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

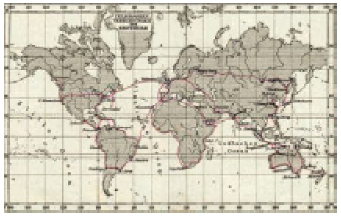
Unit 1: Introduction

Brief history of Computer Networks

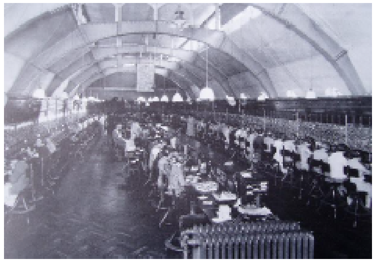
- 1830: Telegraph
- 1866: First transatlantic telegraph cable
- 1875: Alexander Graham Bell invented the telephone
- 1951: First commercial computer
- 1960: Concept of Packet Switching.
- 1960s: ARPANET project, origins of the Internet.
- 1972: First International and commercial Packet Switching Network,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

Pavel Shilling Telegraph, 1832.

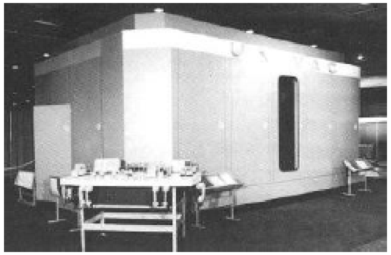
New York Telephone Cabling, 1888



Major Telegraph Lines, 1891.



Telephone Central Office in London, 1926



UNIVAC: First commercial computer, 1951

Today's Networking Equipment.

Source: wikipedia

Video

History of the Internet

Història d'Internet (8')

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

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.

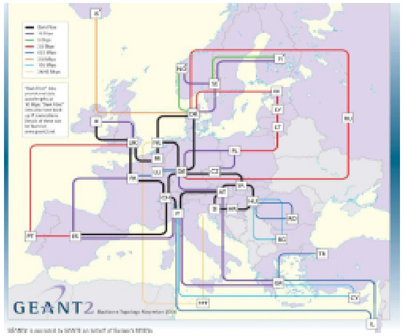
Estos son: De izquierda a derecha, primera fila: **Bob Taylor** (1), **Vint Cerf** (2), Frank Heart (3); segunda fila: Larry Roberts (4), **Len Kleinrock** (5), **Bob Kahn** (6); tercera fila: Wes Clark (7), Doug Engelbart (8), Barry Wessler (9); cuarta fila: Dave Walden (10), Severo Ornstein (11), Truett 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]

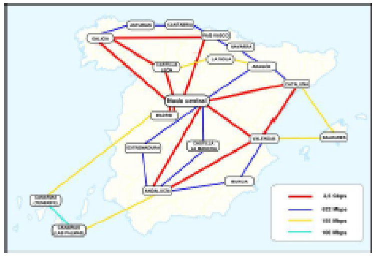
Unit 1: Introduction

Brief History of the Internet

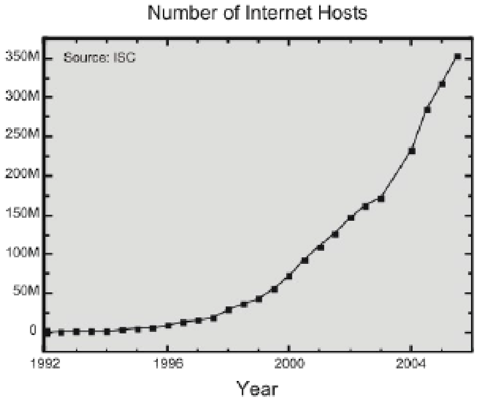
- 1966: Defense Advanced Research Projects Agency (DARPA). ARPANET project.
- ARPANET connected Universities, research labs and military centers. Military portion separated in 1983. **1/1/1983 ARPAnet adopts IP**
- 1970s: End-to-end reliability was moved to hosts, developing TCP/IP. TCP/IP was ported 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



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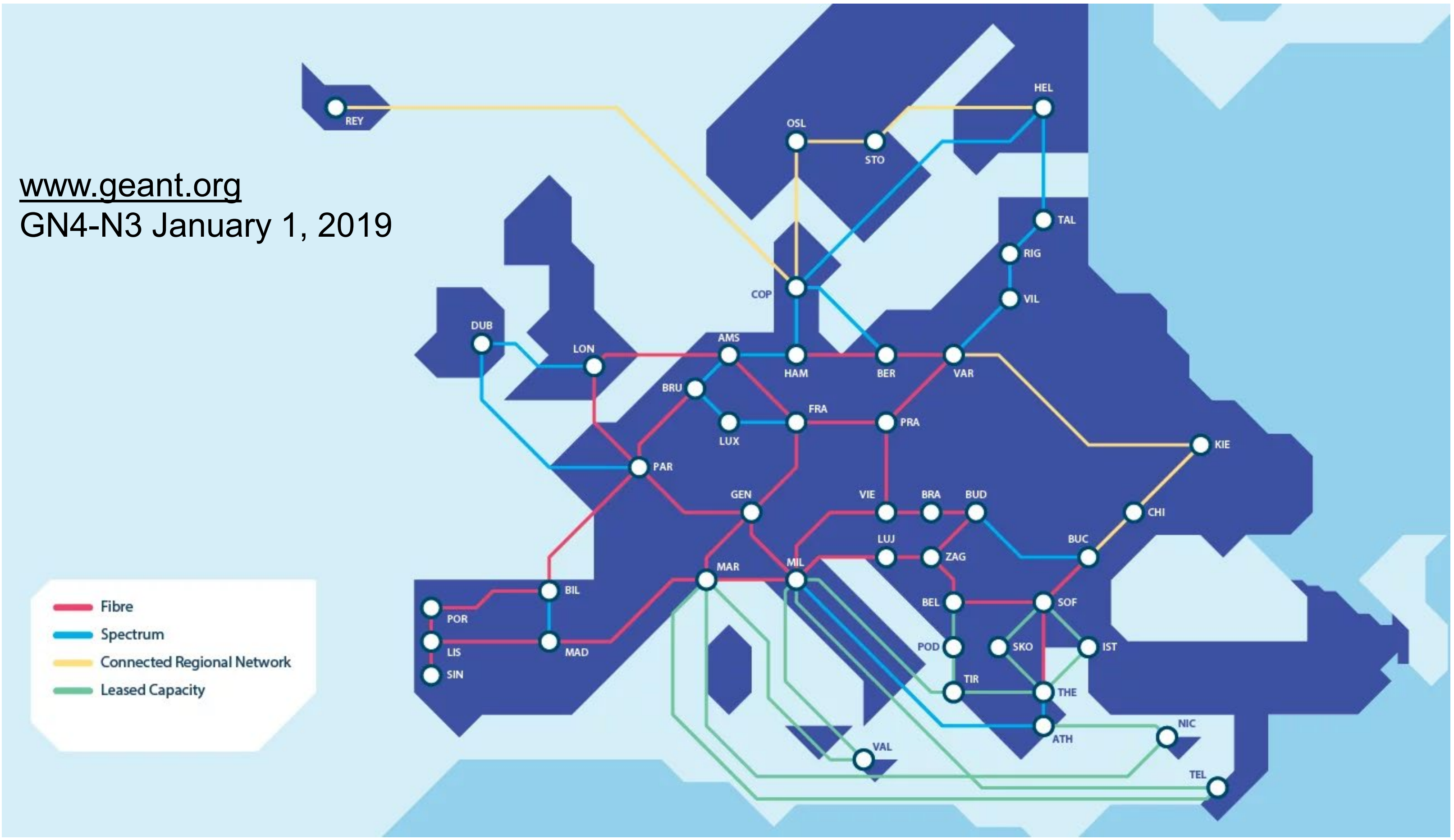

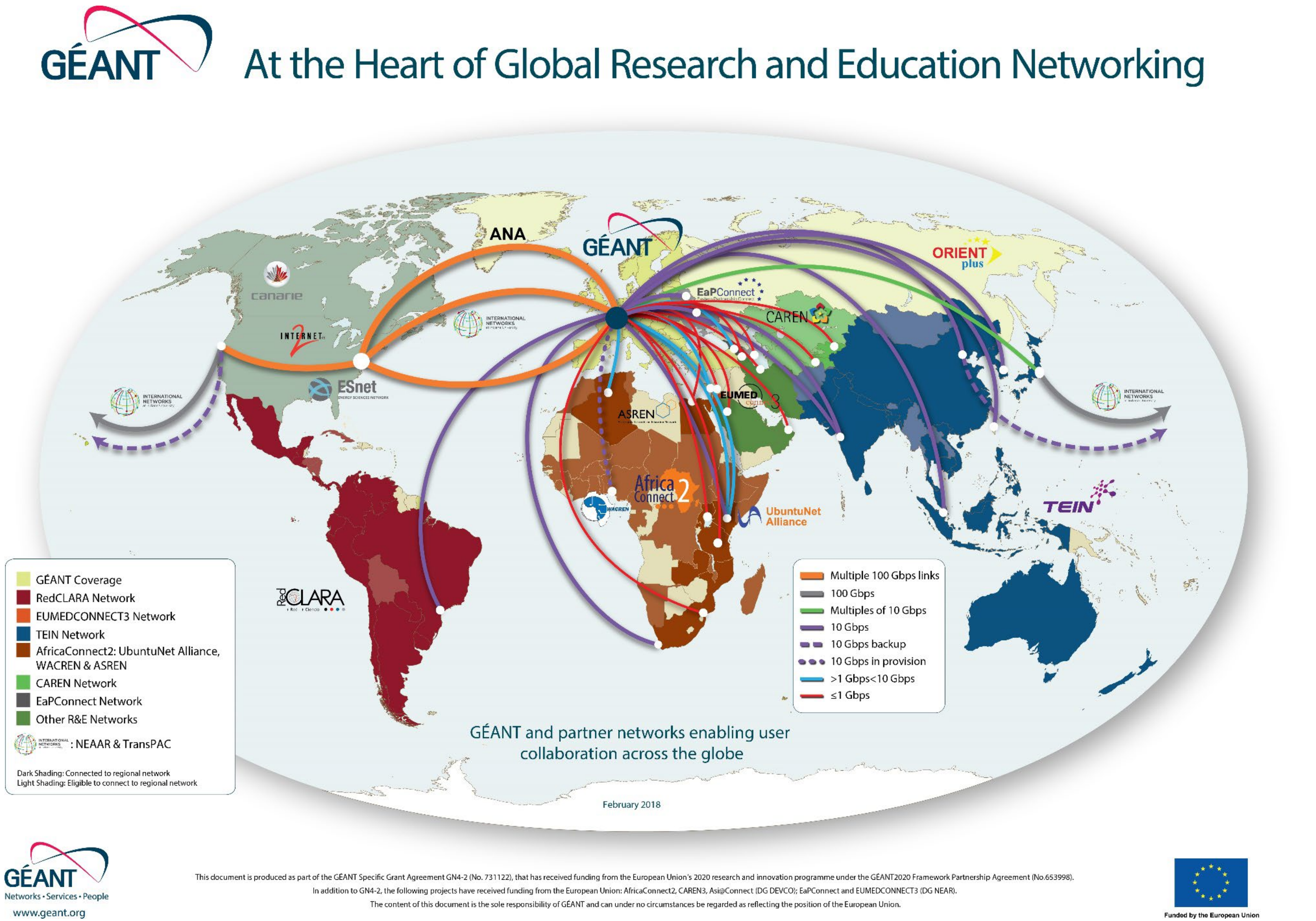
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At the Heart of Global Research and Education Networking
ANA
GÉANT
ORIENT plus
EaPConnect
CAREN
canarie
INTERNET2
ESnet
INTERNATIONAL NETWORKS
ASREN
EUMED conn3
Africa Connect2
WACREN
UbuntuNet Alliance
TEIN
RedCLARA
GÉANT Coverage
RedCLARA Network
EUMEDCONNECT3 Network
TEIN Network
AfricaConnect2: UbuntuNet Alliance, WACREN & ASREN
CAREN Network
EaPConnect Network
Other R&E Networks
: NEAAR & TransPAC
Dark Shading: Connected to regional network
Light Shading: Eligible to connect to regional network
Multiple 100 Gbps links
100 Gbps
Multiples of 10 Gbps
10 Gbps
10 Gbps backup
10 Gbps in provision
>1 Gbps<10 Gbps
≤1 Gbps
GÉANT and partner networks enabling user collaboration across the globe
February 2018
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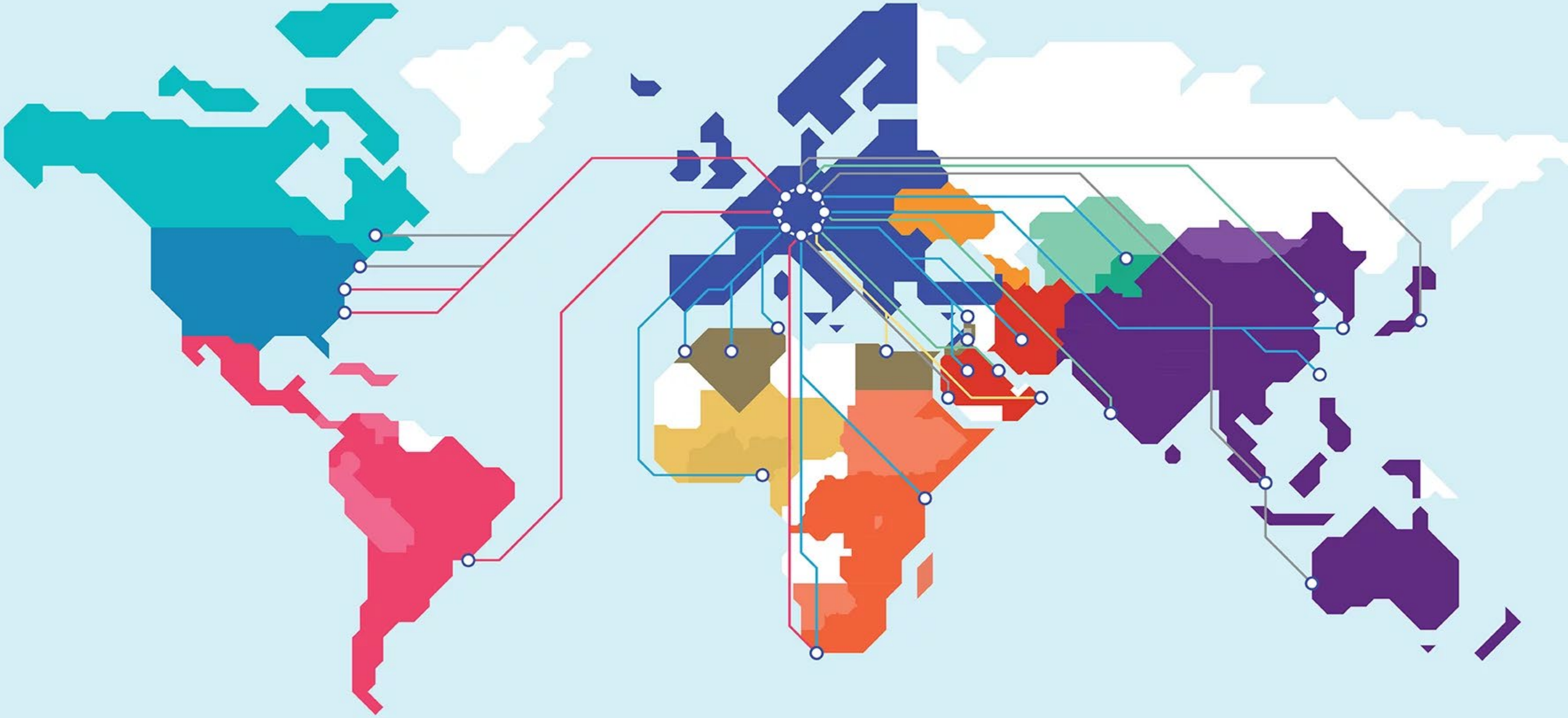
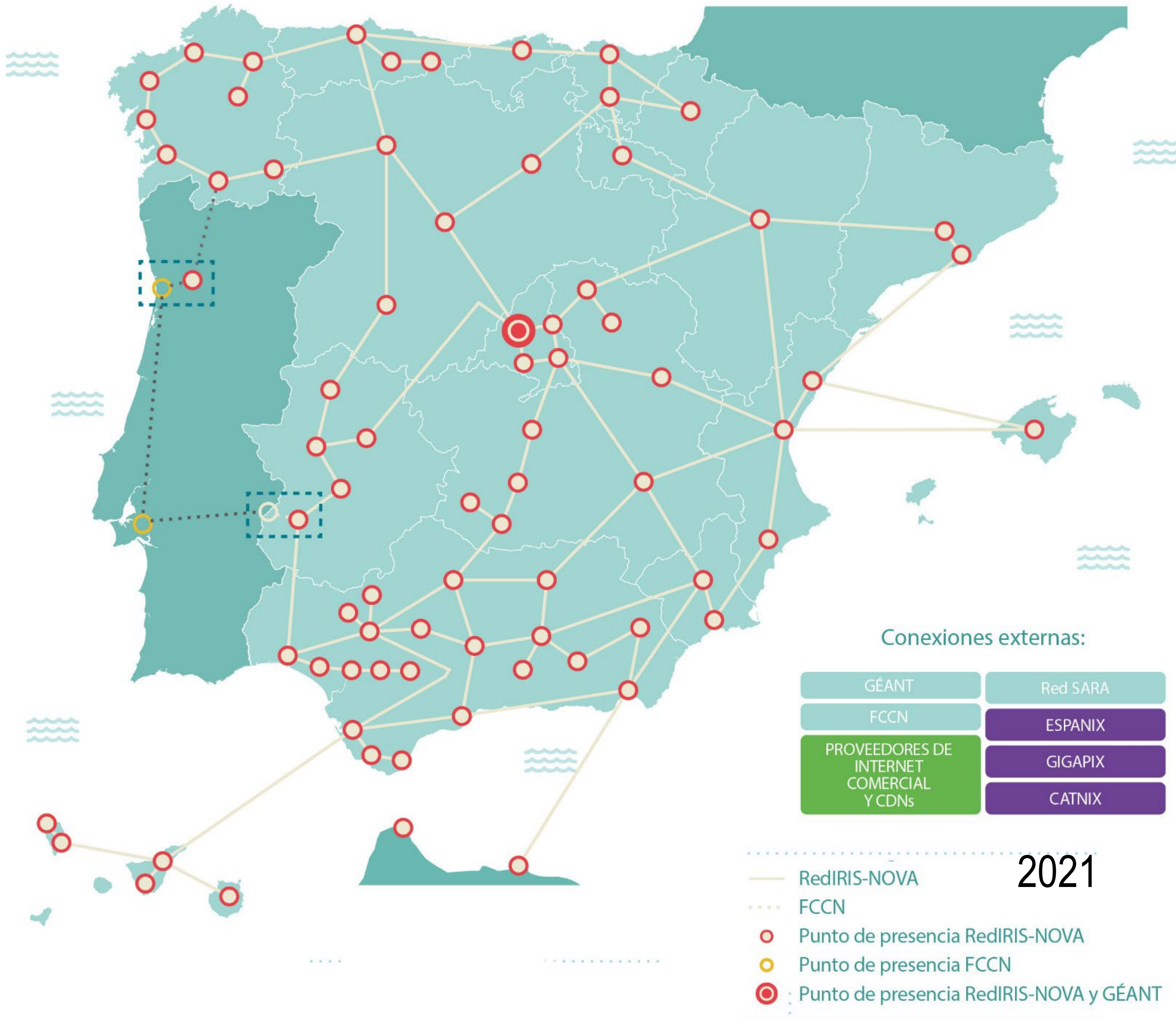



Conexiones externas:
GÉANT
Red SARA
FCCN
ESPANIX
PROVEEDORES DE INTERNET COMERCIAL Y CDNs
GIGAPIX
CATNIX
RedIRIS-NOVA
FCCN
Punto de presencia RedIRIS-NOVA
Punto de presencia FCCN
Punto de presencia RedIRIS-NOVA y GÉANT

2021

Unit 1: Introduction

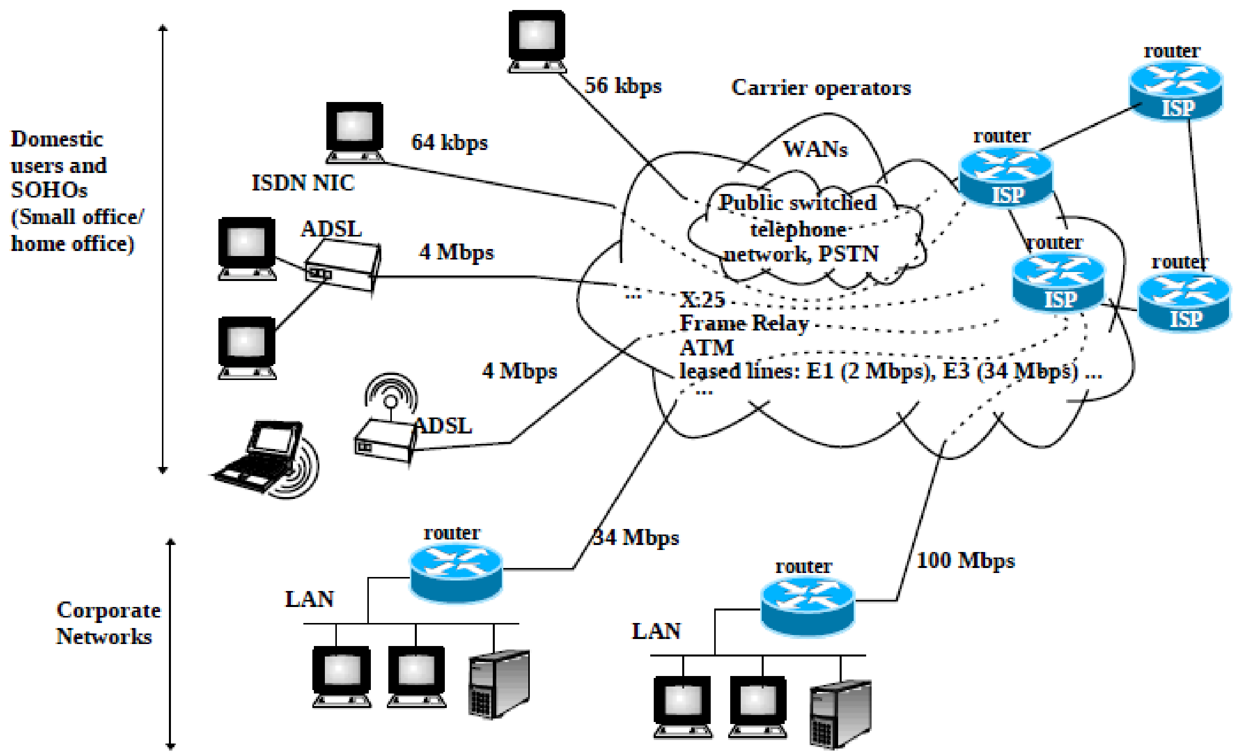
Outline

- 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.

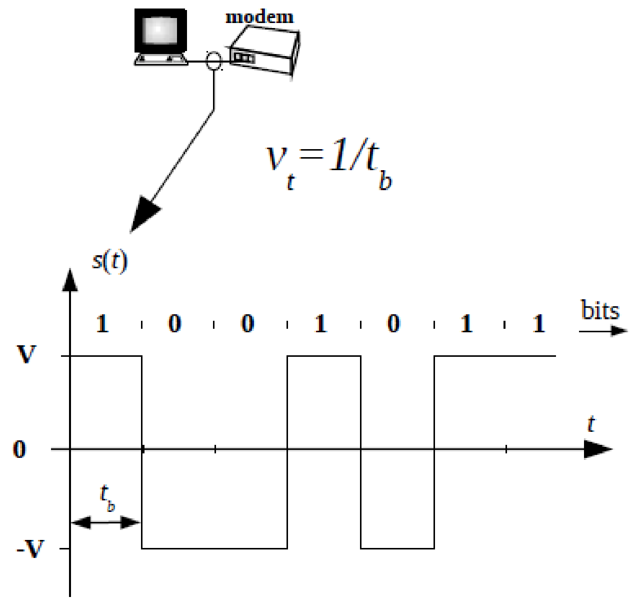


Unit 1: Introduction

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}



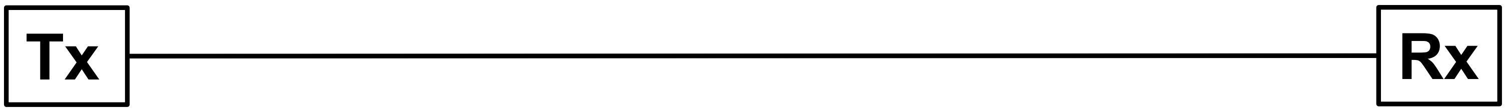
NRZ signal

- 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 Gpbs, ...

Transmission Parameters

- Distance: d meters
- Light transmission speed: $c = 3*10^8$ 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: $t_{packet} = L / V_t$ sec
- Bandwidth-Delay product: $V_t * D$ bits

Example



$d = 10\ Km = 10^4\ m$

$t_p = d / c = 10^4 / 3*10^8 = 0'33*10^{-4} = 0'033*10^{-3} = 0'033\ ms$

$L = 1200\ bits$

$v_t = 10\ Mbps = 10 * 10^6\ bits/sec$

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

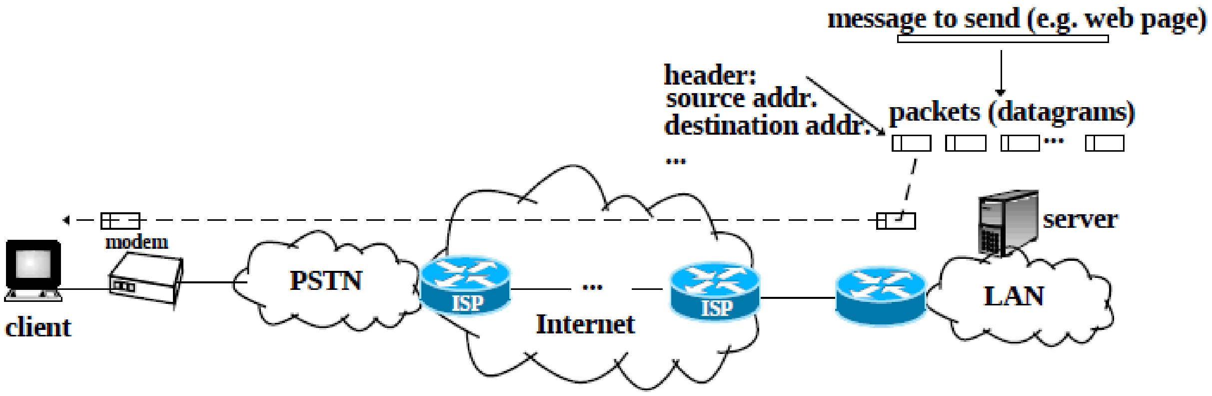
$D = t_p + t_{paq} = 33\ \mu s + 120\ \mu s = 153\ \mu s$

$D * v_t = 153*10^{-6} * 10*10^6 = 1530$ 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.

Store and Forward



Datagram packet switching

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

Store and Forward

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

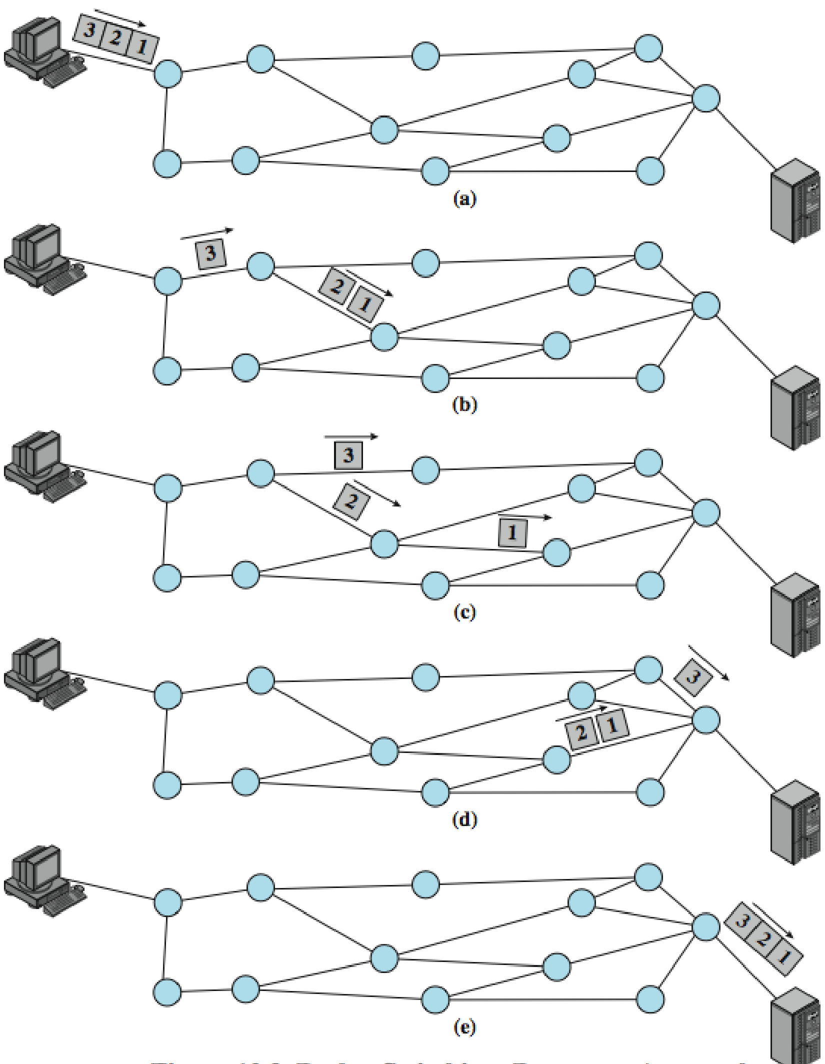


Figure 10.9 Packet Switching: Datagram Approach

Virtual Circuit

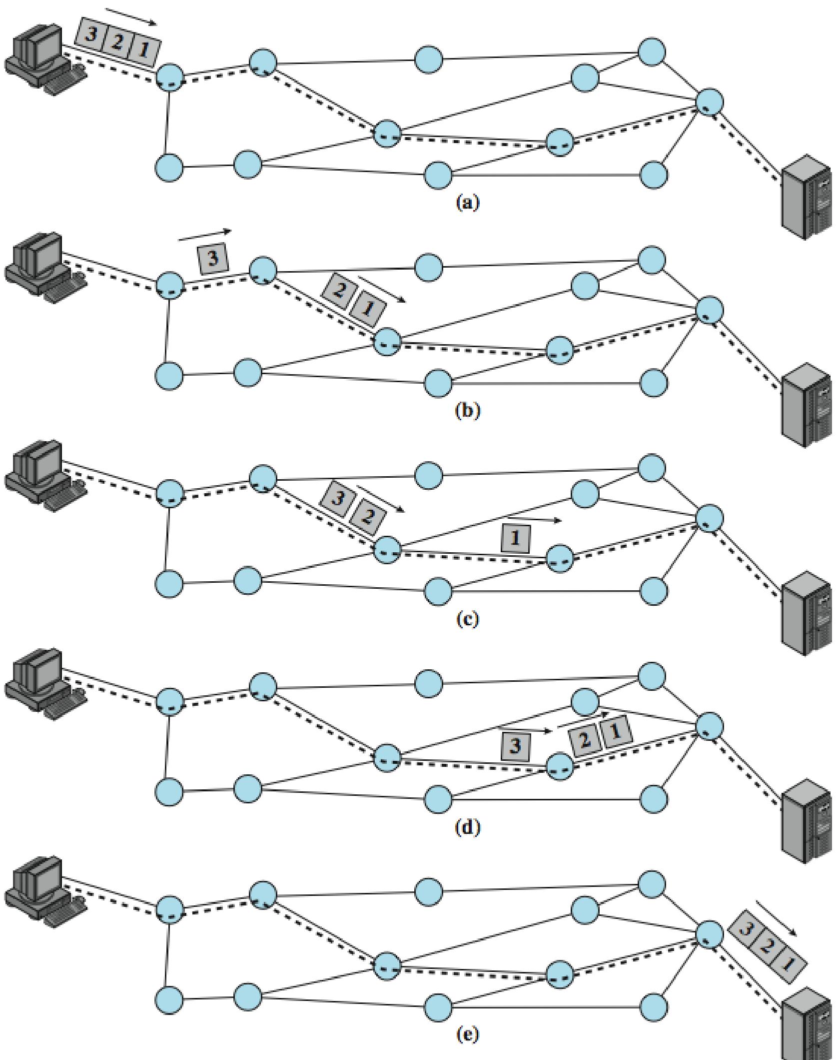


Figure 10.10 Packet Switching: Virtual-Circuit Approach

Packet Switching

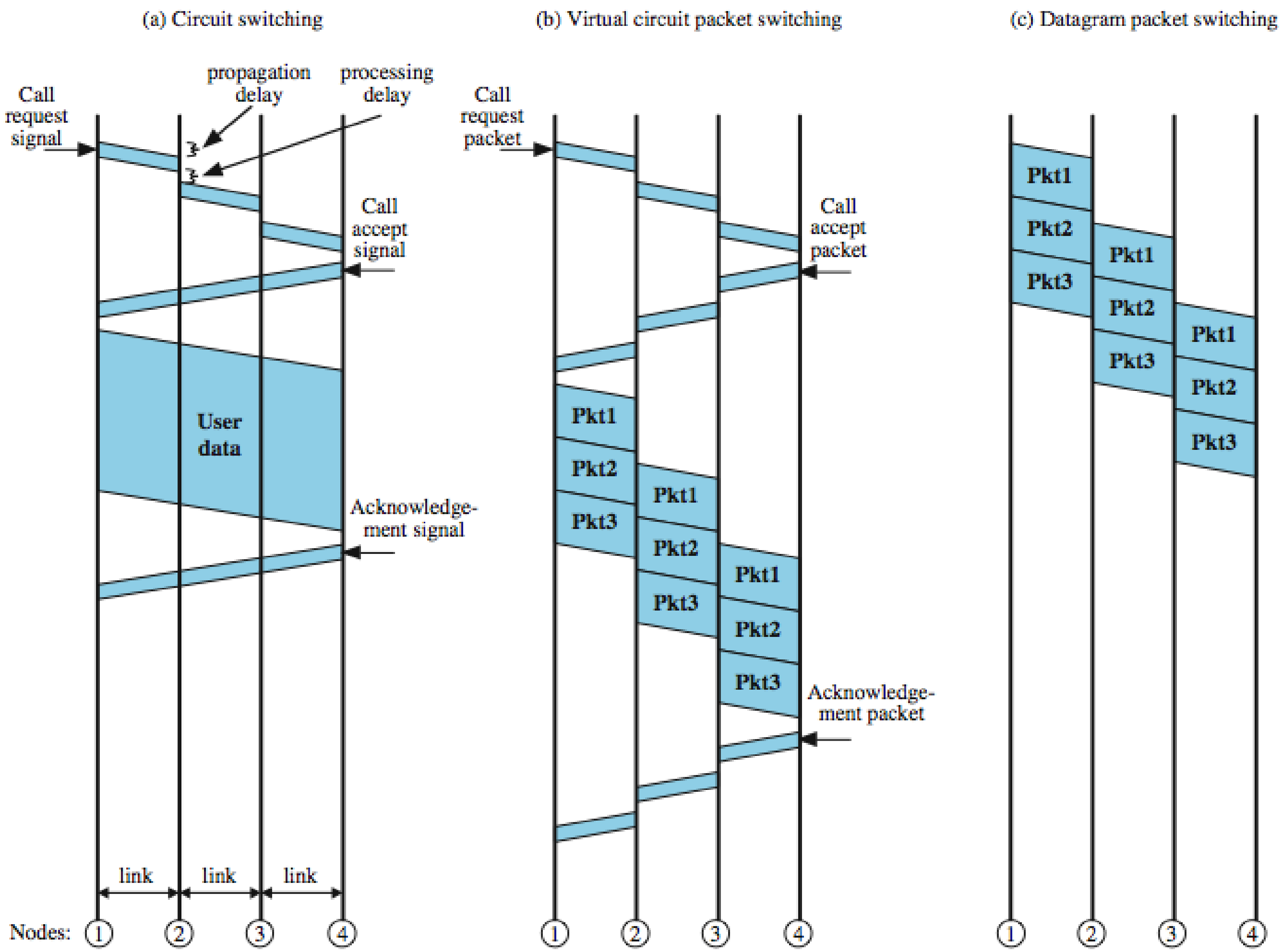
Datagram

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

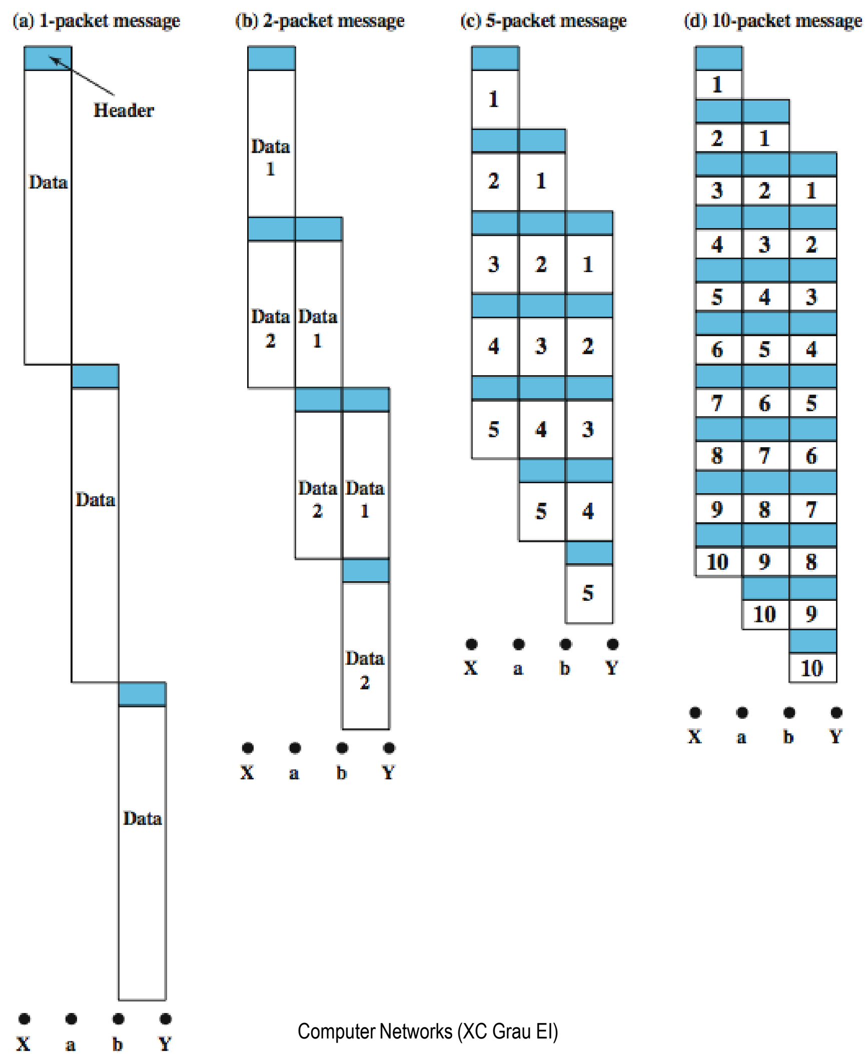
Virtual Circuit

- 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


(a) 1-packet message
Header
Data
Data
Data
X a b Y
(b) 2-packet message
Data 1
Data 2
Data 1
Data 2
Data 1
Data 2
X a b Y
(c) 5-packet message
1 2 3 4 5
X a b Y
(d) 10-packet message
1 2 3 4 5 6 7 8 9 10
X a b Y

Unit 1: Introduction

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- Brief history of Computer Networks and Internet
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- **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
  7th 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 that 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

Application

Provides access to the OSI environment for users and al provides distributed information services.

Presentation

Provides independence to the application processes from differences in data representation (syntax).

Session

Provides the control structure for communication between applications; establishes, manages, and terminates connections (sessions) between cooperating applications.

Transport

Provides reliable, transparent transfer of data between end points; provides end-to-end error recovery and flow control.

Network

Provides upper layers with independence from the data transmission and switching technologies used to connect systems; responsible for establishing, maintaining, and terminating connections.

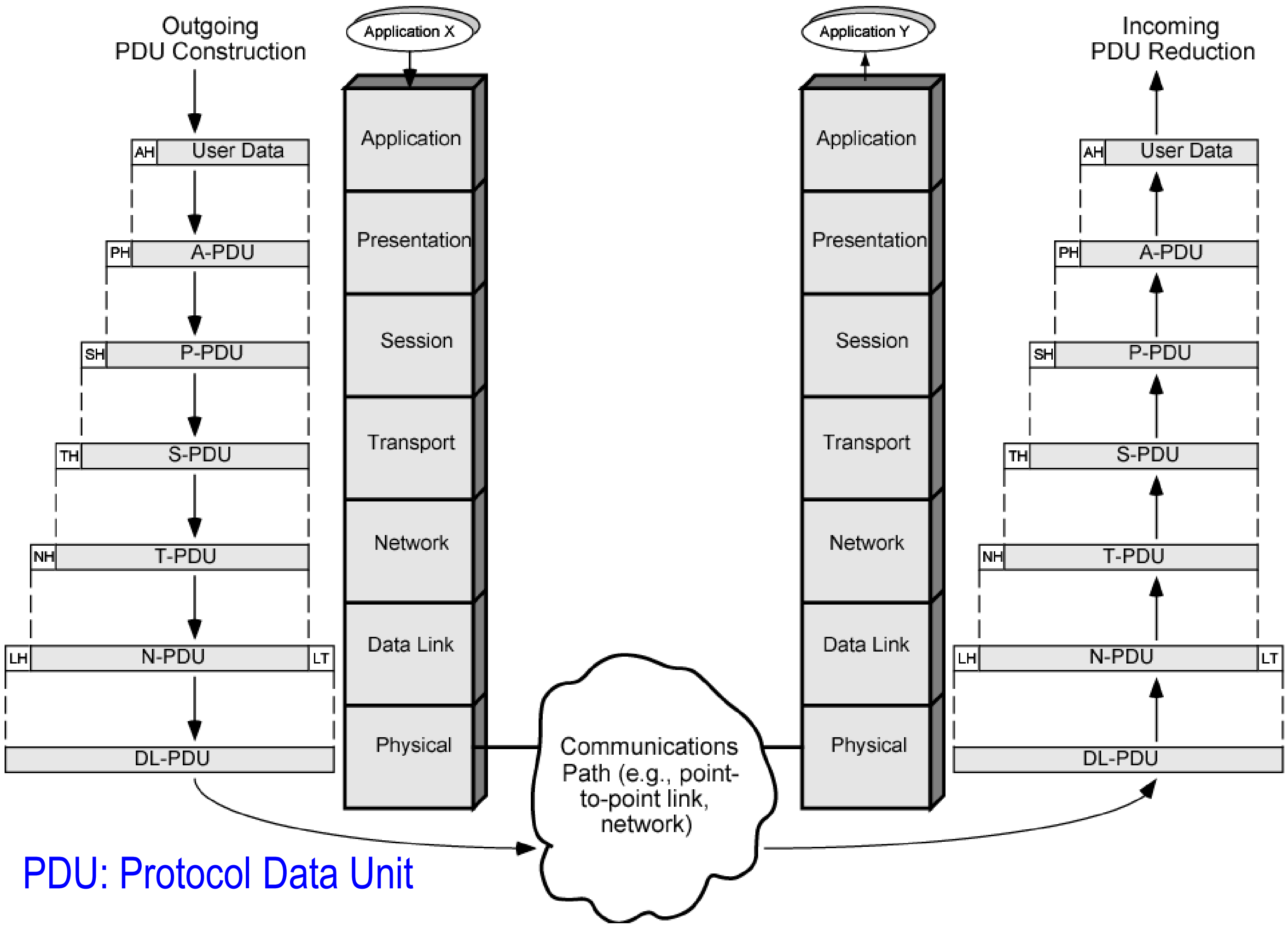
Data Link

Provides for the reliable transfer of information across the physical link; sends blocks (frames) with the necessary synchronization, error control, and flow control.

Physical

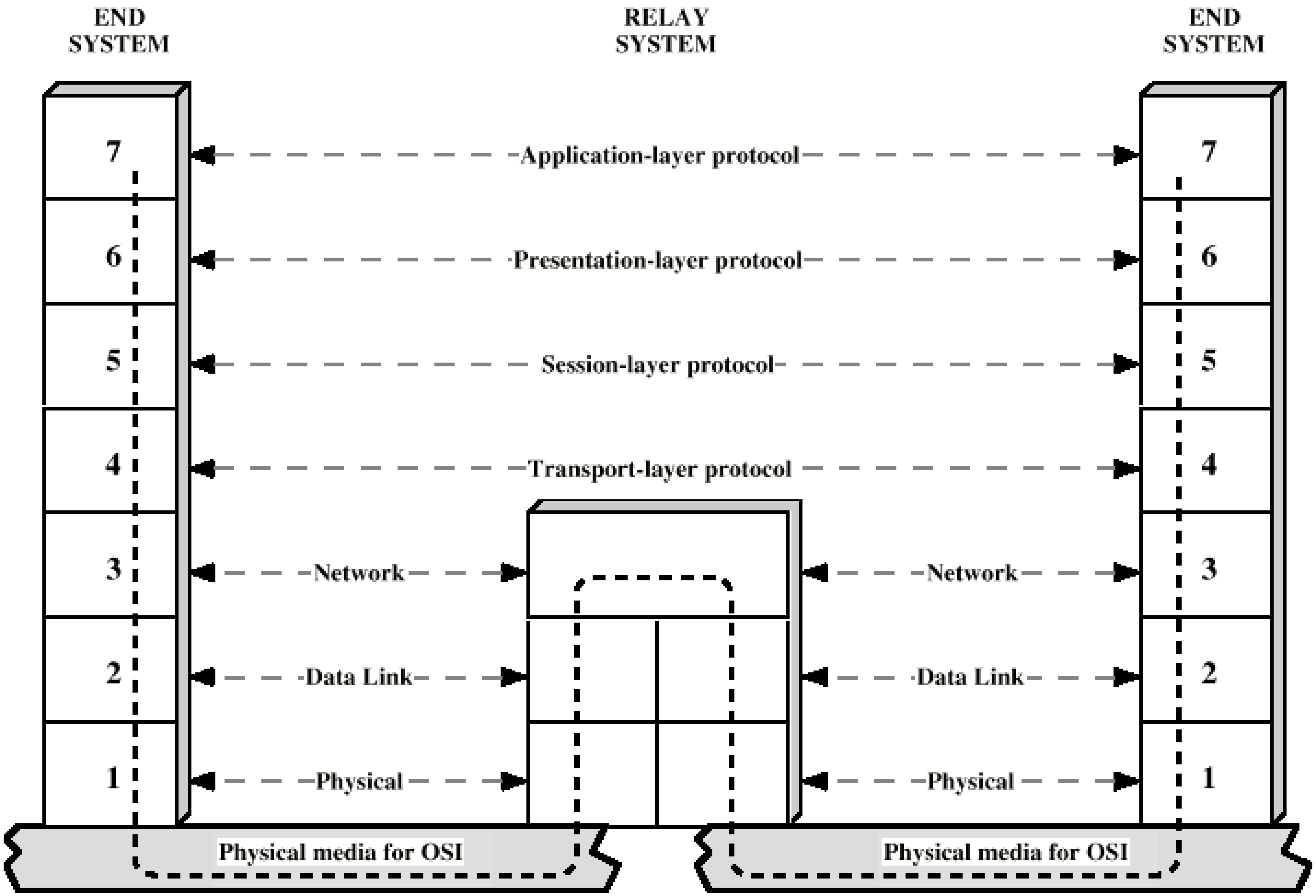
Concerned with transmission of unstructured bit stream over physical medium; deals with the mechanical, electrical, functional, and procedural characteristics to access the physical medium.

The OSI Reference Model



PDU: Protocol Data Unit

Use of a Relay



TCP/IP Protocol Architecture

- Adopted by the US Defense Advanced Research Project Agency (DARPA) for its packet switched network (ARPANET)
- Nowadays it is 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
- Exchange of data between end-systems
- Routing functions across multiple networks
- Implemented on end-systems and routers

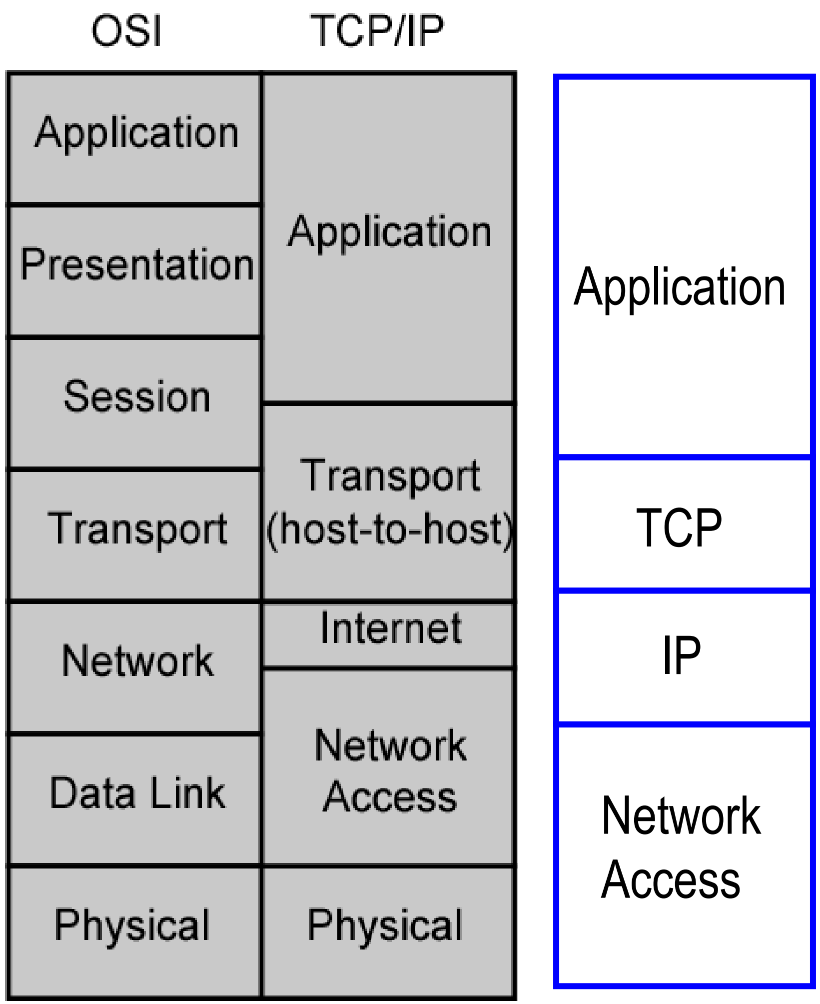
Transport Layer (TCP)

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

Application Layer

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

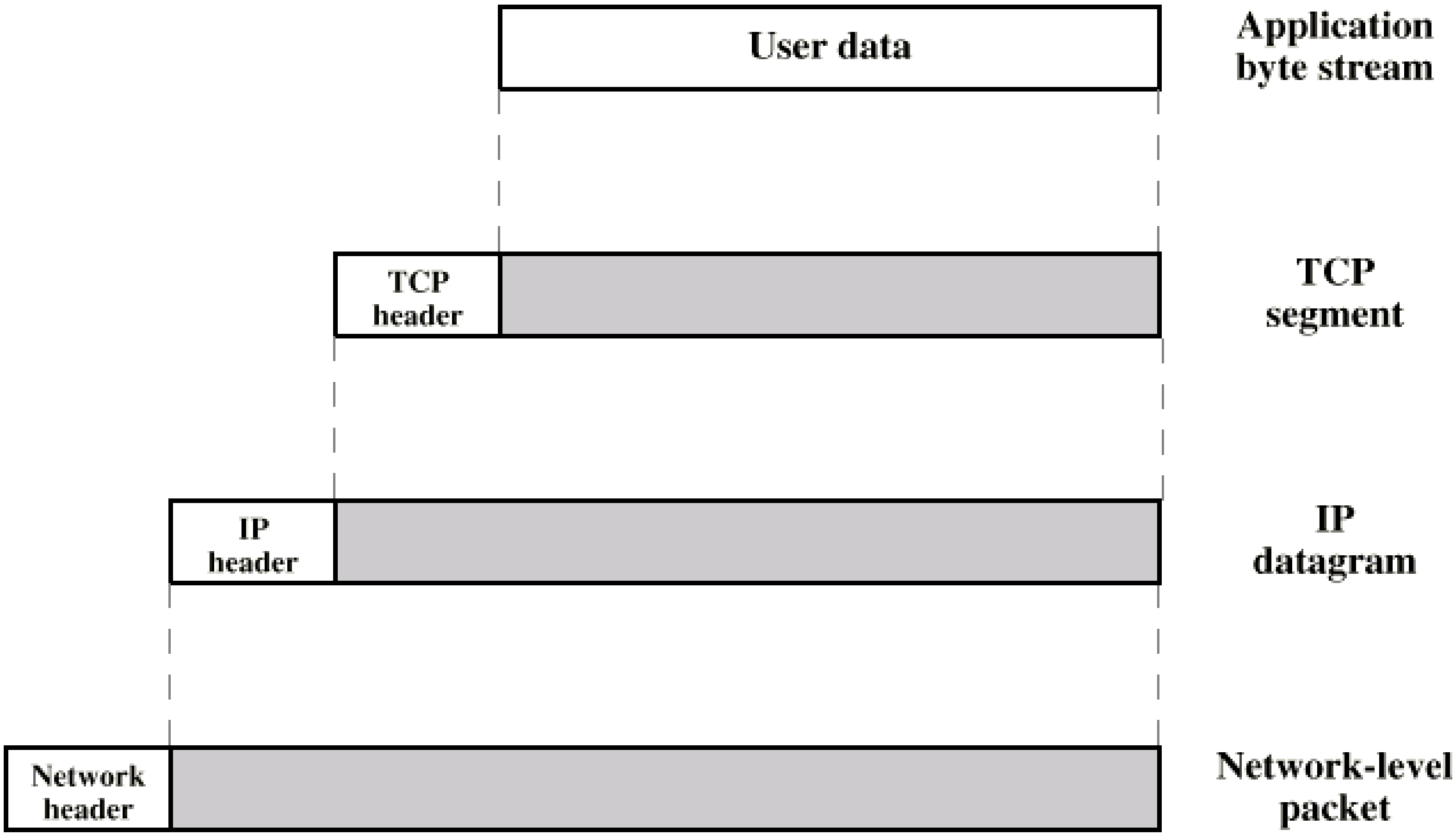
OSI vs TCP/IP


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

TCP

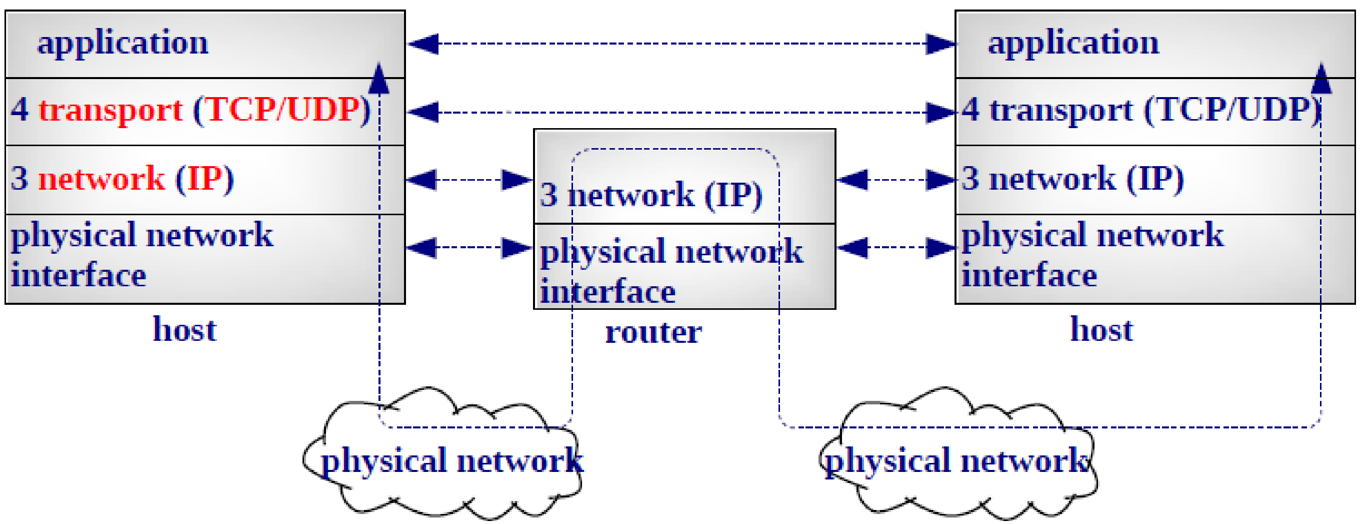
- Usual transport layer is Transmission Control Protocol
  - Reliable connection
- Connection
  - Temporary logical association between entities in different end-systems
- TCP PDU
  - Also known as TCP segment
  - Includes source and destination port (c.f. SAP)
    - Identify end users (applications)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

PDUs in TCP/IP



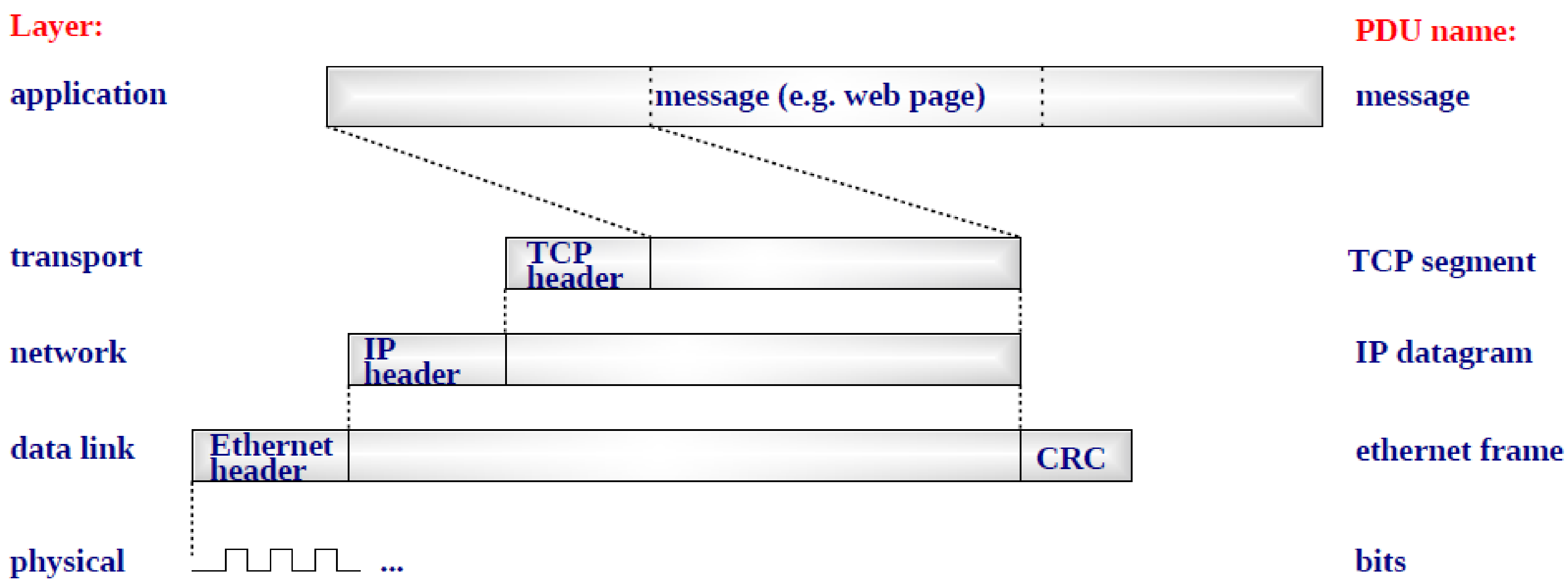
TCP/IP Architecture

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

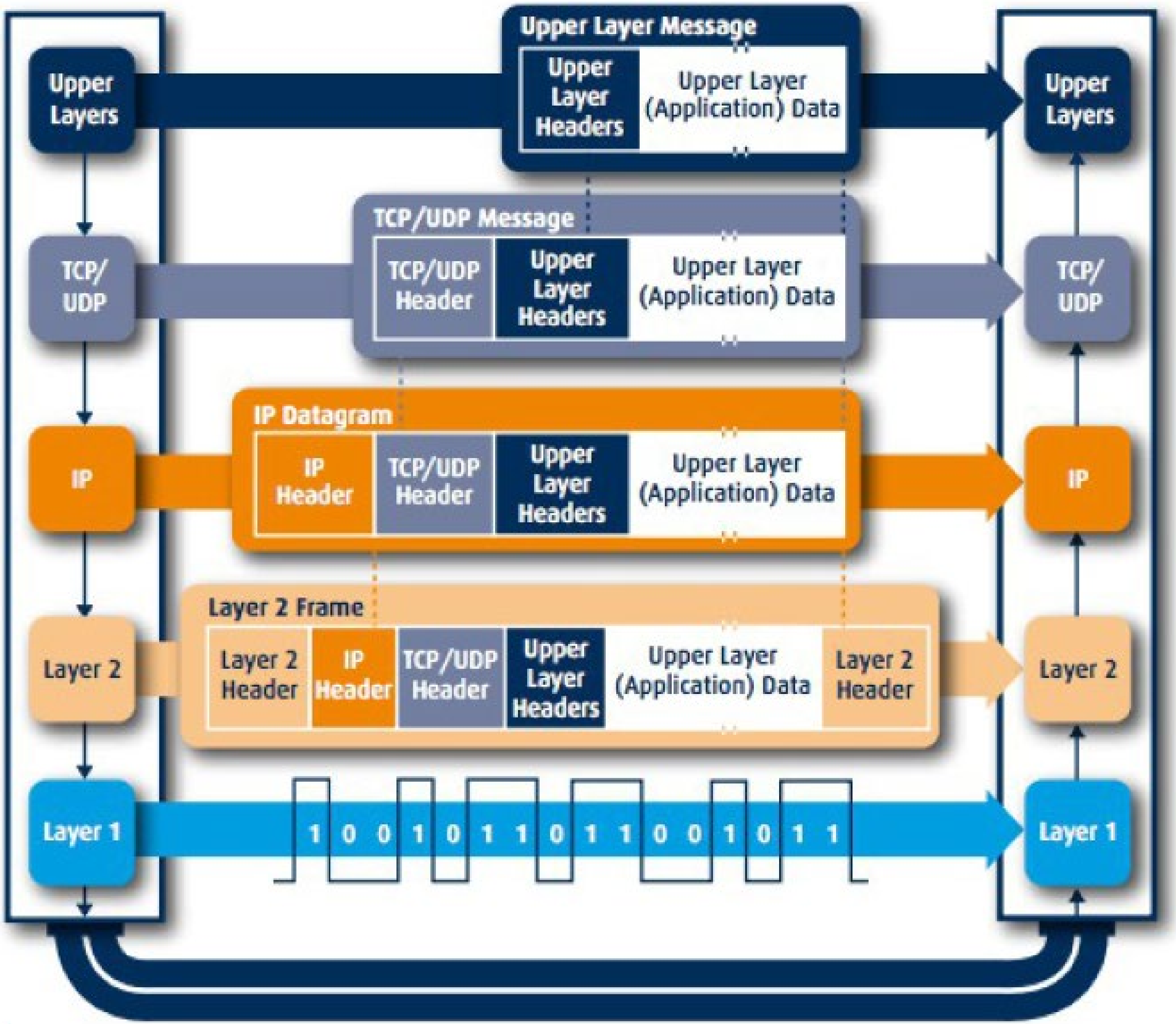


Encapsulation

- Each layer adds/removes the PDU header.



Maximum Transmission Unit (MTU): data in the Ethernet frame



Gateway

Proxy

Router

Switch

Amplifier

Outline

- Brief history of Computer Networks and Internet
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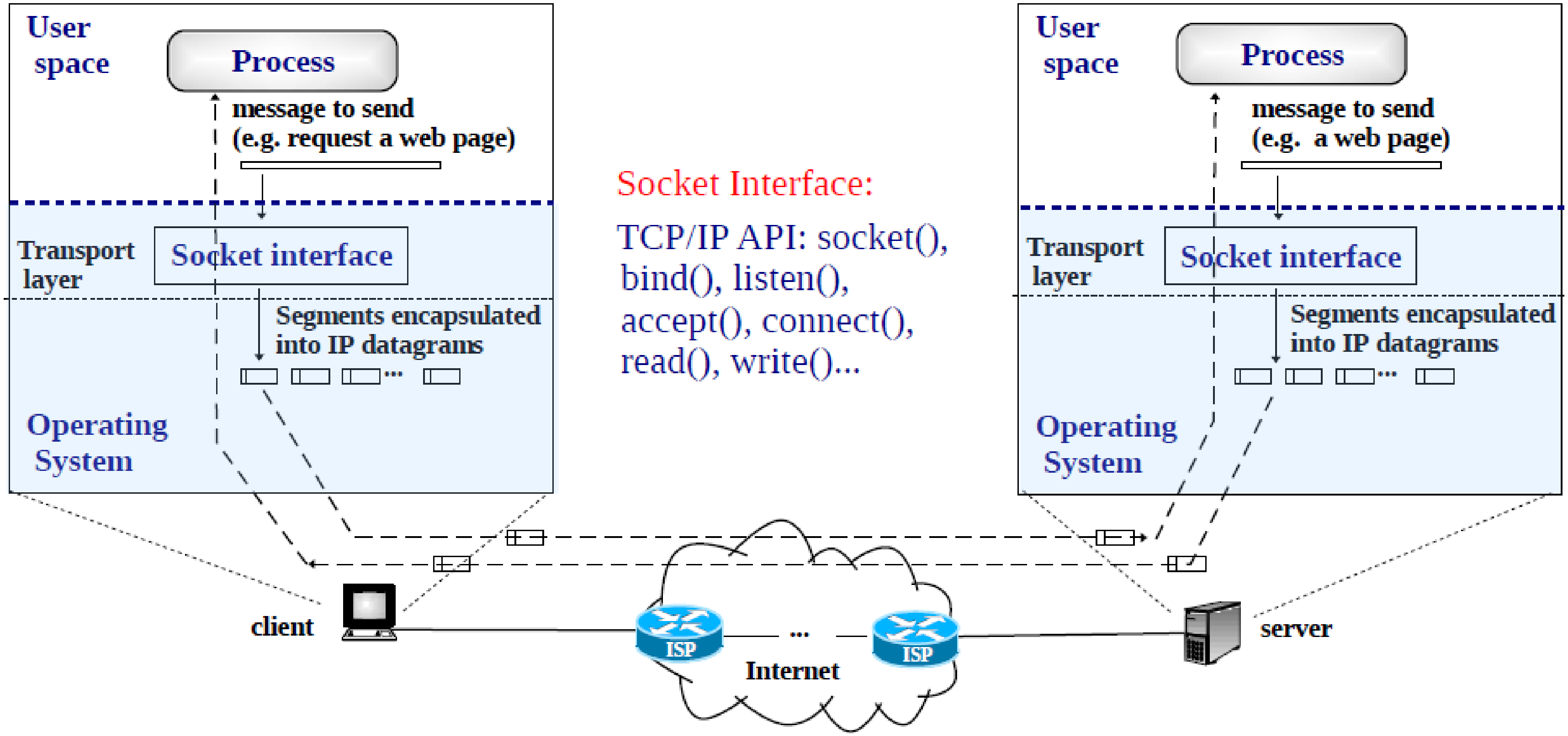
- **Client-Server Paradigm**

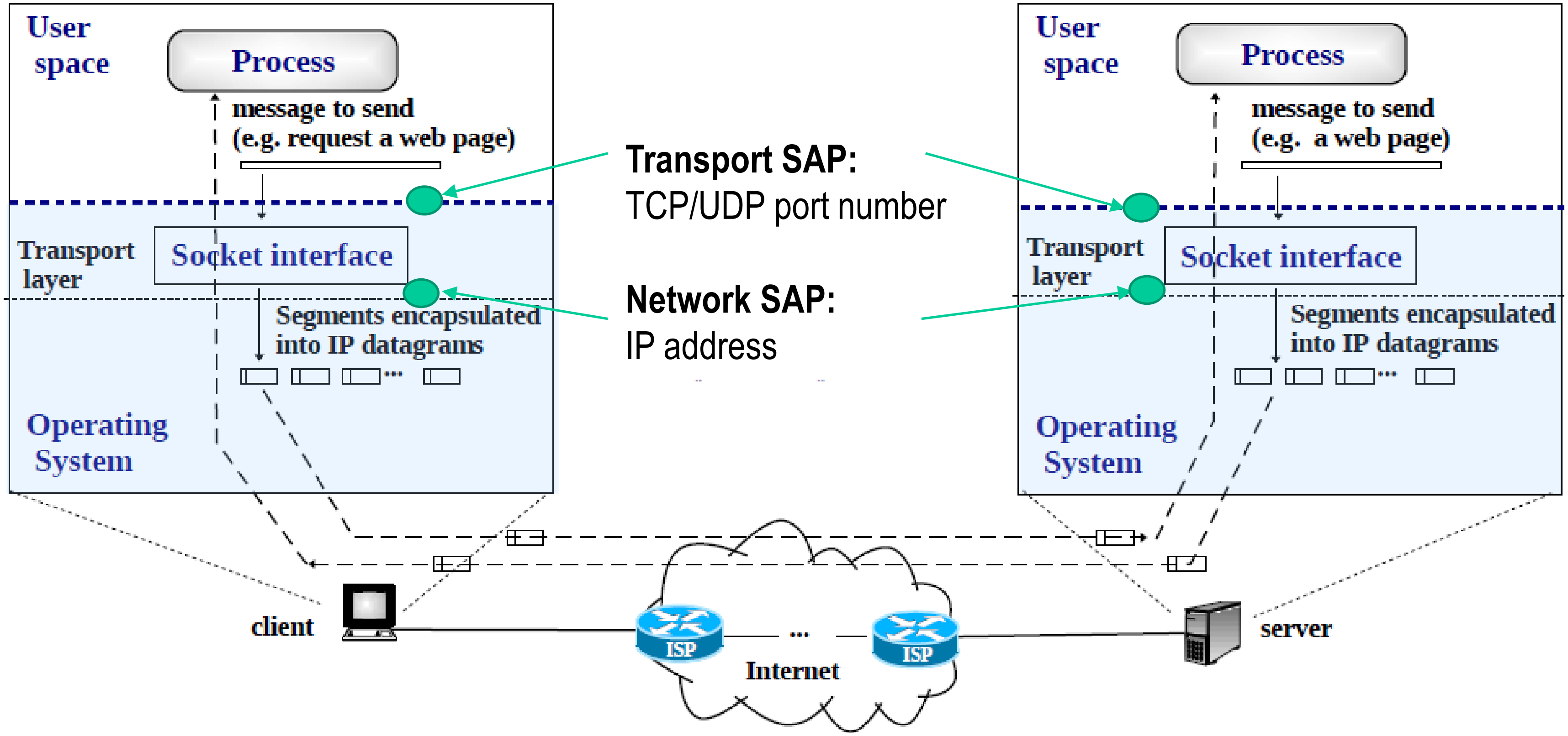
Client Server Paradigm: Processes, messages, sockets segments and IP datagrams



Socket Interface:

TCP/IP API: socket(), bind(), listen(), accept(), connect(), read(), write()...

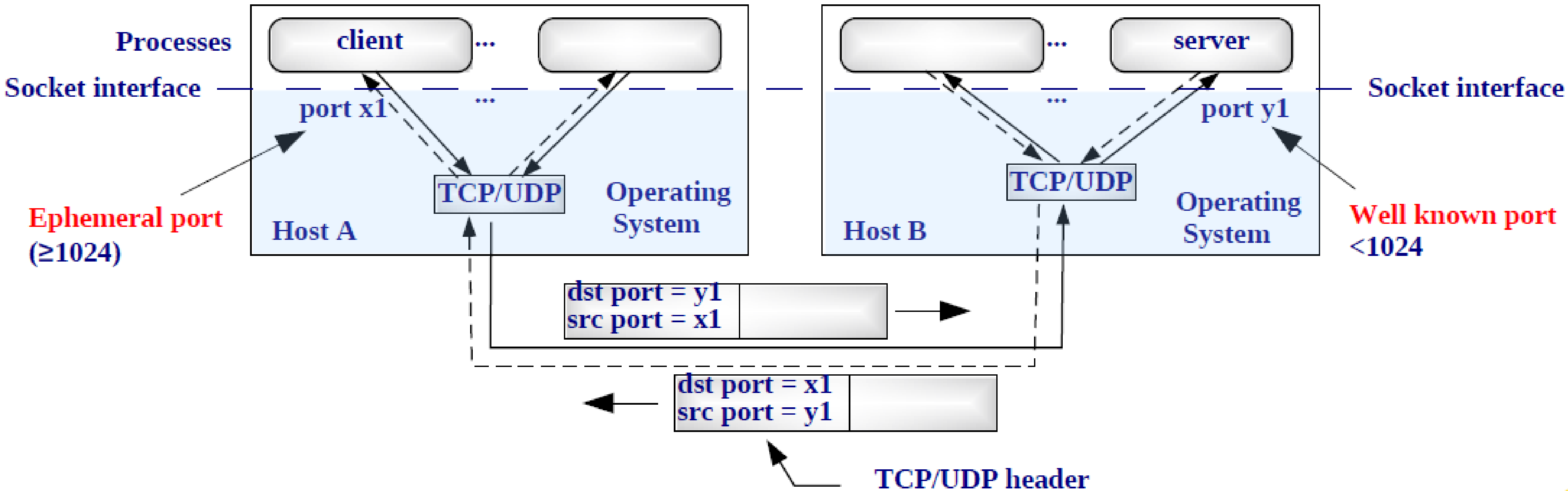
Client Server Paradigm: Processes, messages, sockets segments and IP datagrams



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

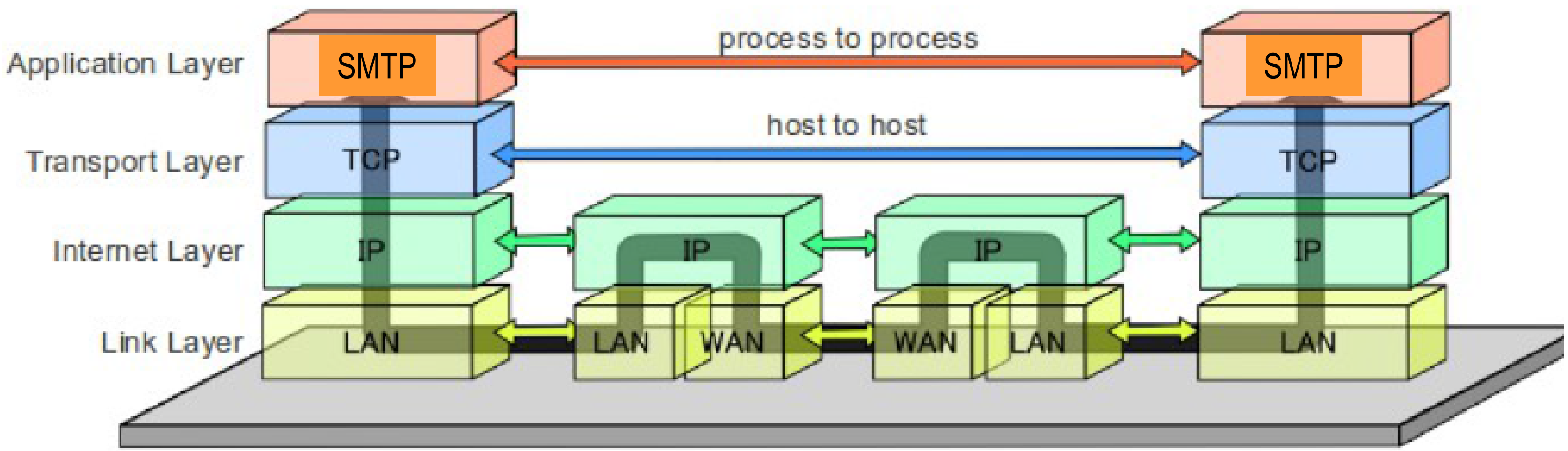
- ftp: 20 (data) 21(control)
- telnet: 23
- ssh: 22
- chargen: 19
- smtp: 25; smtps: 465, 587
- pop3: 110; imap:143; pop3s: 995; imaps: 993
- http: 80; https: 443
- ntp: 123
- dns: 53

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

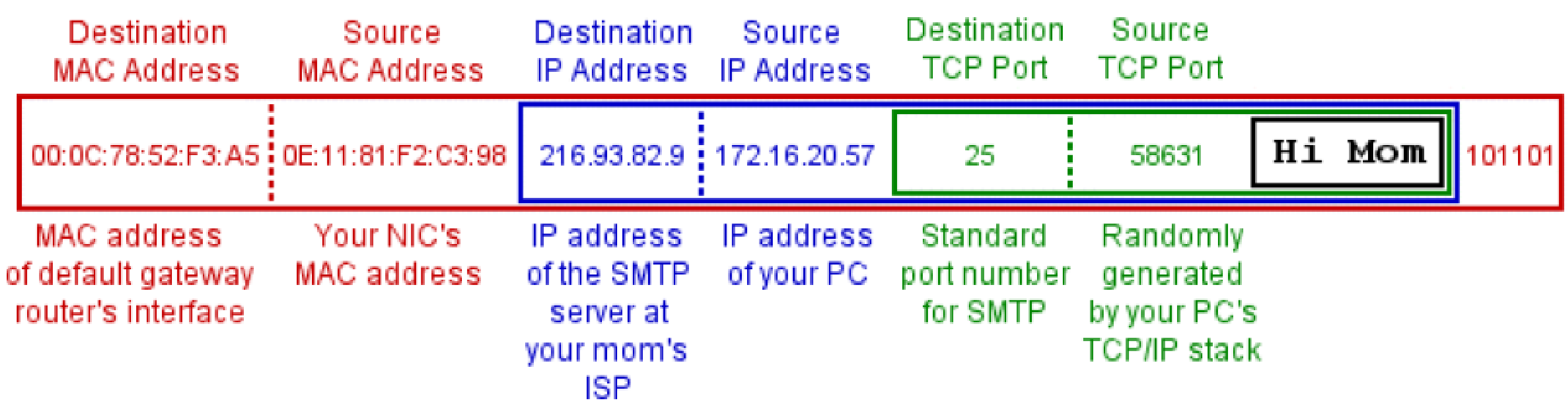
Client Server Paradigm – Network applications

- 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

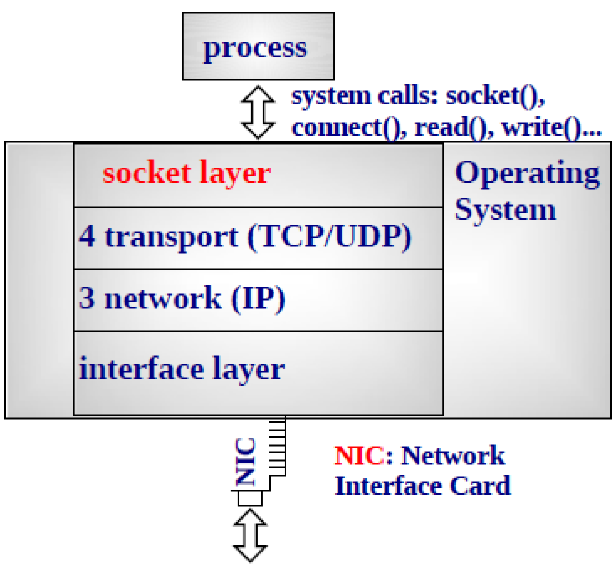


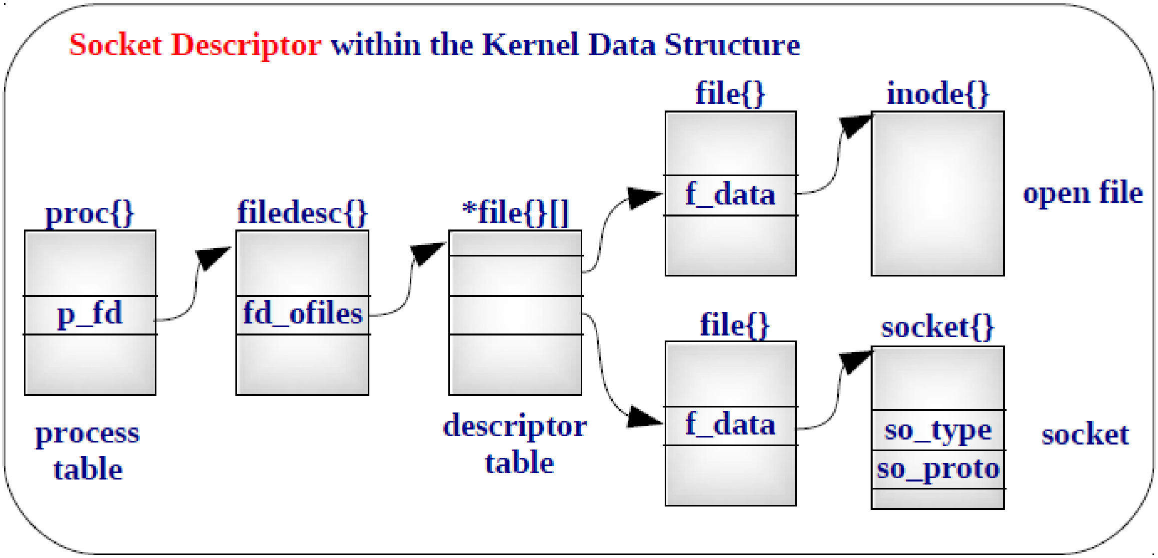
Outgoing E-mail Frame



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

Warriors of the Net (traducció al català)

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- 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.