 2013
    - RFC 6852: *Affirmation of the Modern Paradigm for Standards*