Reti di Calcolatori I

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Computer networks: fundamental concepts

1 **What is a computer network ?**

2 **PSTN and circuit switching**

3 **Computer networks and packet switching**

4 **Type of networks by geographic extension: LAN, WAN, MAN**

5 **Internetworking**

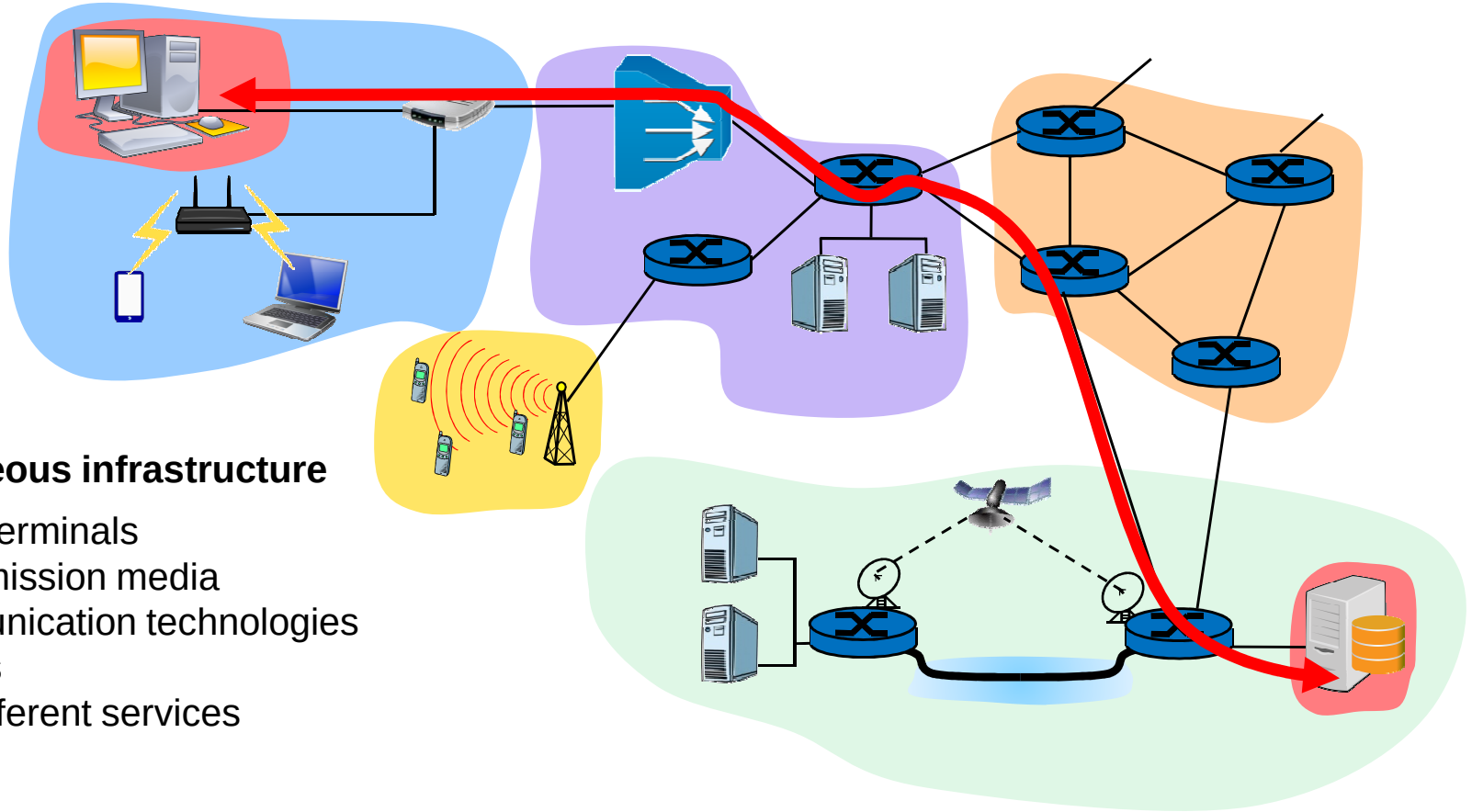
6 **Layered models of computer networks**

7 **Layers and protocols**

8 **Five layers model of the Internet and the Internet Protocol suite**

What is a computer network ?

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



An 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, …

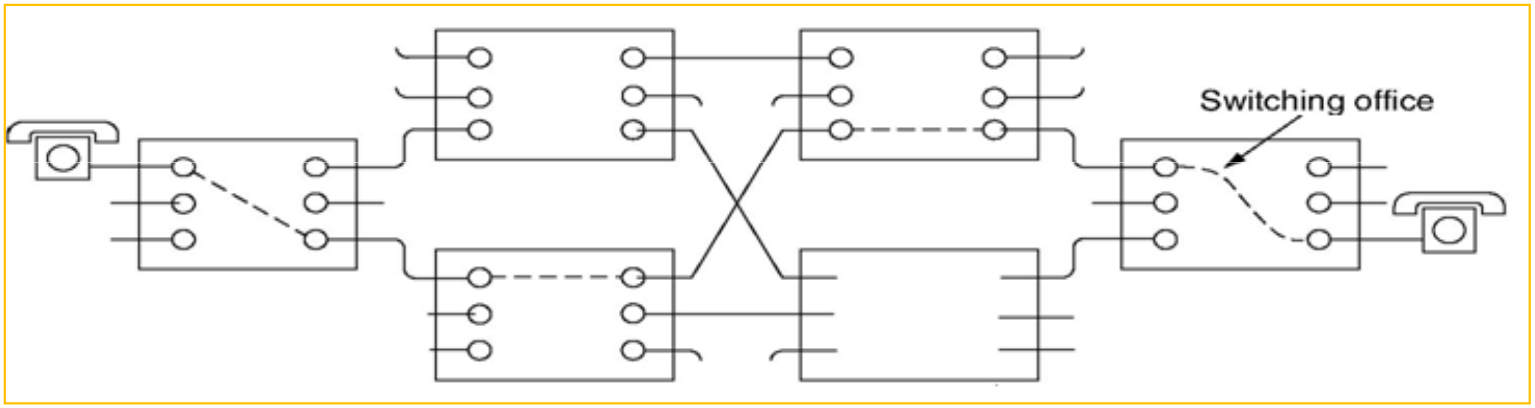
- **Connections (*a.k.a. links*)**
  - ***physical wires*** or cables
  - ***wireless connections***, using radio waves or infrared signals

Digital links: data rate

- A digital link allows to transmit ***bits*** (0 and 1 symbols) from one device to another
- A digital link ***data rate*** is the amount of bits that can be transmitted over the link 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 =** $\dfrac{L \text{ (bits)}}{R \text{ (bits/sec)}}$

PSTN and circuit switching (1/2)

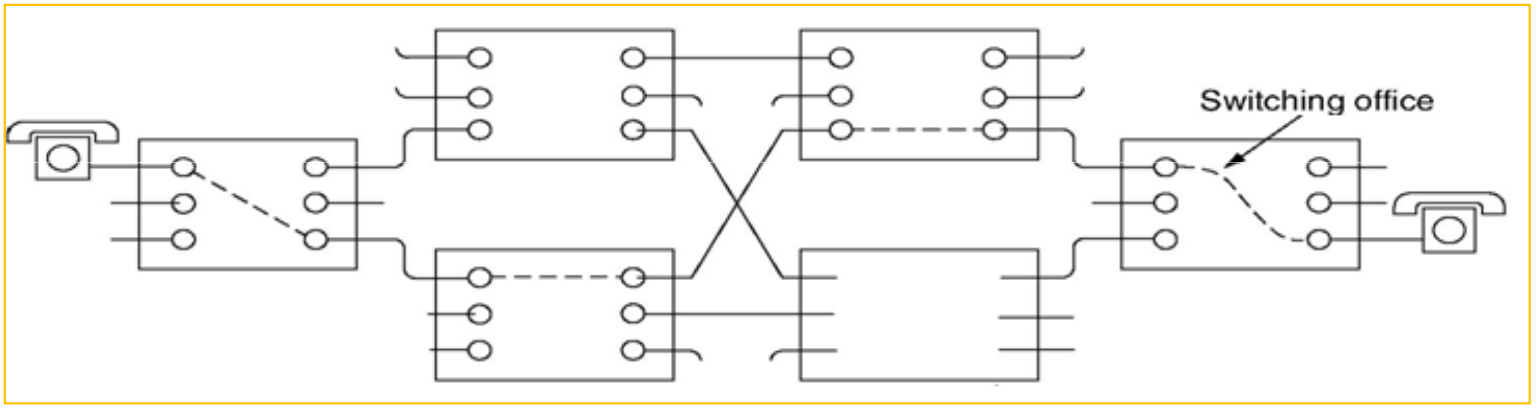
- Computer networks operate according to the ***packet switching model***, while the traditional telephone system operates according to the ***circuit switching model***
- In the PSTN (*Public Switched Telephone Network*), communicating terminals (*phones*) are connected through switching offices
  - 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)

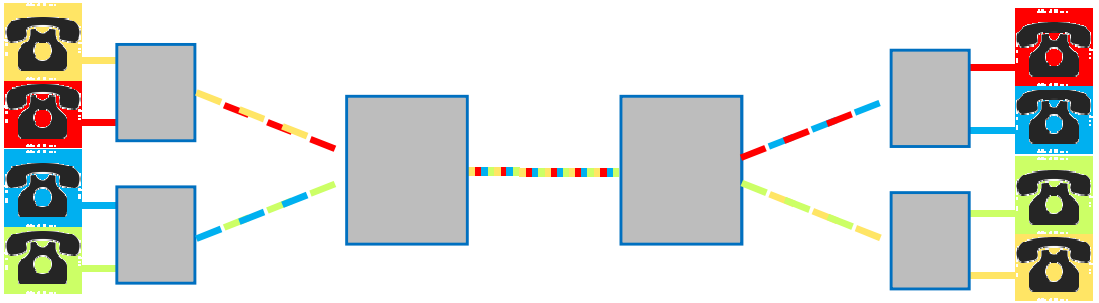
- Establishing a communication in a circuit switching network involves 3 phases:
  1) Circuit establishment
     - Route selection and link by link resource allocation
  2) Call or data transfer
  3) Circuit tear-down
     - Resource deallocation

- 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)



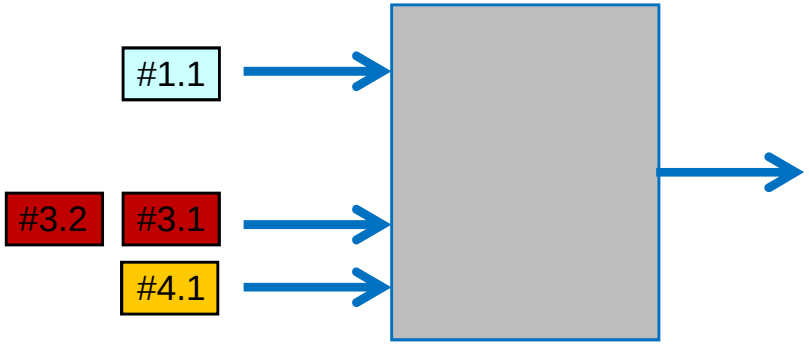
- Both TDM and FDM partition a link capacity in channels of fixed capacity
  - A single phone call is typically transmitted over a 64 kb/s channel
  - A channel is associated to a specific call during the circuit establishment phase

Computer networks and packet switching

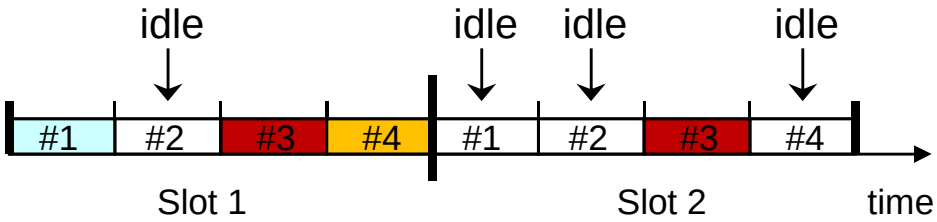
- Computer networks operate according to the ***packet switching model***
- In a packet switched network, information is transmitted in ***packets*** formed by a ***header*** and a ***payload***
  - the header contains control information including a destination ***address*** identifying the terminal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

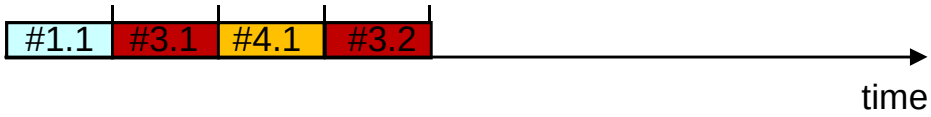
Packet switching and statistical multiplexing



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



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

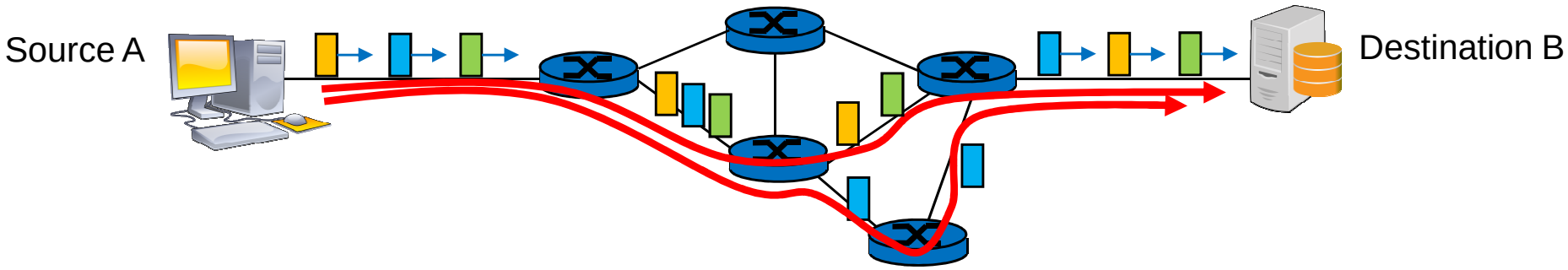


Packet switching allows ***statistical multiplexing*** of packets

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

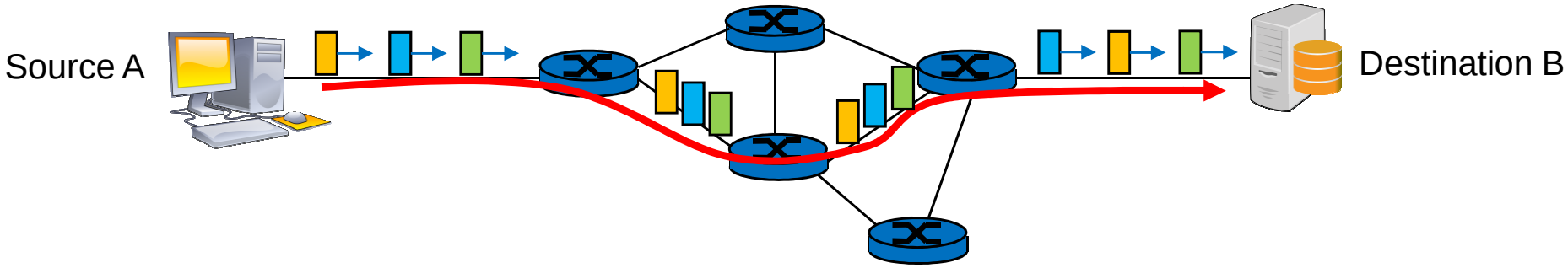


Beware: packets may get lost during their journey from A to B

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 (but this is packet switching!)

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

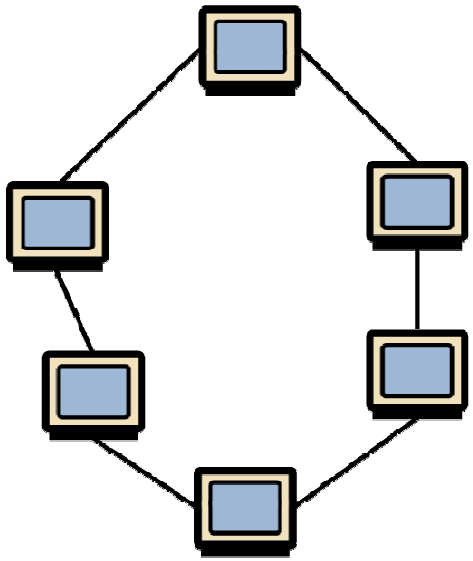
Wide-area network (WAN)
Connects two or more local-area networks over a potentially large geographic distance

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

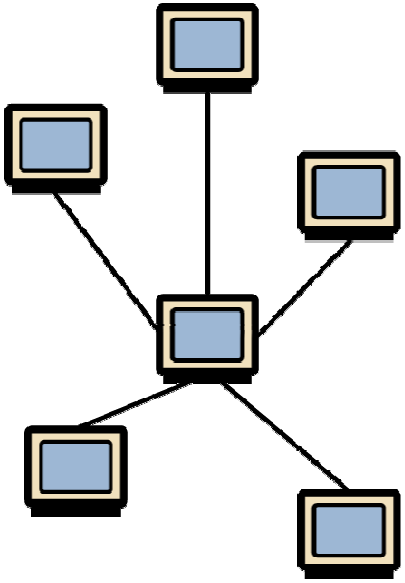
The Internet, as we know it today, is essentially the ultimate wide-area network, spanning the entire globe

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

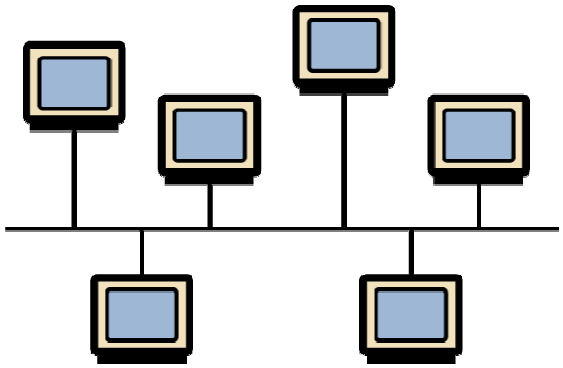
LAN topologies



Ring topology



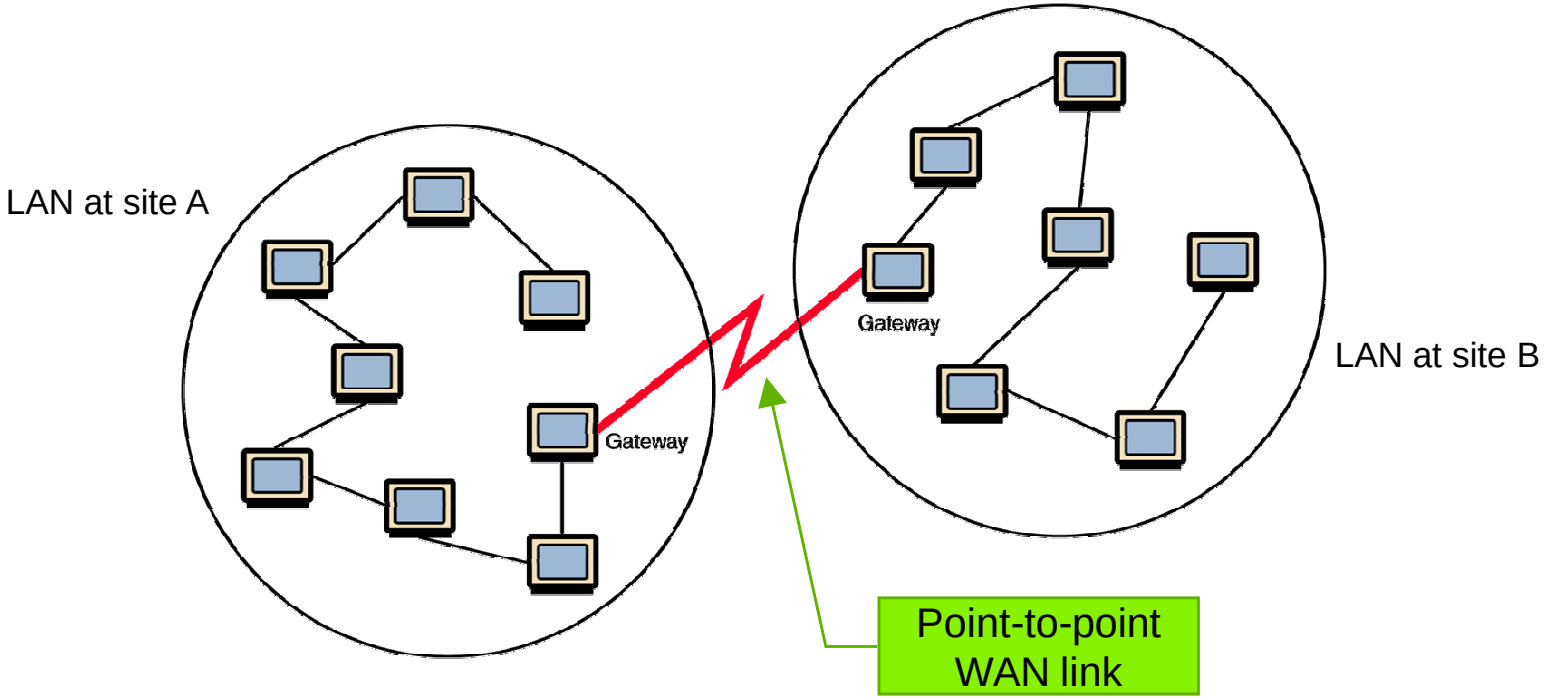
Star topology



Bus topology

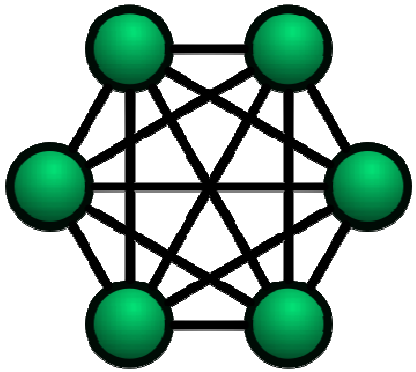
Internetworking

- 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

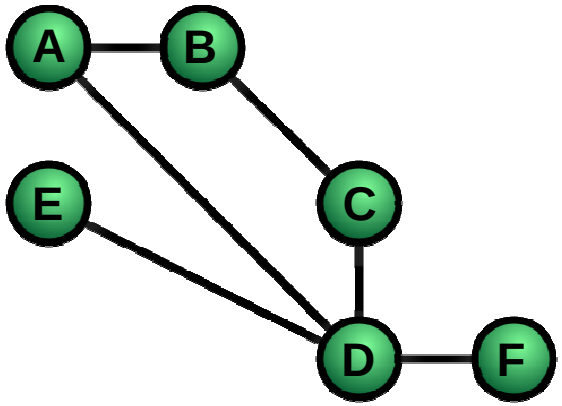


- Large scale internetworks (such as the Internet) cannot have a full mesh topology for scalability reasons
    - Most of the links would be rarely used anyway

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

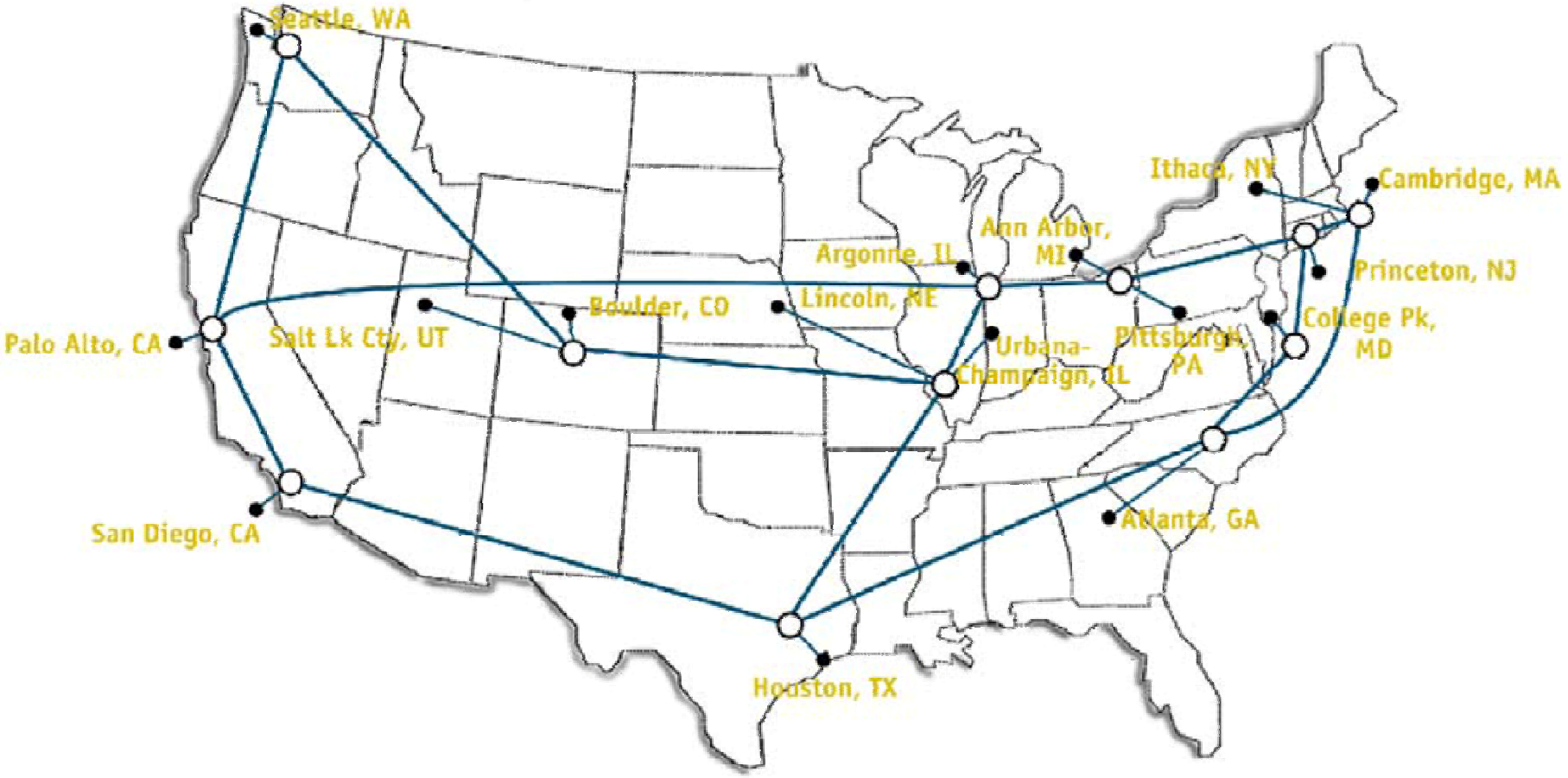
If not directly connected, two nodes may communicate along a **path** traversing other intermediate nodes



A may communicate with F along the paths:

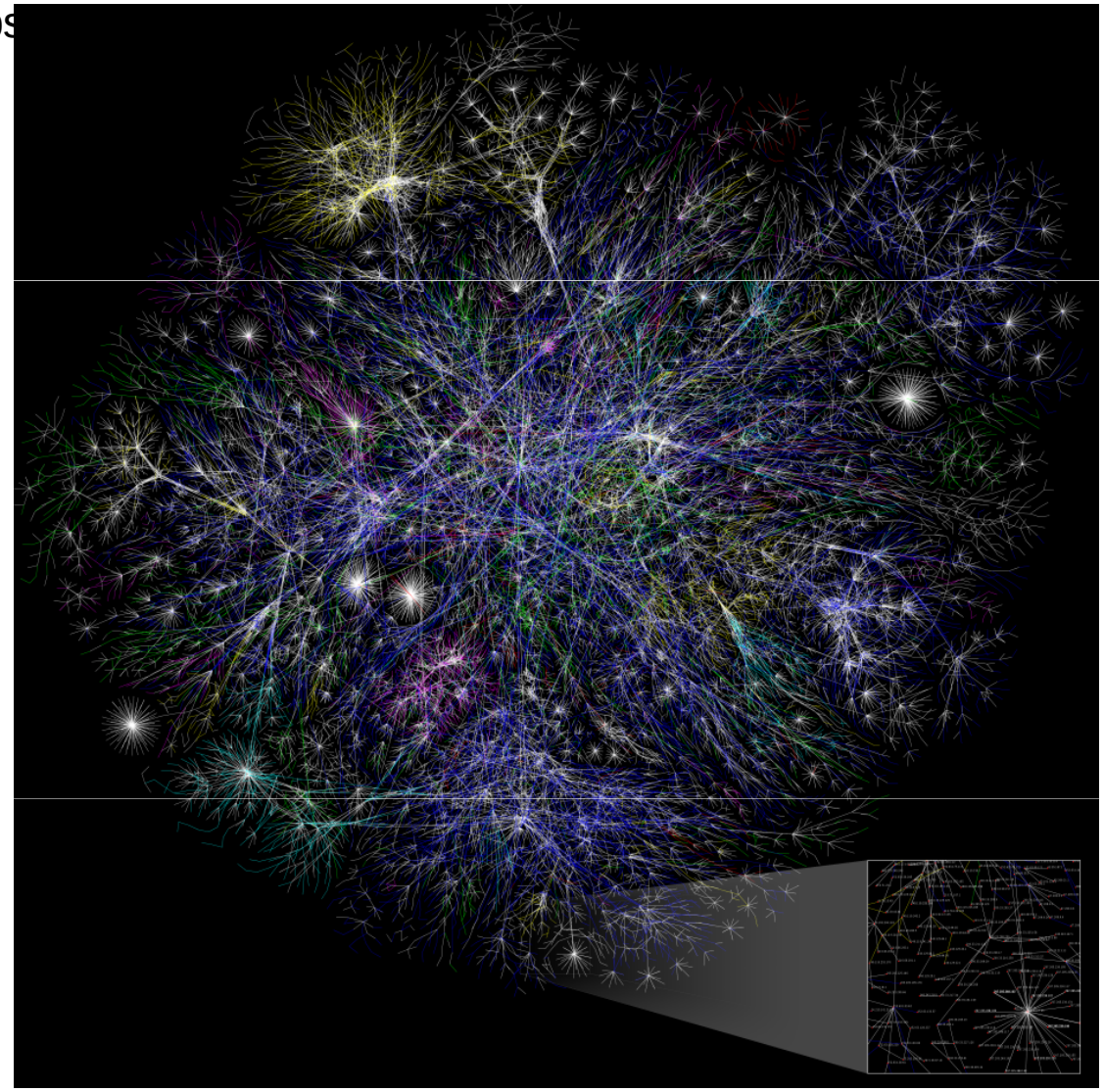
a) A ↔ D ↔ F
b) A ↔ B ↔ C ↔ D ↔ F

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



Layered models of computer networks

- Computer networks are engineered according to layered conceptual models
  - Each layer deals with a particular aspect of network communication

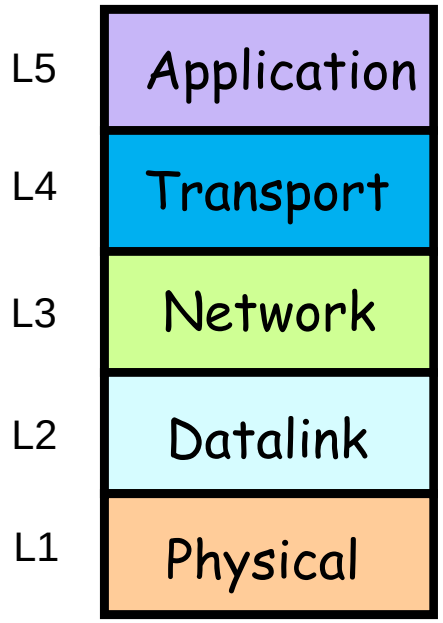
- Historically, the **International Organization for Standardization** (ISO) established the **Open Systems Interconnection** (OSI) Reference Model, based on seven layers
  - Today used almost exclusively for teaching purposes
  - Layers 1 to 3 are implemented in both terminals and gateways
  - Layers 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

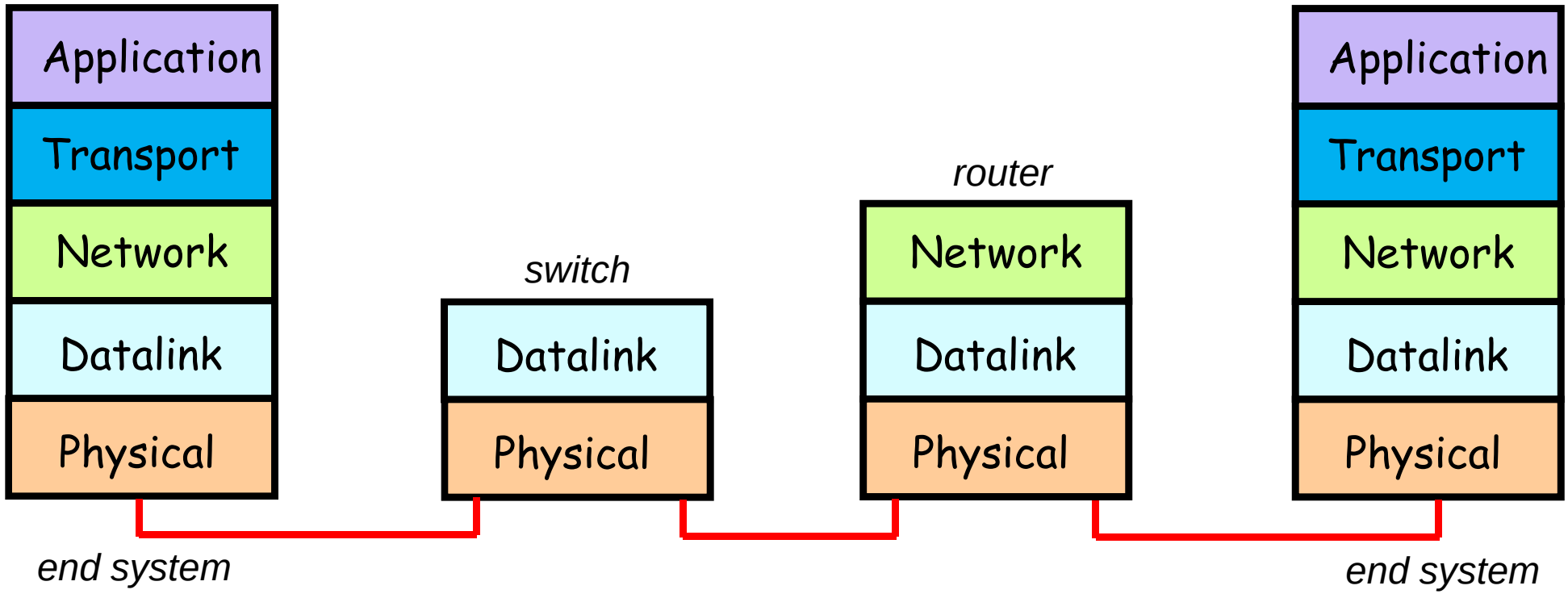
Five layers model of the Internet

- 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



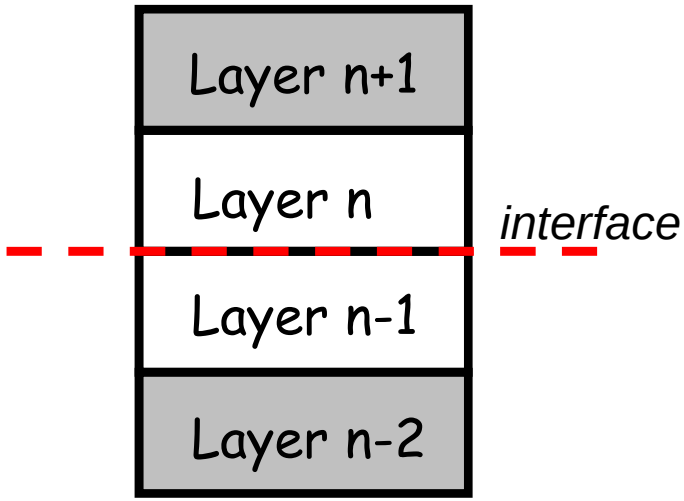
Layers and intermediate devices

- 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



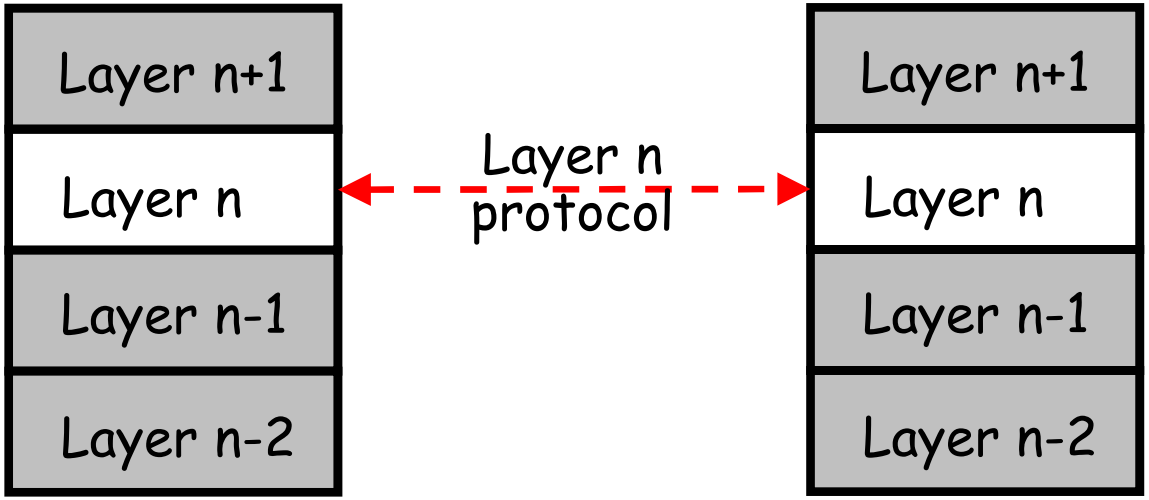
Layers: roles and interactions

- 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

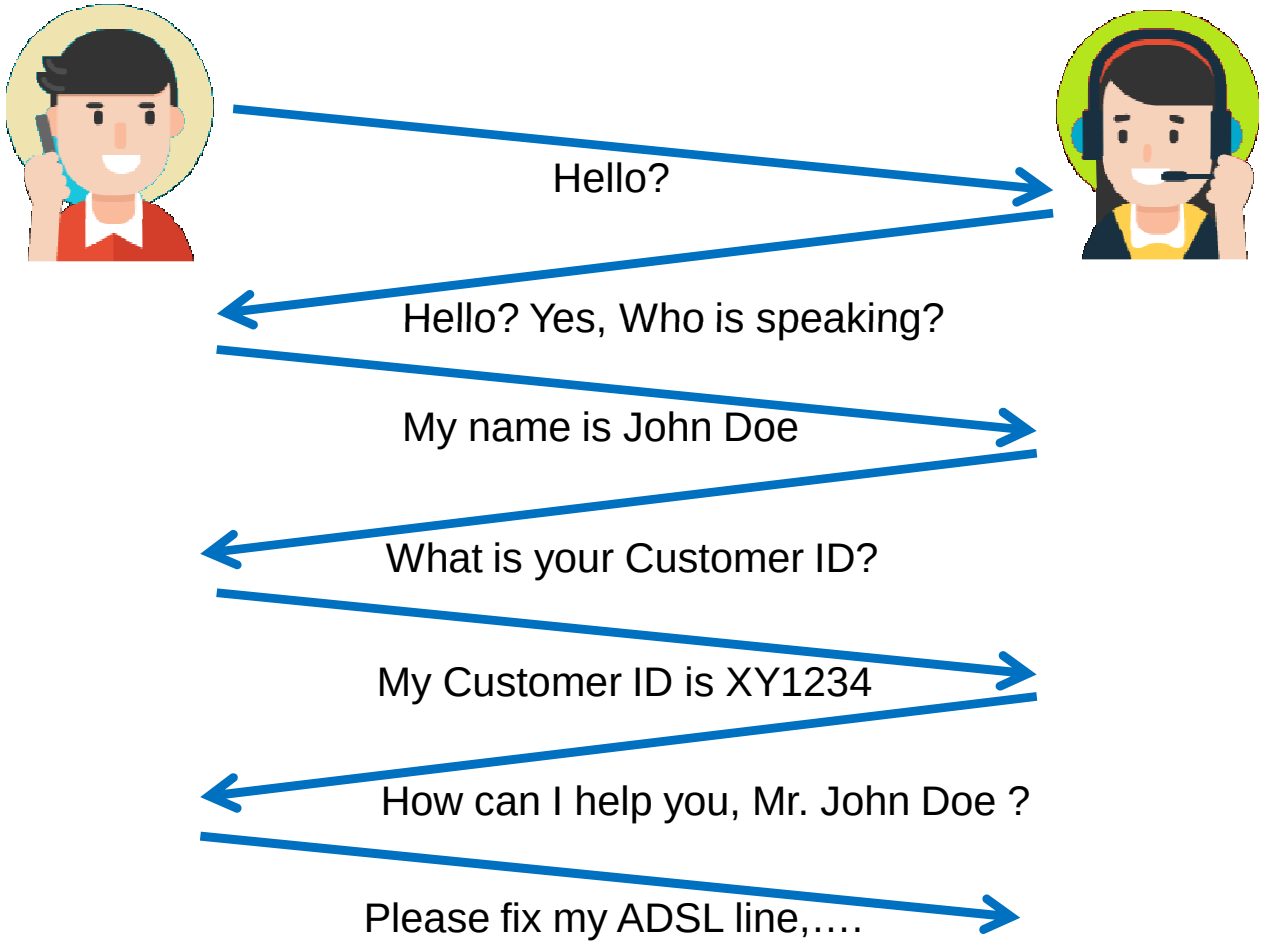


Protocols

- 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

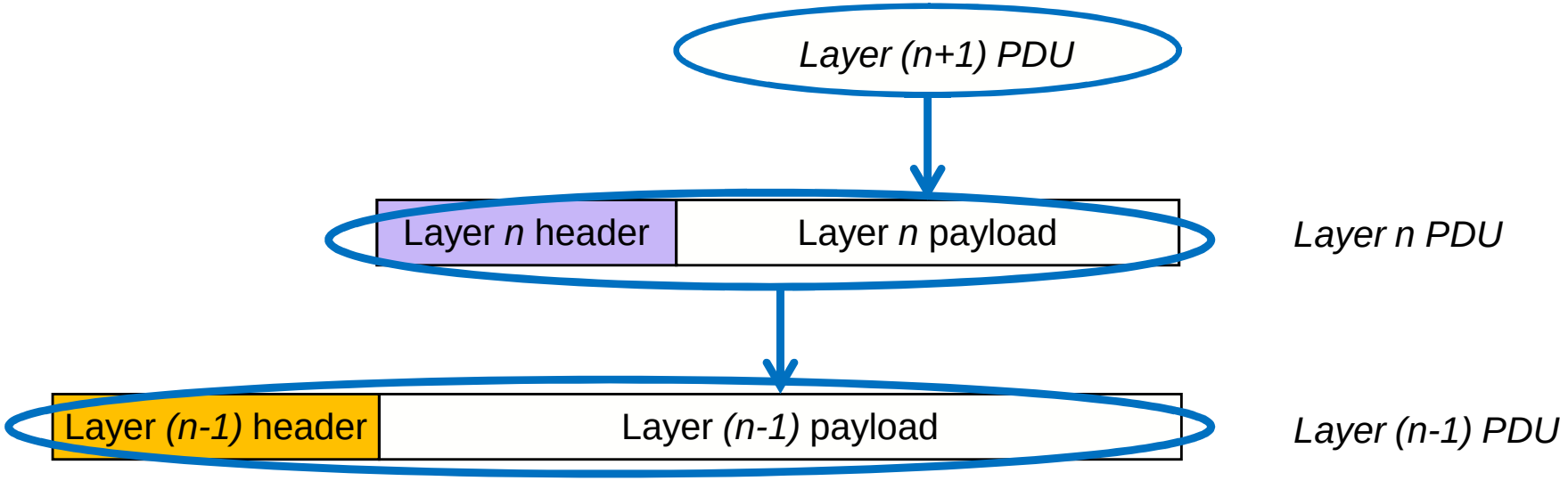


Protocols in real life



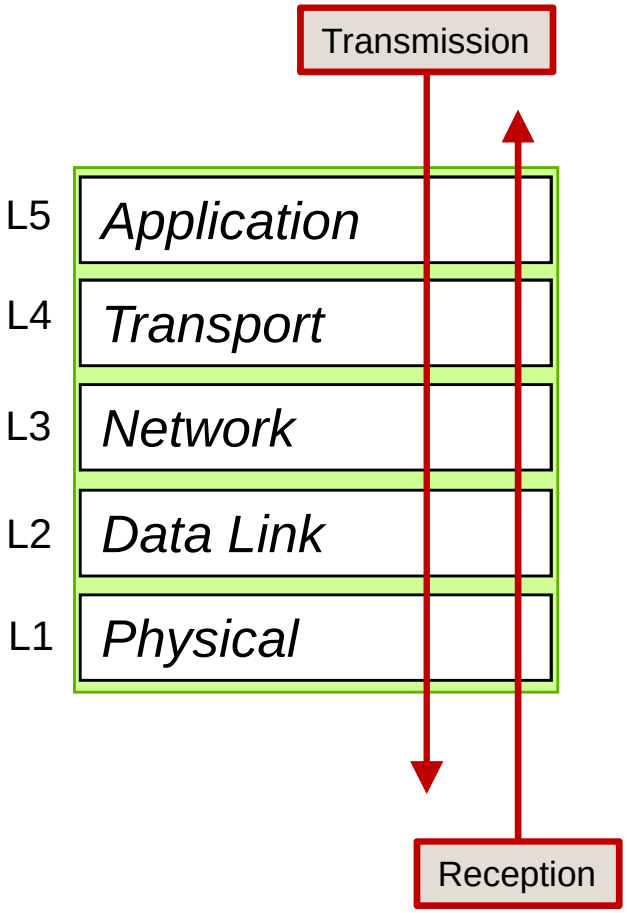
Protocols: PDUs handling (1/2)

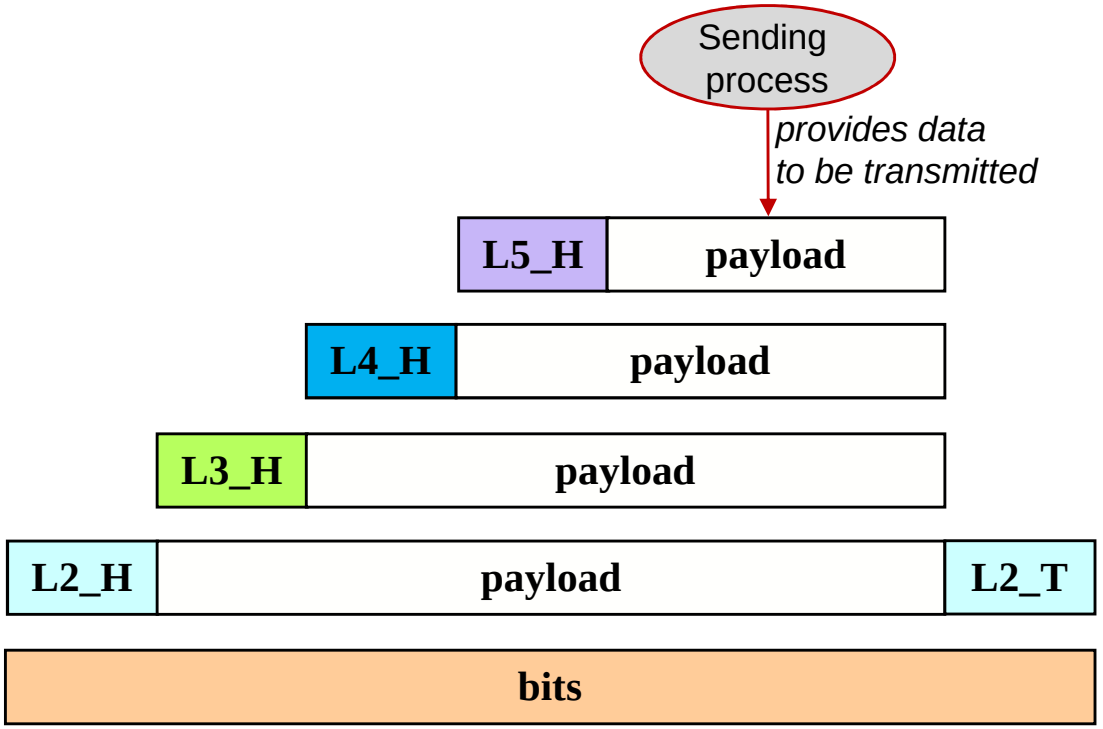
- In a layered stack of protocols, each layer receives a payload from the upper layer and forms a ***Protocol Data Unit*** (PDU) made of a ***header*** and a ***payload***



- 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

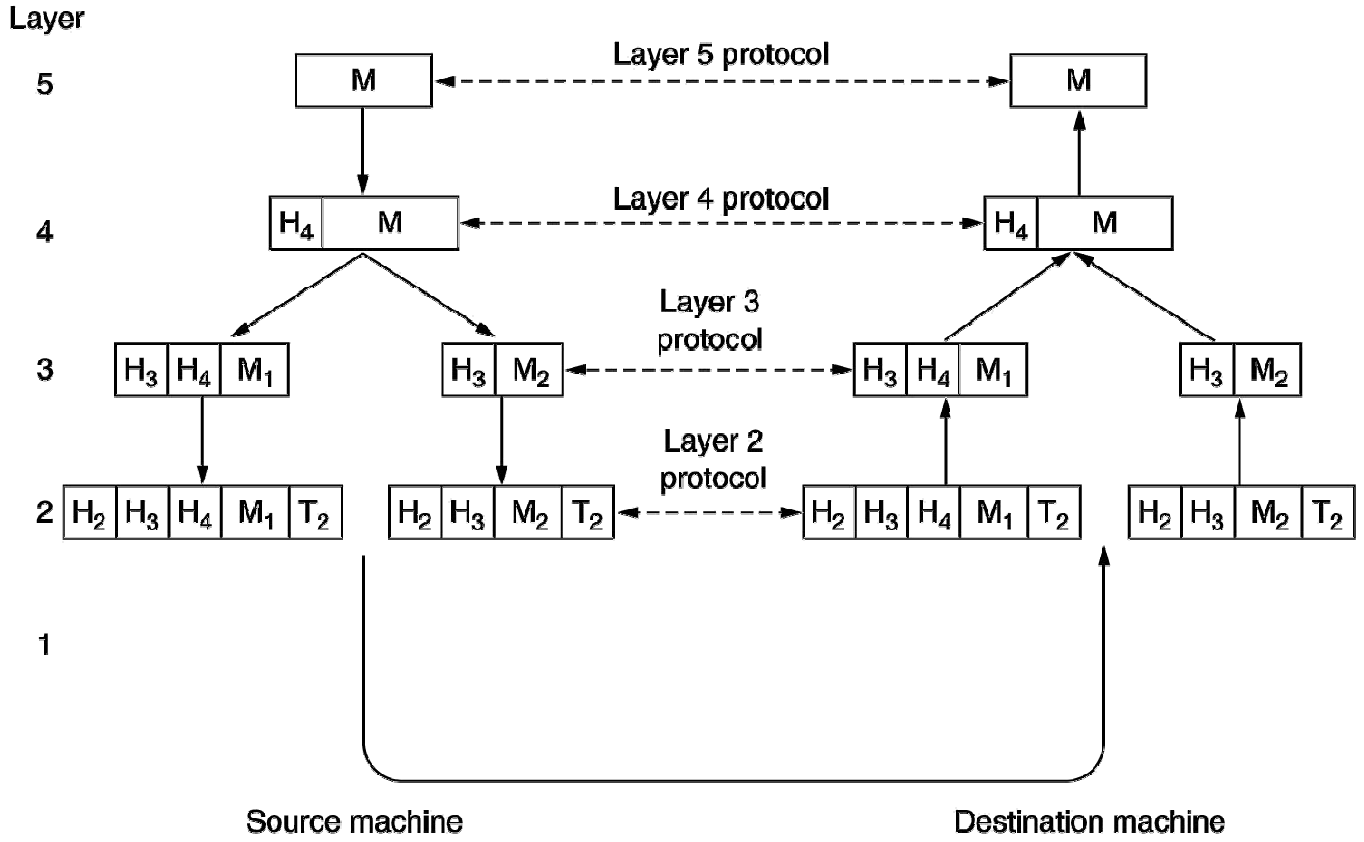
Protocols: PDUs handling (2/2)





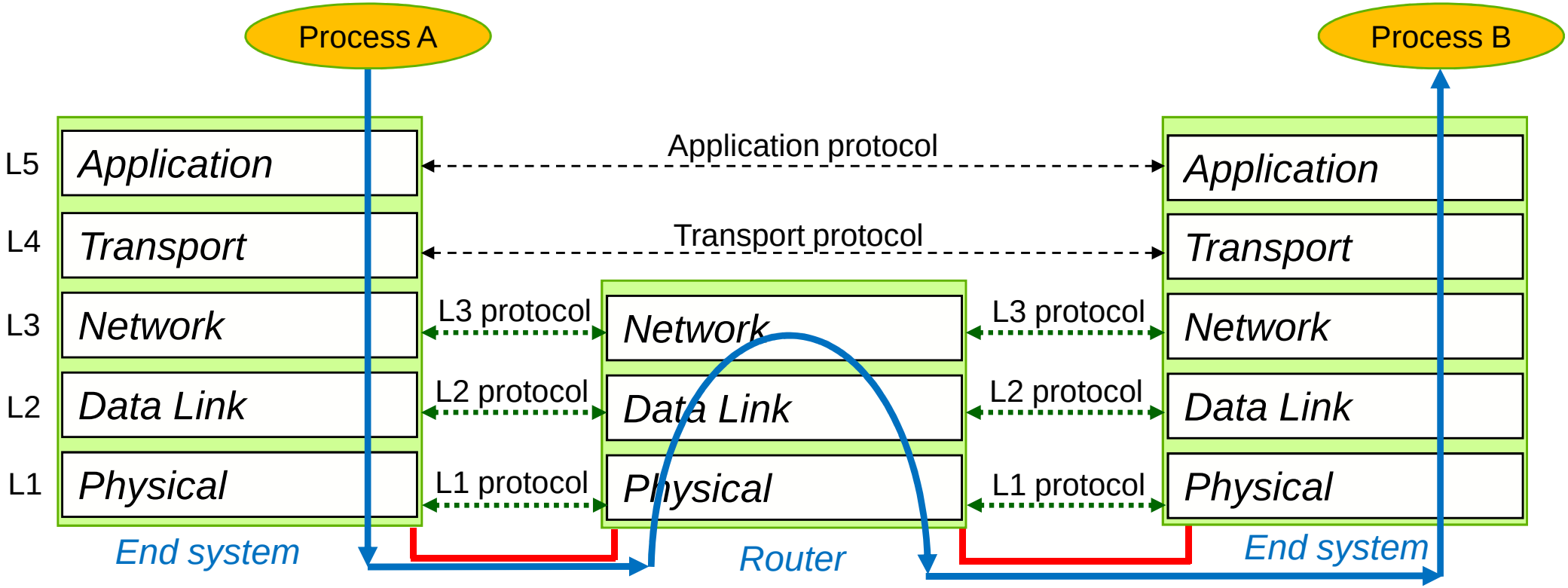
Message fragmentation

- 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

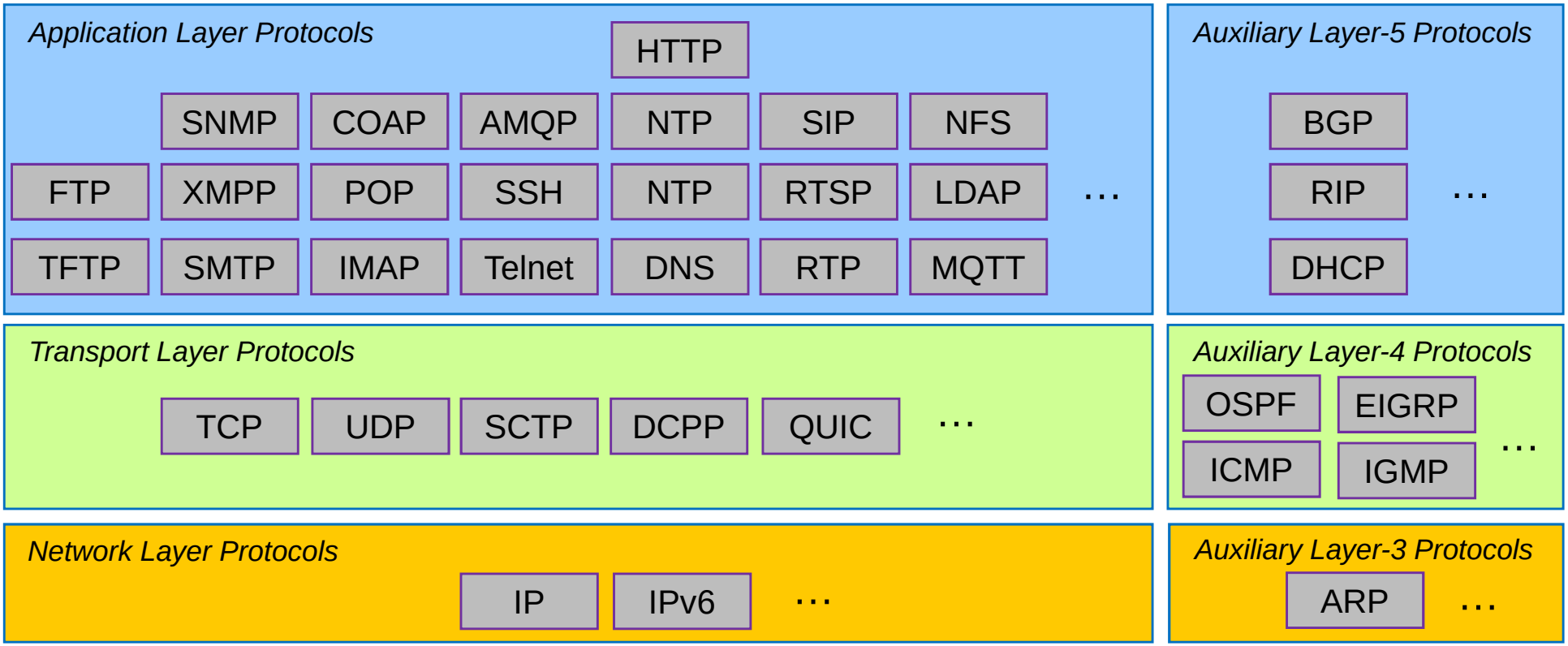


PDU names according to layers

- 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)
- 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