

# Outline

- Course Syllabus
- **Unit 1: Introduction**
- Unit 2. IP Networks
- Unit 3. LANs
- Unit 4. TCP
- Unit 5. Network applications

These slides are based on the set of slides provided by Llorenç Cerdà for this course. They include some modifications and some new slides.

# Disclaimer

- Most of the material for the slides is borrowed from the common set of slides prepared by Llorenç Cerdà for this course
- Other slides are borrowed from other colleagues in our Department (Leandro Navarro, Jaime Delgado, David Carrera, among others)
- The rest of the material is available in several web sites
- The corresponding source is stated when appropriate

# Unit 1: Introduction

## Outline

- **Brief history of Computer Networks and Internet**
- Introduction to the Internet
- Standardization Organizations and OSI Reference Model
- Client-Server Paradigm

# Unit 1: Introduction

## Brief history of Computer Networks

- 1830: **Telegraph**
- 1866: First **transatlantic telegraph** cable
- 1875: Alexander Graham Bell invented the **telephone**
- 1951: First **commercial computer**
- 1960: Concept of **Packet Switching**.
- 1960s: **ARPANET** project, origins of the Internet.
- 1972: First International and **commercial Packet Switching** Network, X.25.
- 1990s: The **Internet** is opened to the general public.



Pavel Shilling Telegraph, 1832.



Major Telegraph Lines, 1891.



UNIVAC: First commercial computer, 1951

Source: wikipedia



New York Telephone Cabling, 1888



Telephone Central Office in London, 1926



Today's Networking Equipment.

# Video

History of the Internet

Història d'Internet (8')





Foto (c) Clark Quinn, Boston, Massachusetts.

En 1994, para conmemorar los 25 años transcurridos desde la creación de ARPANET la empresa Bolt Beranek and Newman, a la que la ARPA contrató para poner en marcha esta red, reunió en su sede de Boston a la mayoría de los que formaron parte del grupo que puso todo en marcha.

Estos son: De izquierda a derecha, primera fila: **Bob Taylor** (1), **Vint Cerf** (2), Frank Heart (3); segunda fila: Larry Roberts (4), **Len Kleinrock** (5), **Bob Kahn** (6); tercera fila: Wes Clark (7), Doug Engelbart (8), Barry Wessler (9); cuarta fila: Dave Walden (10), Severo Ornstein (11), Truett Thach (12), Roger Scantlebury (13), Charlie Herzfeld (14); quinta fila: Ben Barker (15), **Jon Postel** (16), **Steve Crocker** (17); última fila: Bill Naylor (18), Roland Bryan (19)

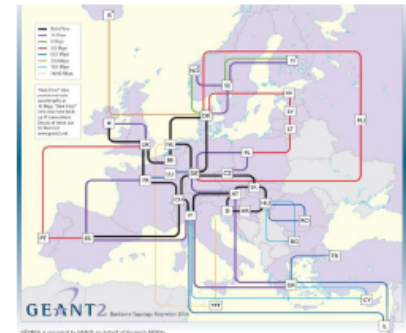
[A brief History of the Internet](#)

Los verdaderos creadores de Internet / Foto: Clark Quinn, Boston, Massachusetts

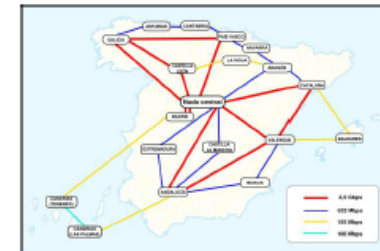
# Unit 1: Introduction

## Brief History of the Internet

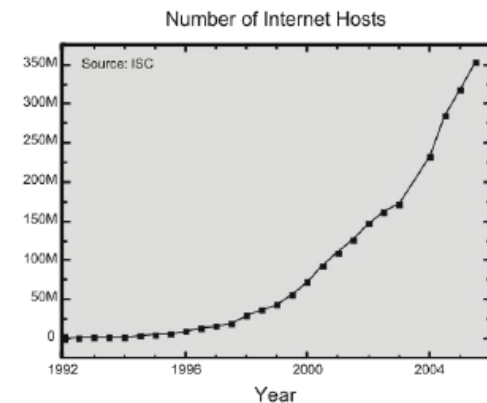
- 1966: Defense Advanced Research Projects Agency (DARPA). **ARPANET** project.
- ARPANET connected **Universities**, **research labs** and **military centers**. Military portion separated in 1983. 1/1/1983 ARPAnet adopts IP
- 1970s: End-to-end reliability was moved to hosts, developing **TCP/IP**. TCP/IP was ported to **UNIX Berkeley distribution**, **BSD**.
- 1990s: The **Internet** is opened to **commerce** and the general public by the **Internet Service Providers, ISP**.



<http://www.geant2.net>

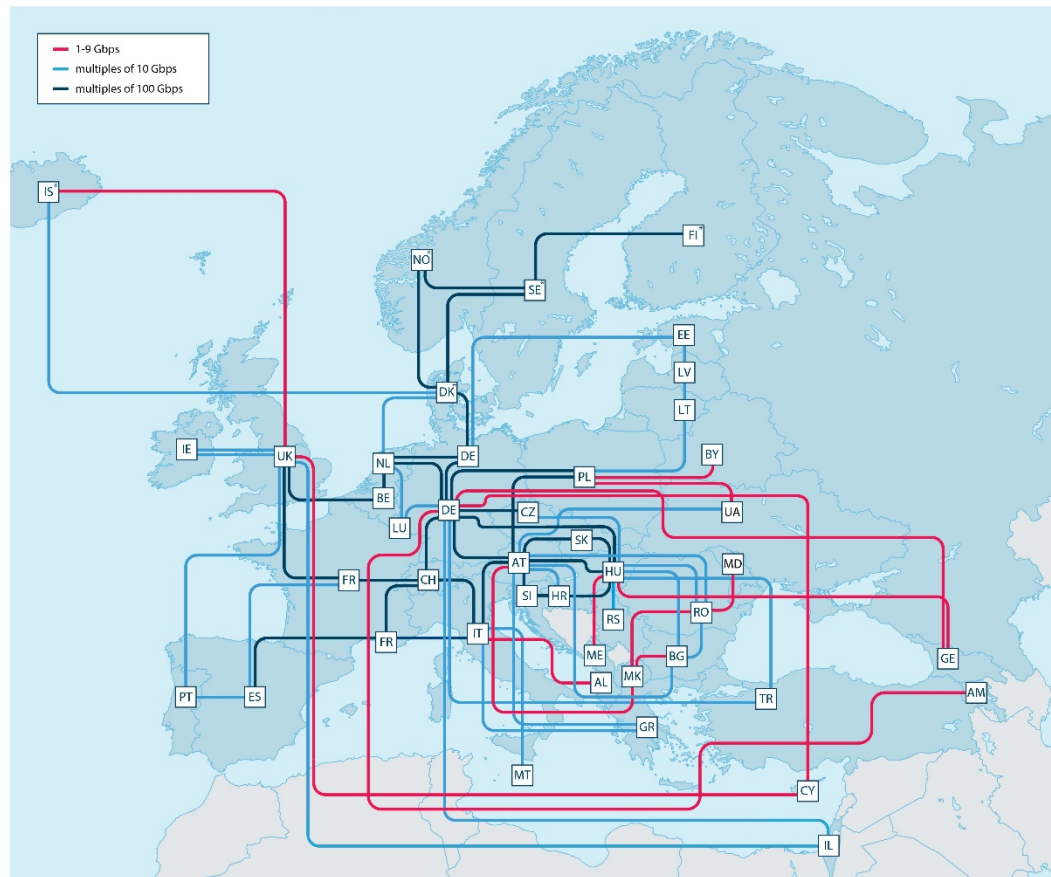


<http://www.rediris.es>





GÉANT's pan-European **research and education network** interconnects Europe's National Research and Education Networks (NRENs). Together we connect over **50 million users** at 10,000 institutions across Europe.

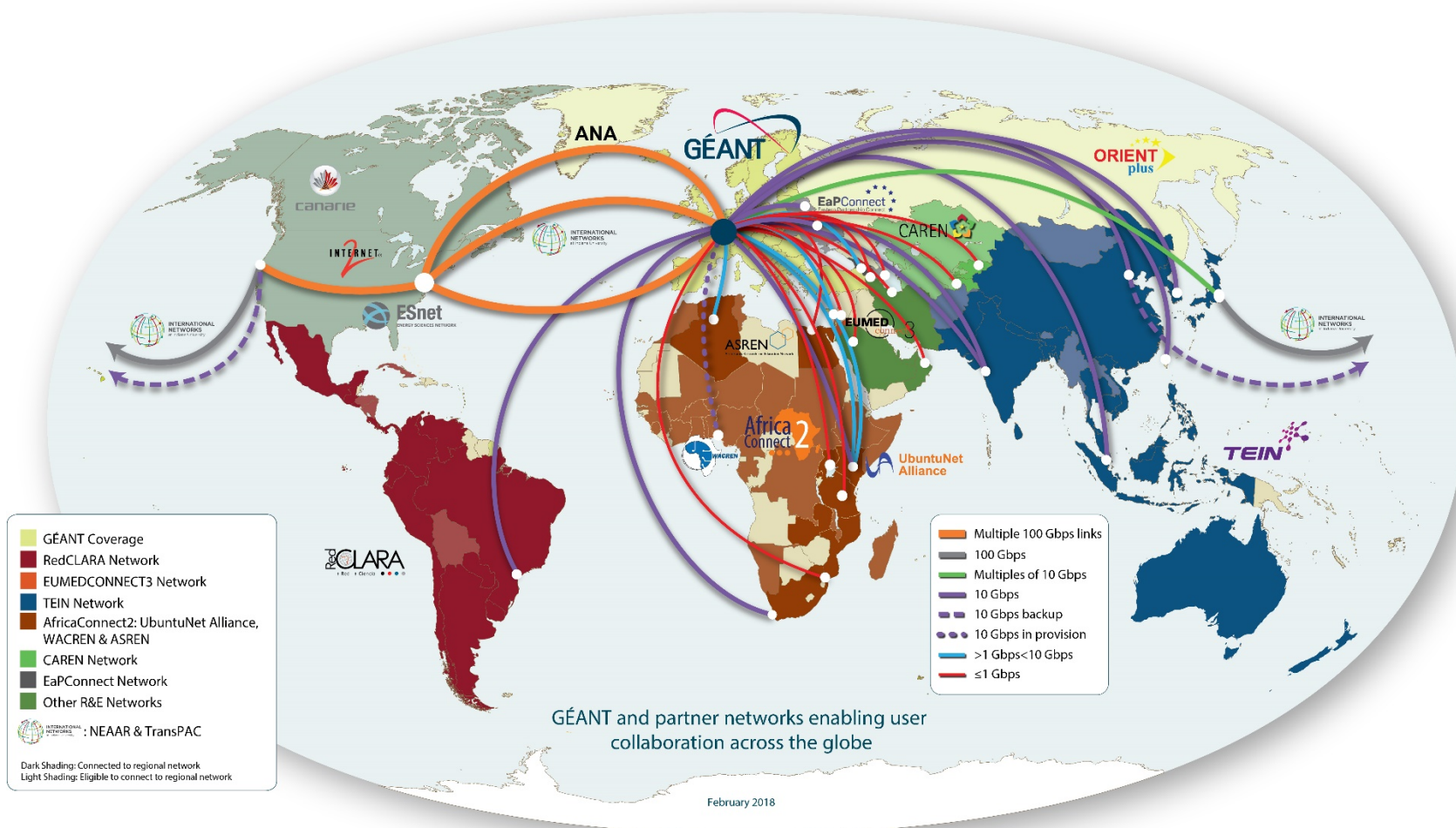


[www.geant.org](http://www.geant.org)  
August 2017

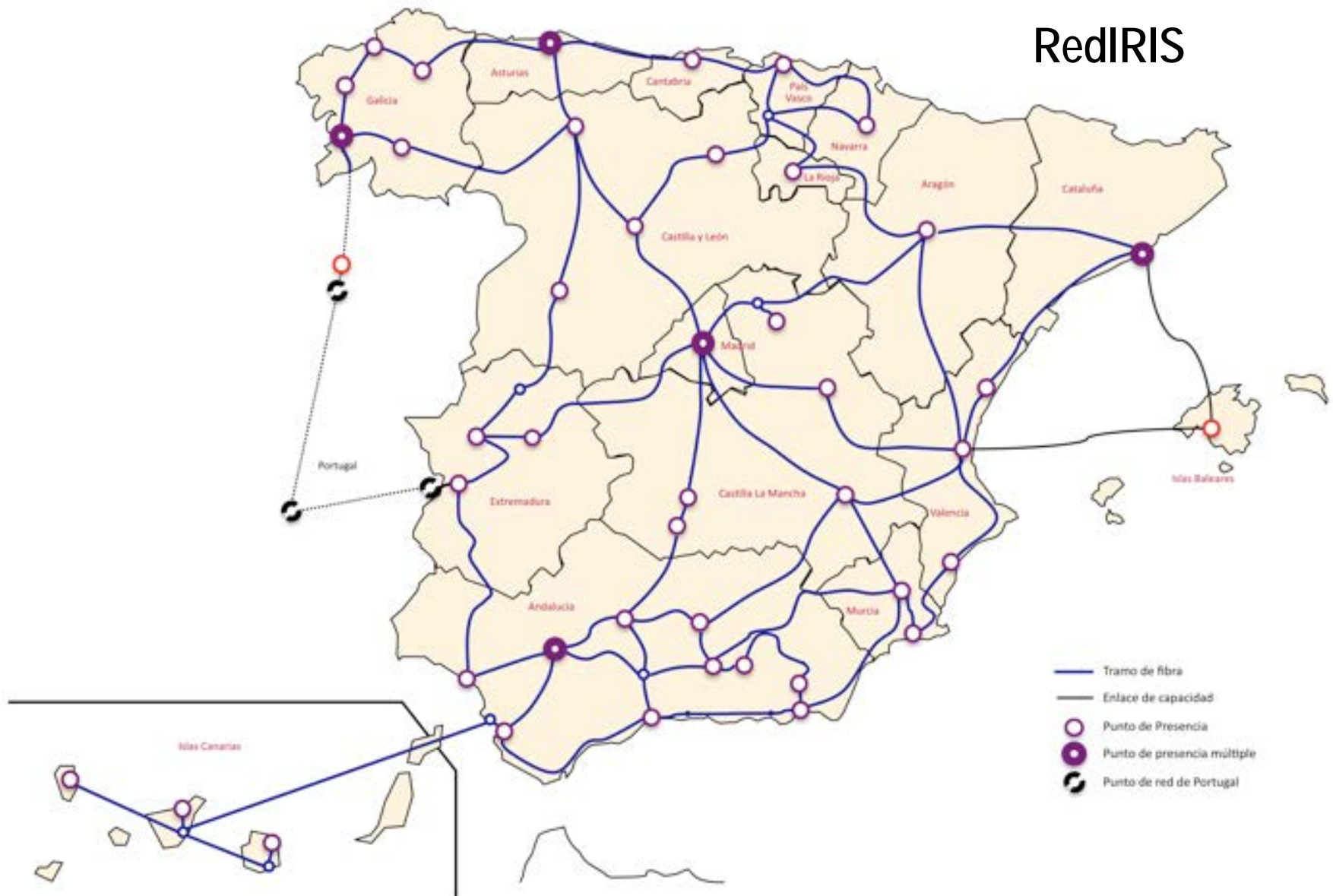




# At the Heart of Global Research and Education Networking



## RedIRIS



# Unit 1: Introduction

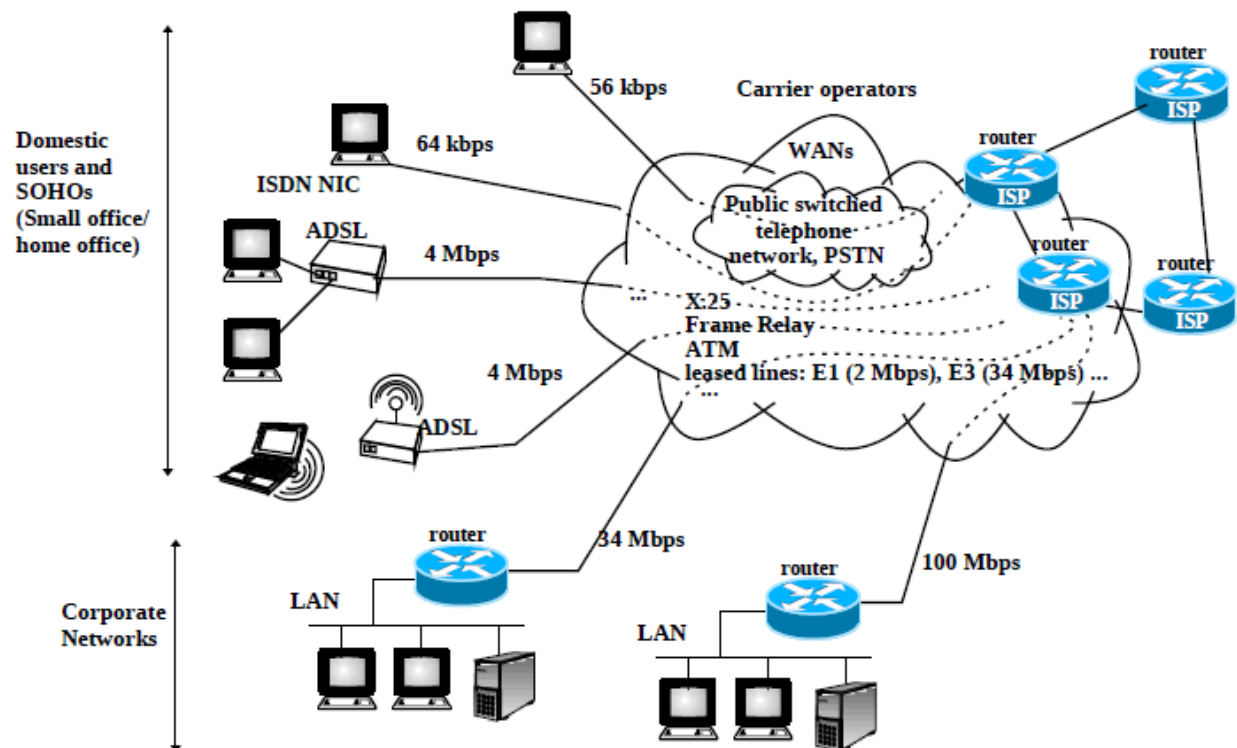
## Outline

- Brief history of Computer Networks and Internet
- **Introduction to the Internet**
- Standardization Organizations and OSI Reference Model
- Client-Server Paradigm

# Unit 1: Introduction

## Organization of the Internet and Terminology

- Host
- Access Network
- LAN
- WAN
- Telephone company, telco, or carrier.
- Router
- Line Bitrate
- Bits per second, bps.



# Unit 1: Introduction

## Bitrate

$t_b$  is the transmission time of 1 bit.

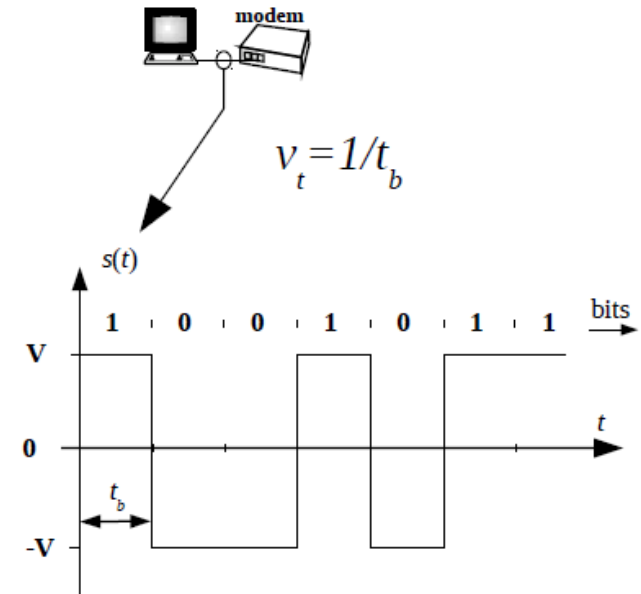
- $v_t = 1/t_b$  is the **line bitrate** in bits per second (**bps**)

- typical bitrate prefixes:

- **k**, kilo:  $10^3$
- **M**, Mega:  $10^6$
- **G**, Giga:  $10^9$
- **T**, Tera:  $10^{12}$
- **P**, Peta:  $10^{15}$

- Examples:

- Public Switched Telephone Network (PSTN) **modem**: 56 kbps
- **ADSL**: 4 Mbps
- **LAN** Ethernet: 10 Mbps, 100 Mbps, 1Gbps, 10 Gbps.
- **Carrier** lines E3: 34 Mbps, OC-192: 9,9 Gbps, ...



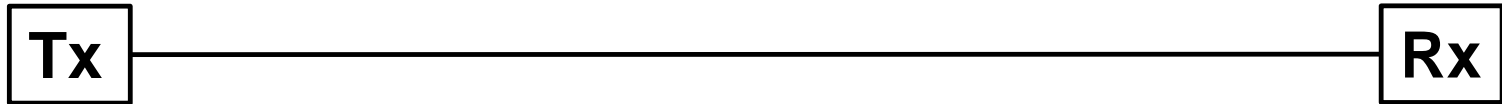
NRZ signal



# Transmission Parameters

- Distance:  $d$  meters
- Light transmission speed:  $c = 3 \cdot 10^8$  m/s
- Propagation delay:  $t_p = d / c$  seconds
- End-to-end delay:  $D$  seconds
- Packet size:  $L$  bits
- Transmission bitrate:  $V_t$  b/s (bps)
- Packet transmission time:  $t_{\text{packet}} = L / V_t$  sec
- Bandwidth-Delay product:  $V_t * D$  bits

# Example



$$d = 10 \text{ Km} = 10^4 \text{ m}$$

$$t_p = d / c = 10^4 / 3 \cdot 10^8 = 0.33 \cdot 10^{-4} = 0.033 \cdot 10^{-3} = 0.033 \text{ ms}$$

$$L = 1200 \text{ bits}$$

$$v_t = 10 \text{ Mbps} = 10 \cdot 10^6 \text{ bits/sec}$$

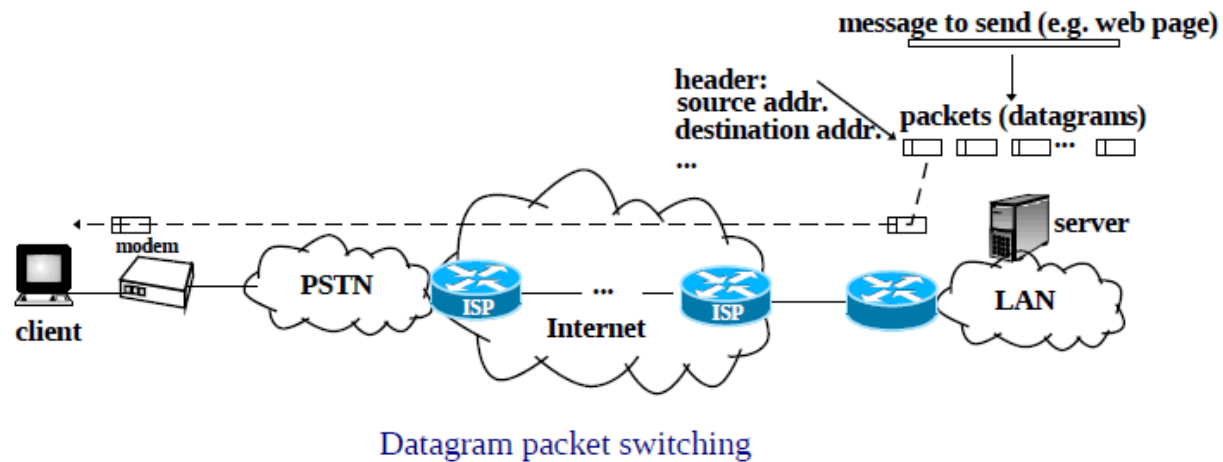
$$t_{\text{paq}} = L / v_t = 1200 / 10 \cdot 10^6 = 120 \cdot 10^{-6} = 120 \mu\text{s}$$

$$D = t_p + t_{\text{paq}} = 33 \mu\text{s} + 120 \mu\text{s} = 153 \mu\text{s}$$

$$D \cdot v_t = 153 \cdot 10^{-6} \cdot 10 \cdot 10^6 = 1530 \text{ bits ("on the way")}$$

# Types of Switching

- **Circuit switching**, e.g. PSTN (Public Switched Telephone Network)
- **Packet switching**:
  - **Virtual Circuit**, e.g. X.25, ATM.
  - **Datagram**: Internet.



# Switching and routing paradigms

# Switching paradigms

## Circuit Switching

- Reserved resources end-to-end (e2e)
- Fixed bitrate e2e
- Flow of bits
- Connection setup
- Fixed e2e delay

## Packet Switching

- Resources used on-the-fly
- At link bitrates
- Flow of packets
- Sharing of resources
- Variable e2e delay



# Datagram concept

- Datagram:
- “A self-contained, independent entity of data carrying sufficient information to be routed from the source to the destination computer without reliance on earlier exchanges between this source and destination computer and the transporting network.” —RFC 1594 (March 1994)

# Datagram

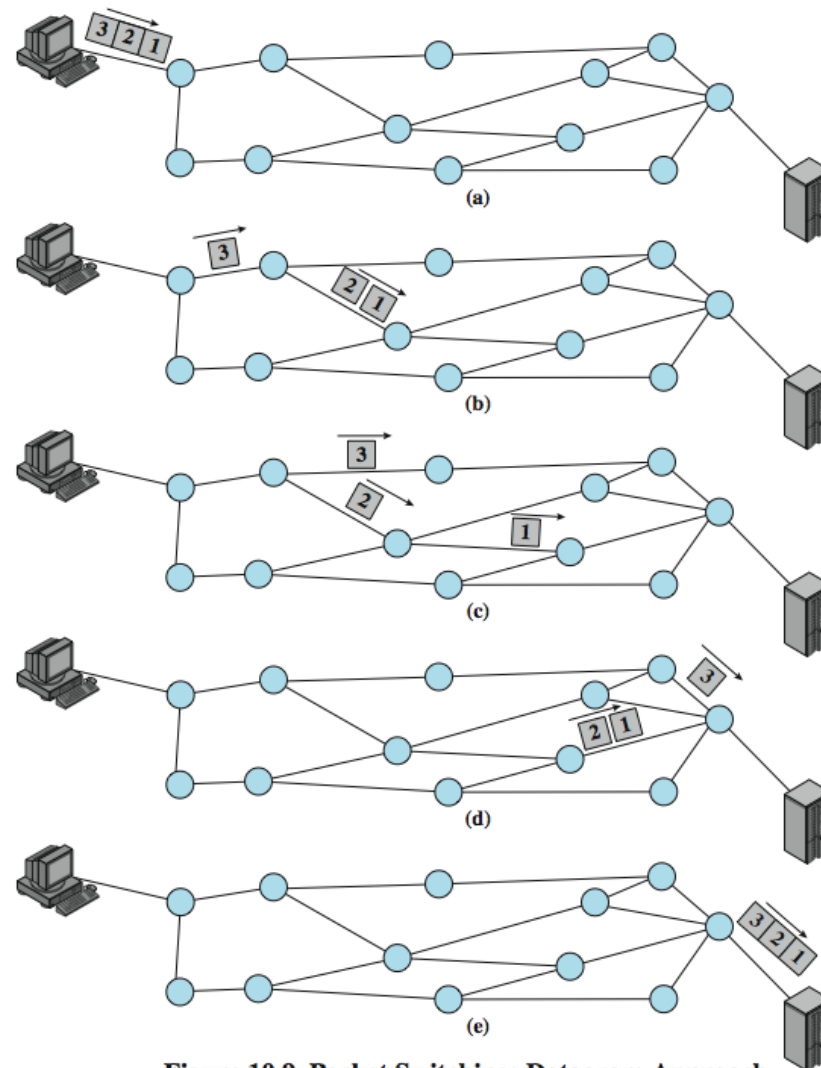


Figure 10.9 Packet Switching: Datagram Approach

# Virtual Circuit

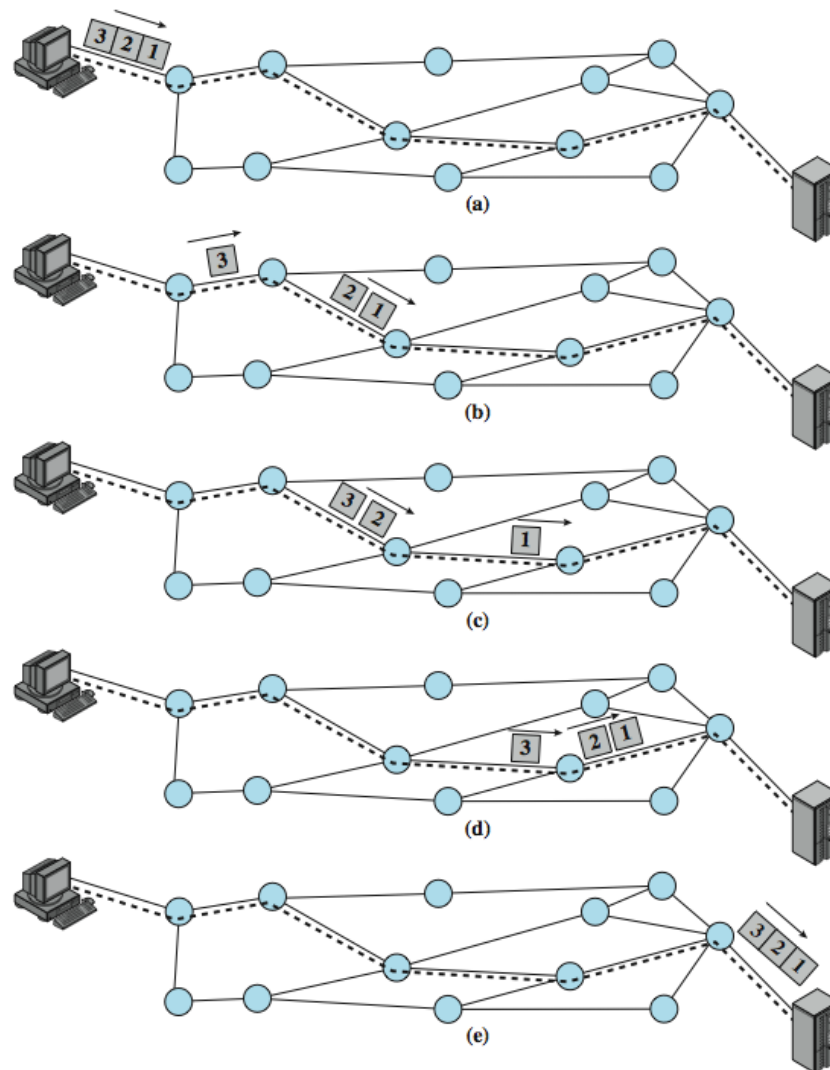


Figure 10.10 Packet Switching: Virtual-Circuit Approach

# Packet Switching

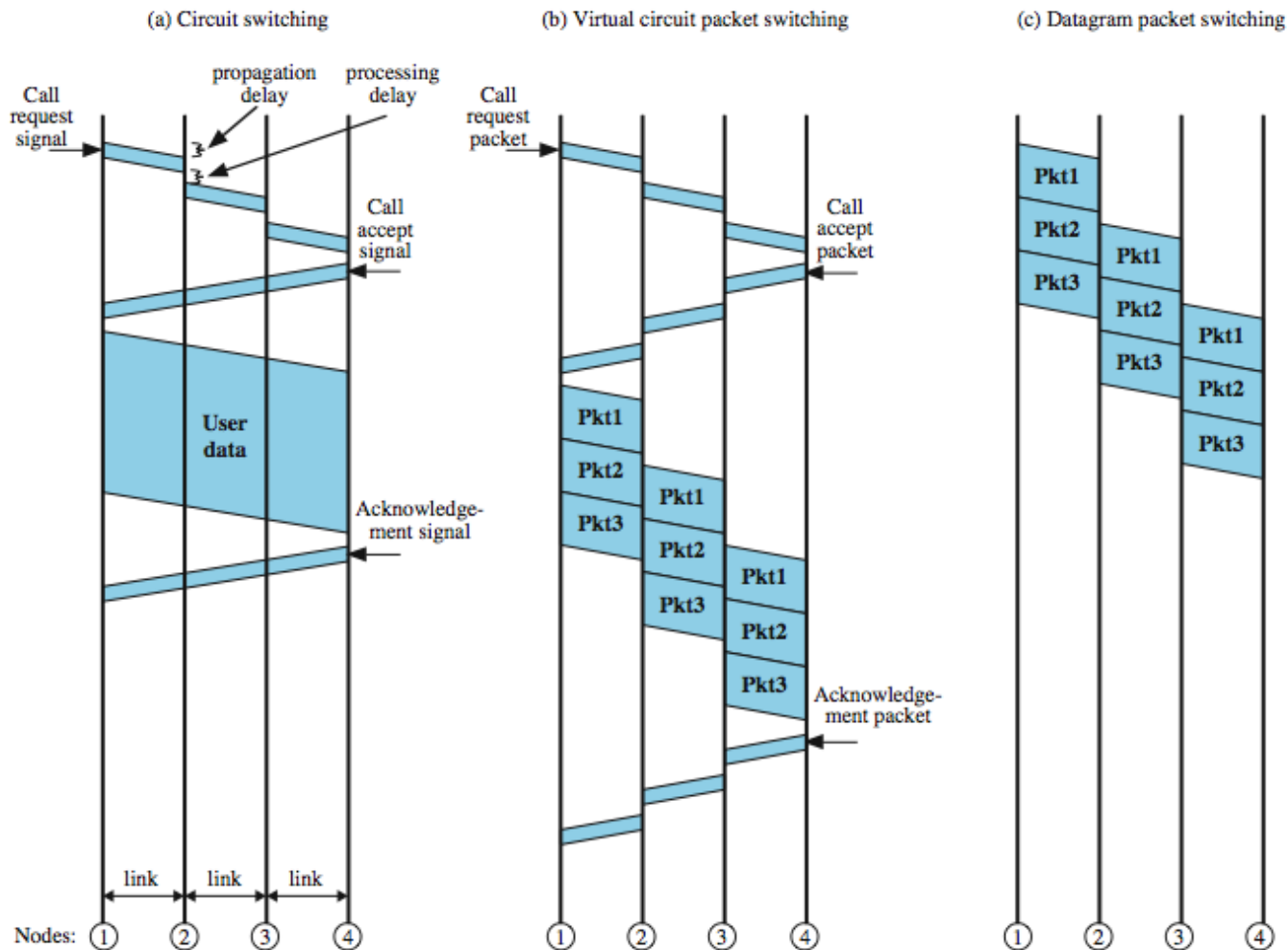
## Datagram

- Header info includes destination address
- No setup is needed
- Nodes process each datagram independently
- Datagrams may get lost, delayed, duplicated, or out-of-order

## Virtual Circuit

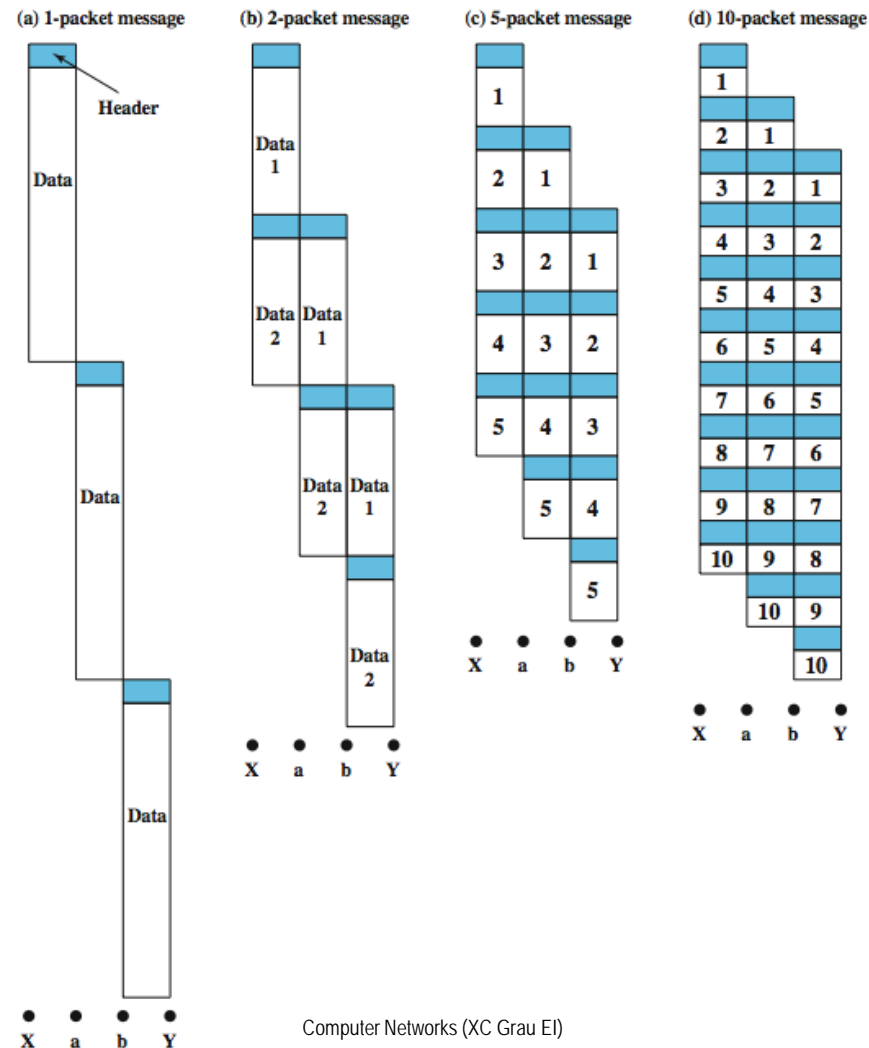
- Header info includes VC identifier
- Setup required
- Nodes keep track of VC and process all the packets of the VC in the same way
- All packets arrive in order and with controlled delay

# Event Timing Comparison





# Packet Size



# Unit 1: Introduction

## Outline

- Brief history of Computer Networks and Internet
- Introduction to the Internet
- **Standardization Organizations and OSI Reference Model**
- Client-Server Paradigm

# Standardization Bodies

- International Telecommunication Union, **ITU**: WAN standards.  
<http://www.itu.org/>.
- International Organization for Standardization, **ISO**: Industrial standards.  
<http://www.iso.org/>.
- Institute of Electrical and Electronics Engineers, **IEEE**: LAN standards.  
<http://www.ieee.org/>.
- European Telecommunications Standards Institute, **ETSI**: Mobile phone standards (GSM). <http://www.etsi.org/>.
- Electronic Industries Alliance, **EIA**: Cabling standards. <http://www.eia.org/>.
- Internet Engineering Task Force, **IETF**: Internet standards. <http://www.ietf.org>.  
Standardization proposals are done through *Request For Comments*, RFCs.  
They are mirrored around the world, e.g. <http://www.rfc-editor.org>
- World Wide Web Consortium (**W3C**). <http://www.w3.org>

# *Open Systems Interconnection Reference Model*

- Credits:  
William Stallings  
Data and Computer Communications  
7<sup>th</sup> Edition
- Chapter 2  
Protocols and Architecture

# OSI Reference Model

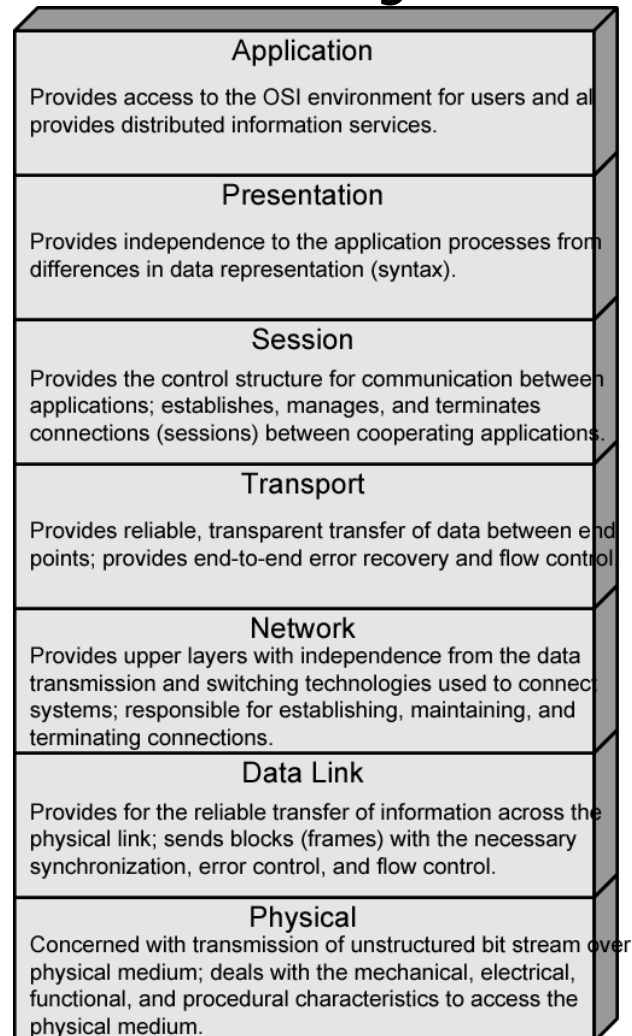
- Open Systems Interconnection
- Developed by the International Organization for Standardization (ISO)
- Seven layers
- A theoretical system was delivered too late!
- TCP/IP is the de facto standard



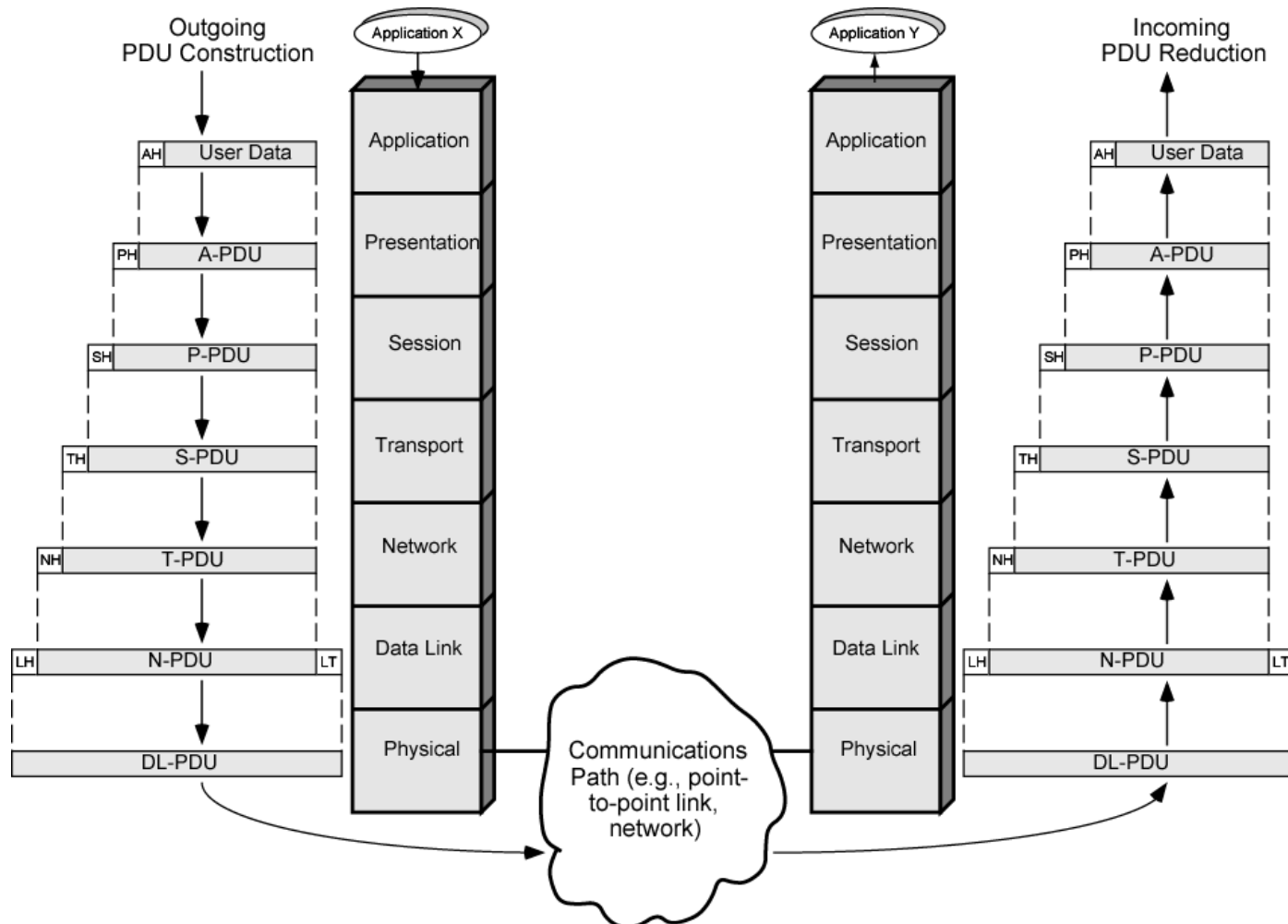
# OSI Reference Model

- A layer model
- Each layer performs a subset of the required communication functions
- Each layer relies on the next lower layer to perform more primitive functions
- Each layer provides services to the next higher layer
- Changes in one layer should not require changes in other layers

# OSI Layers



# The OSI Reference Model



# TCP/IP Protocol Architecture

- Developed by the US Defense Advanced Research Project Agency (DARPA) for its packet switched network (ARPANET)
- Used in the global Internet
- No official model but a working one.
  - Application layer
  - Host to host or transport layer
  - Internet layer
  - Network access layer
  - Physical layer

# Physical Layer

- Physical interface between data transmission device (e.g. computer) and transmission medium or network
- Characteristics of transmission medium
- Signal levels
- Data rates
- etc.

# Network Access Layer

- Exchange of data between end-system and network
- Destination address provision
- Invoking services like priority

# Internet Layer (IP)

- Systems may be attached to different networks
- Routing functions across multiple networks
- Implemented in end-systems and routers

# Transport Layer (TCP)

- Reliable delivery of data
- Ordering of delivery
- Implemented in end-systems (hosts)



# Application Layer

- Support for user applications
- e.g. HTTP, SMTP, DNS, FTP, Telnet

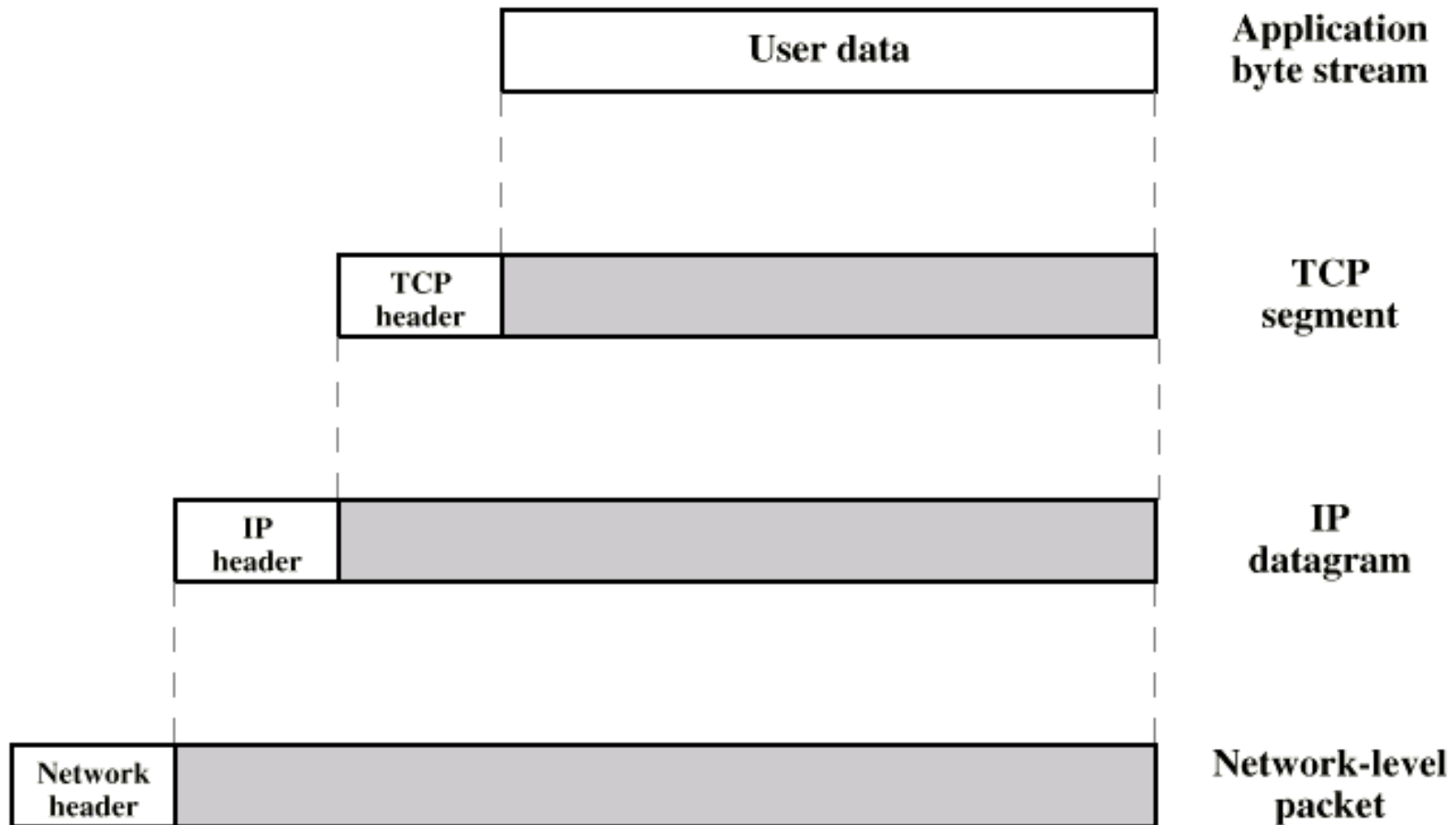
# OSI vs TCP/IP

OSI	TCP/IP
Application	Application
Presentation	
Session	
Transport	Transport (host-to-host)
Network	Internet
Data Link	Network Access
Physical	Physical

# TCP

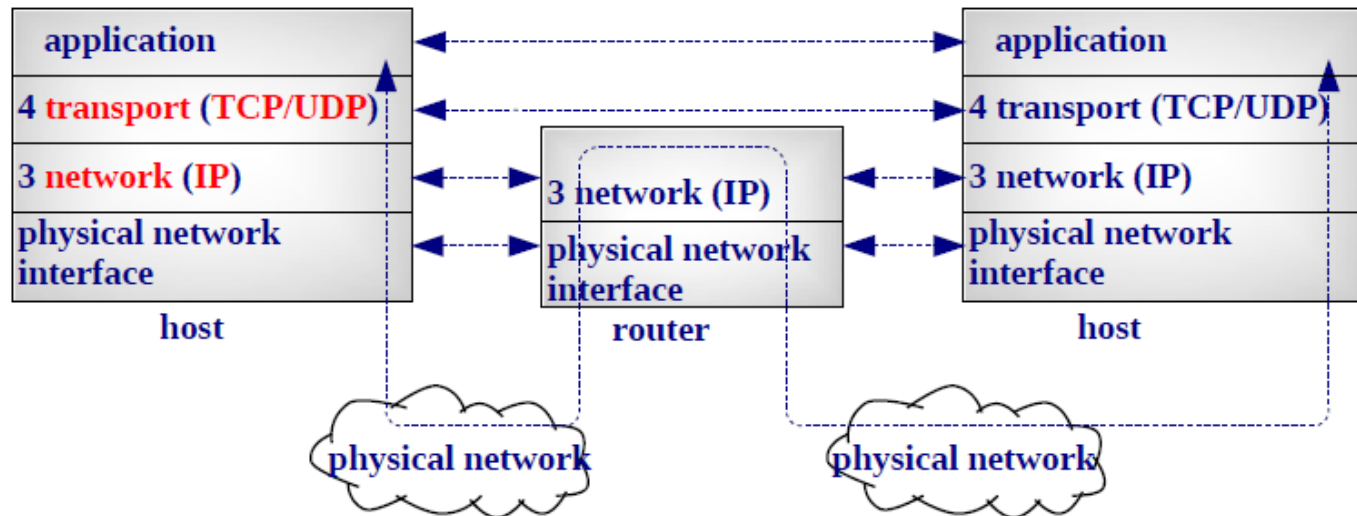
- Usual transport layer is Transmission Control Protocol
  - Reliable connection
- Connection
  - Temporary logical association between entities in different end-systems
- TCP PDU
  - Also known as TCP segment
  - Includes source and destination port (c.f. SAP)
    - Identify end users (applications)
    - Connection refers to a pair of ports
- TCP tracks segments between entities on each connection

# PDU in TCP/IP



# TCP/IP Architecture

- No RFC specifies the TCP/IP model.
- Networking literature usually identifies the layer model:



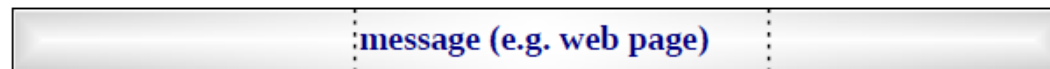
# Encapsulation

- Each layer adds/removes the **PDU header**.

**Layer:**

**PDU name:**

application



message

transport



TCP segment

network



IP datagram

data link

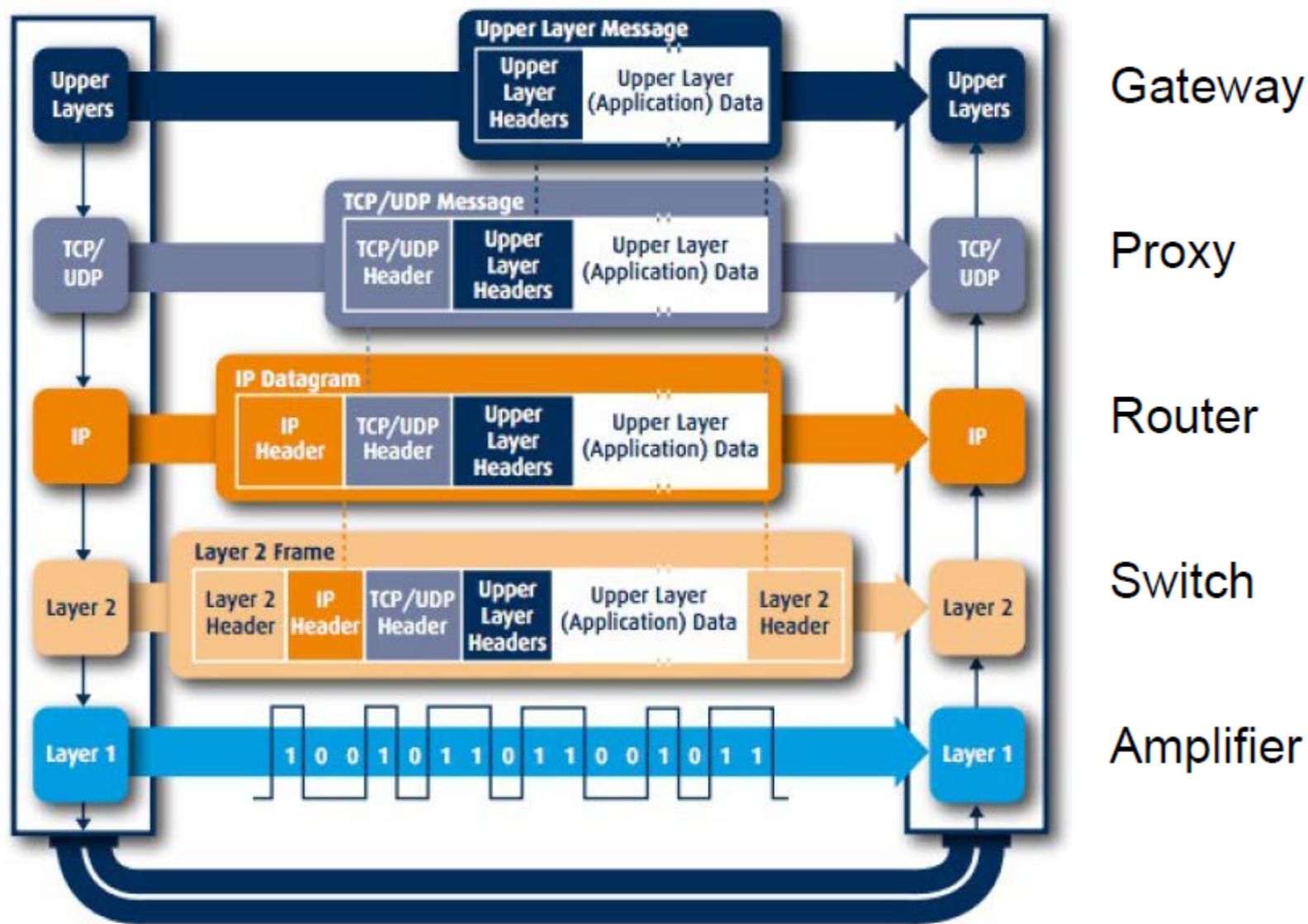


ethernet frame

physical



bits

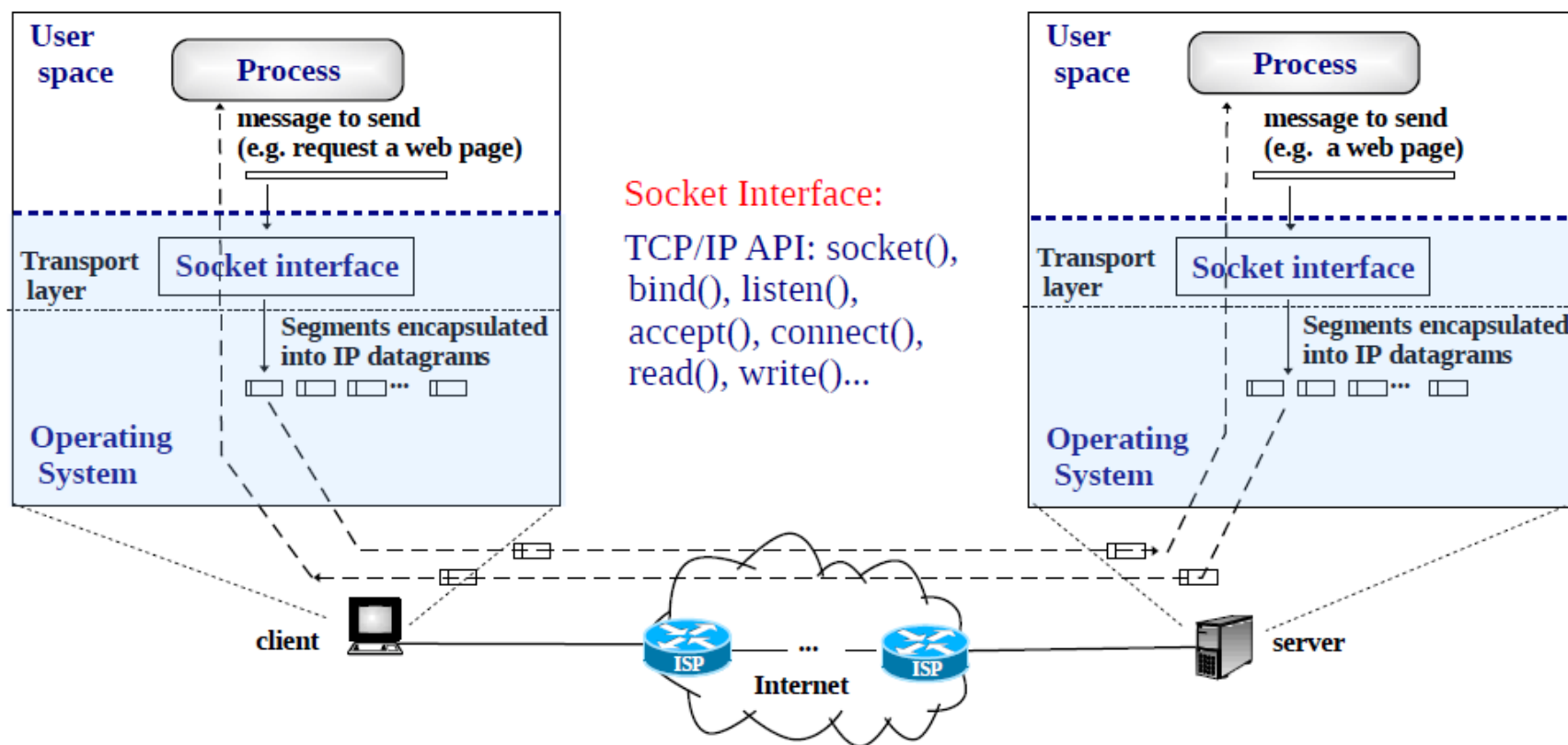




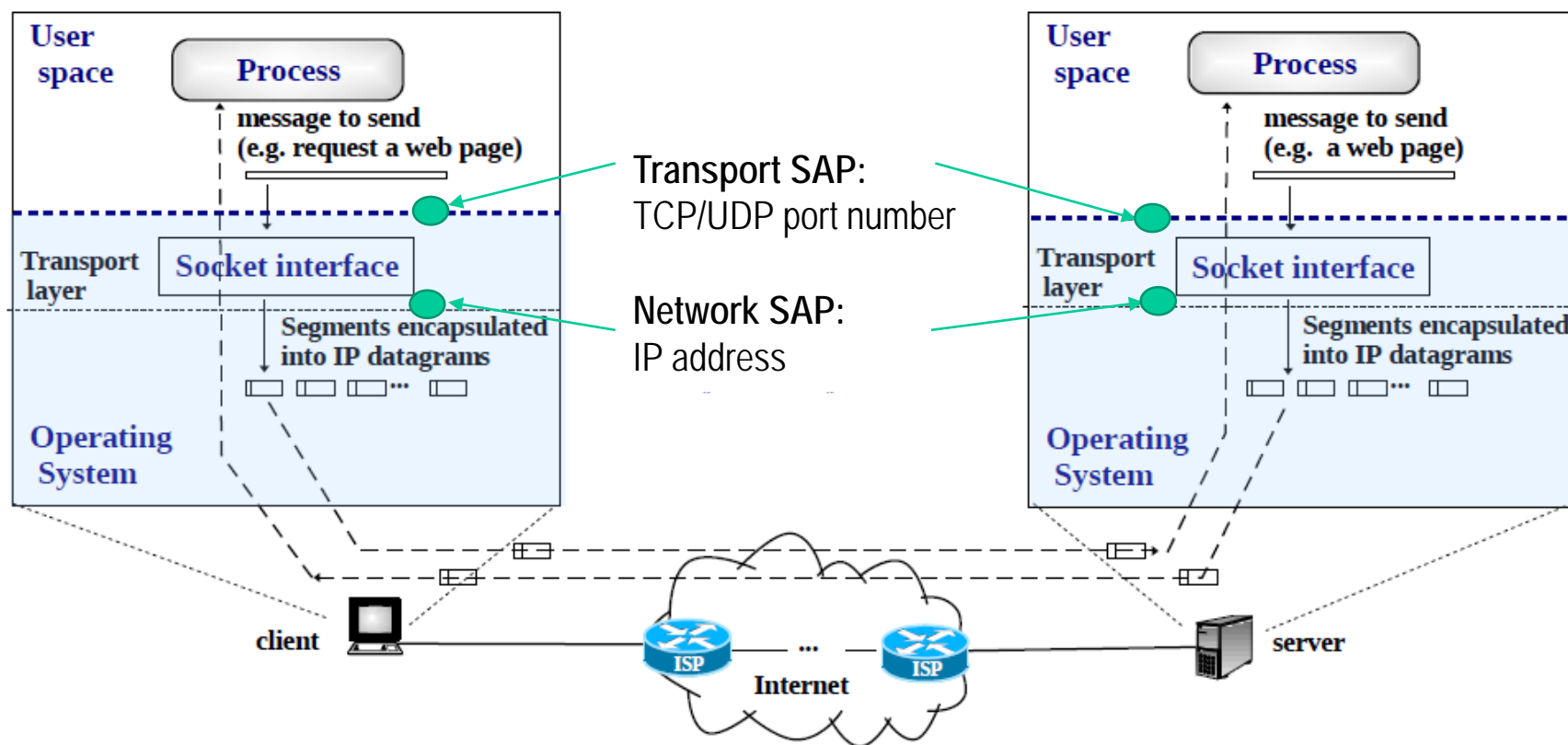
# Outline

- Brief history of Computer Networks and Internet
- Introduction to the Internet
- Standardization Organizations and OSI Reference Model
- **Client-Server Paradigm**

# Client Server Paradigm: Processes, messages, sockets segments and IP datagrams



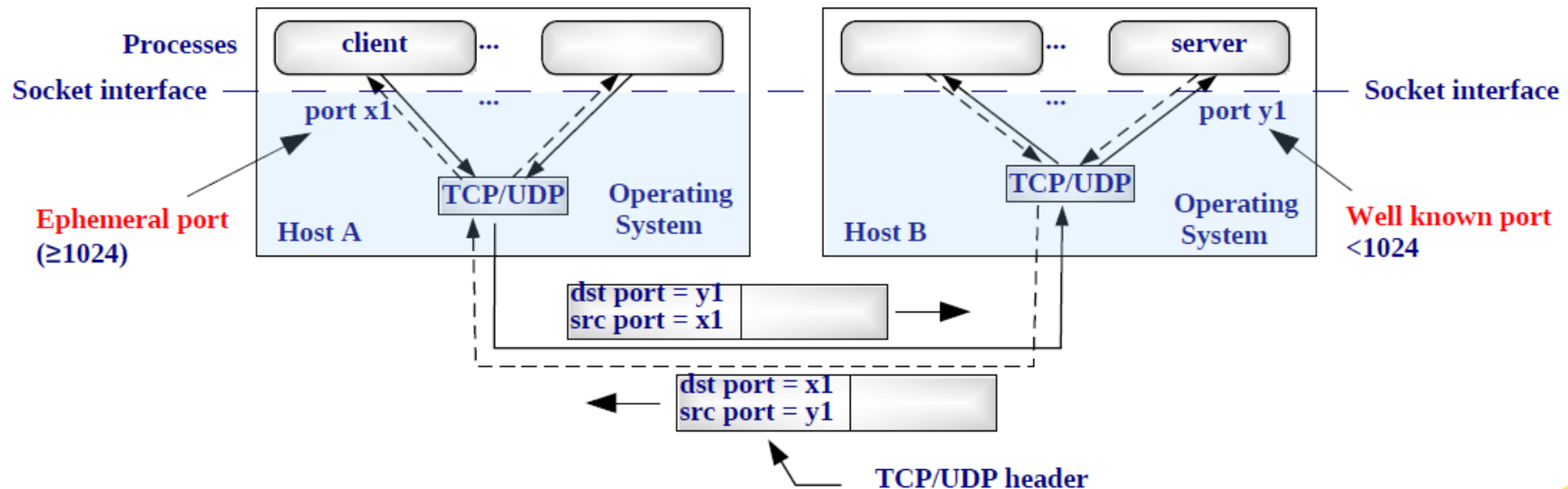
# Client Server Paradigm: Processes, messages, sockets segments and IP datagrams



# Client Server Paradigm

- How connection is established among processes?
- The client always initiates the connection towards a known IP address, in the IP header, and a *well known port* ( $< 1024$ ), in the TCP/UDP header.
- Well known ports are standardized by IANA in RFC-1700 (*Assigned Numbers*). In a unix machine can be found in `/etc/services`.
- The server is a *daemon* waiting for client requests.

The socket interface includes the port number and the IP address



# Client Server Paradigm – UNIX /etc/services File

- Enables server and client programs to convert service names to well known ports.

```
linux> cat /etc/services
# Network services, Internet style
# Note that it is presently the policy of IANA to assign a single well-known
# port number for both TCP and UDP; hence, most entries here have two entries
# even if the protocol doesn't support UDP operations.
# This list could be found on:
#      http://www.iana.org/assignments/port-numbers
# *****
# WELL KNOWN PORT NUMBERS
# The Well Known Ports are assigned by the IANA and on most systems can
# only be used by system (or root) processes or by programs executed by
# privileged users.
#
# Keyword  Decimal  Description
# -----  -
echo      7/tcp    Echo
echo      7/udp    Echo
discard   9/tcp    # Discard
discard   9/udp    # Discard
daytime   13/tcp   # Daytime (RFC 867)
daytime   13/udp   # Daytime (RFC 867)
chargen   19/tcp   # Character Generator
chargen   19/udp   # Character Generator
ftp-data  20/tcp   # File Transfer [Default Data]
ftp-data  20/udp   # File Transfer [Default Data]
ftp       21/tcp   # File Transfer [Control]
ssh       22/tcp   # SSH Remote Login Protocol
ssh       22/udp   # SSH Remote Login Protocol
telnet    23/tcp   # Telnet
telnet    23/udp   # Telnet
```

# Well-known port numbers

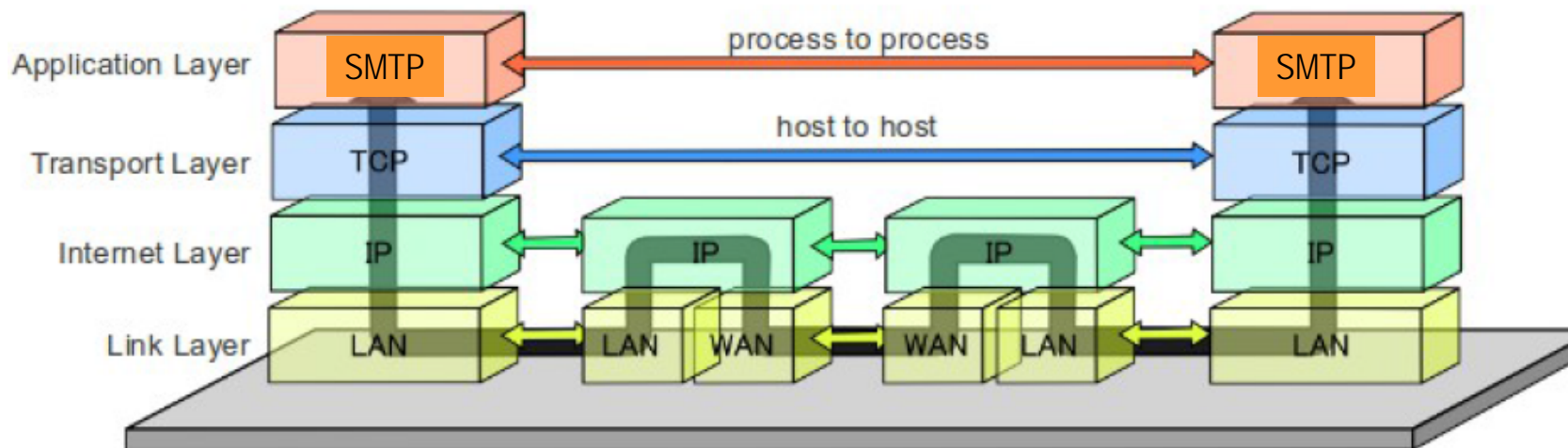
- ftp: 20 (data) 21(control)
- telnet: 23
- ssh: 22
- chargen: 19
- smtp: 25; smtps: 465, 587
- http: 80; https: 443
- ntp: 123
- dns: 53
- pop3: 110; imap:143; pop3s: 995; imaps: 993

<http://www.iana.org/assignments/service-names-port-numbers/service-names-port-numbers.xhtml>

# Client Server Paradigm – Network applications

- Remote commands
  - telnet
  - ssh
- Exchange of documents
  - ftp, sftp
  - peer-to-peer
- Web based applications
- Email
- Network management
- Real time
  - Voice over IP
  - Video streaming
- ...

## Data Flow of the Internet Protocol Suite



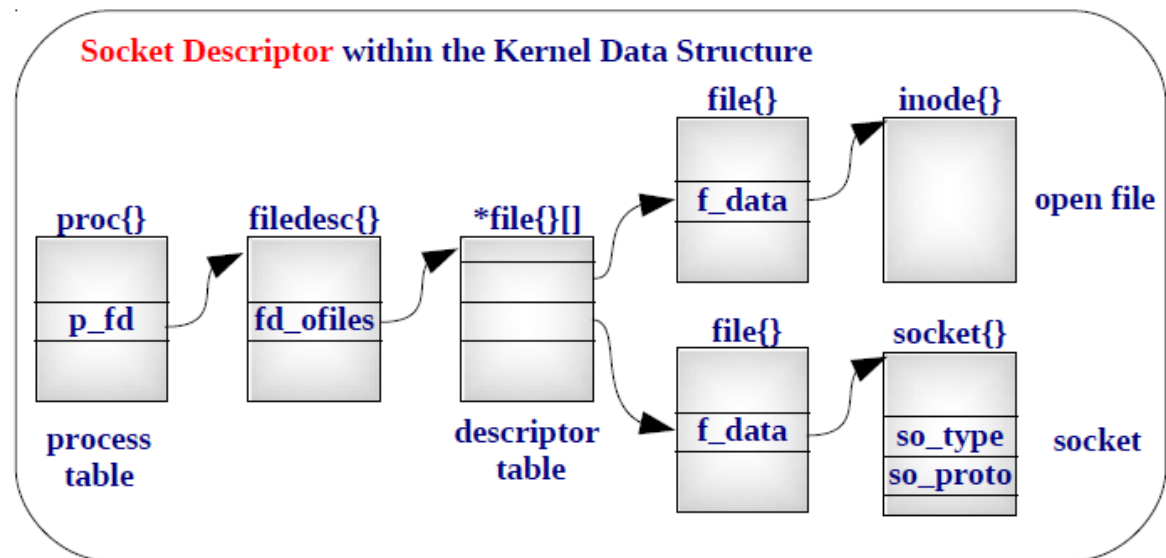
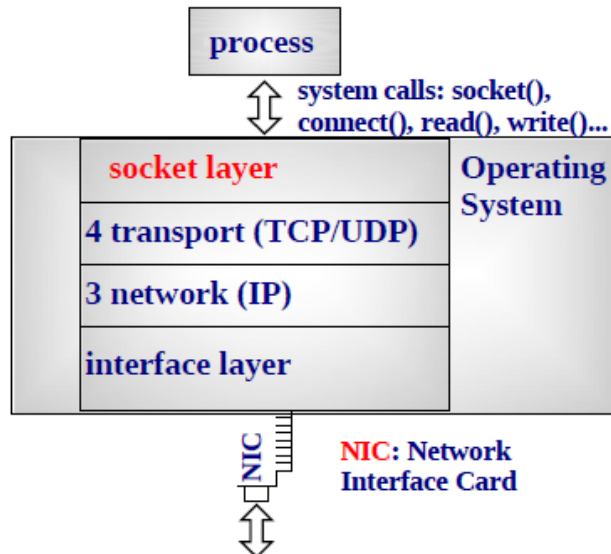
## Outgoing E-mail Frame

Destination MAC Address	Source MAC Address	Destination IP Address	Source IP Address	Destination TCP Port	Source TCP Port		
00:0C:78:52:F3:A5	0E:11:81:F2:C3:98	216.93.82.9	172.16.20.57	25	58631	Hi Mom	101101
MAC address of default gateway router's interface	Your NIC's MAC address	IP address of the SMTP server at your mom's ISP	IP address of your PC	Standard port number for SMTP	Randomly generated by your PC's TCP/IP stack		



# TCP/IP Implementation

- TCP/IP **networking code** is part of the Operating System kernel.
- **Socket interface**: Is the Unix networking interface for the processes. It was first implemented in Berkeley Software Distribution, BSD.
- The **socket system call** creates a **socket descriptor** used to store all information associated with a network connection, similarly as an inode descriptor for a file.



Video (13'):

How data Network works WARRIORS OF THE NET

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