Computer Networks - *Xarxes de Computadors*

Outline

- **General information**
- Unit 1. Introduction
- Unit 2. IP Networks
- Unit 3. LANs
- Unit 4. TCP
- Unit 5. Network applications

Based on: https://studies.ac.upc.edu/FIB/grau/XC/#slides

General information

Lecturer

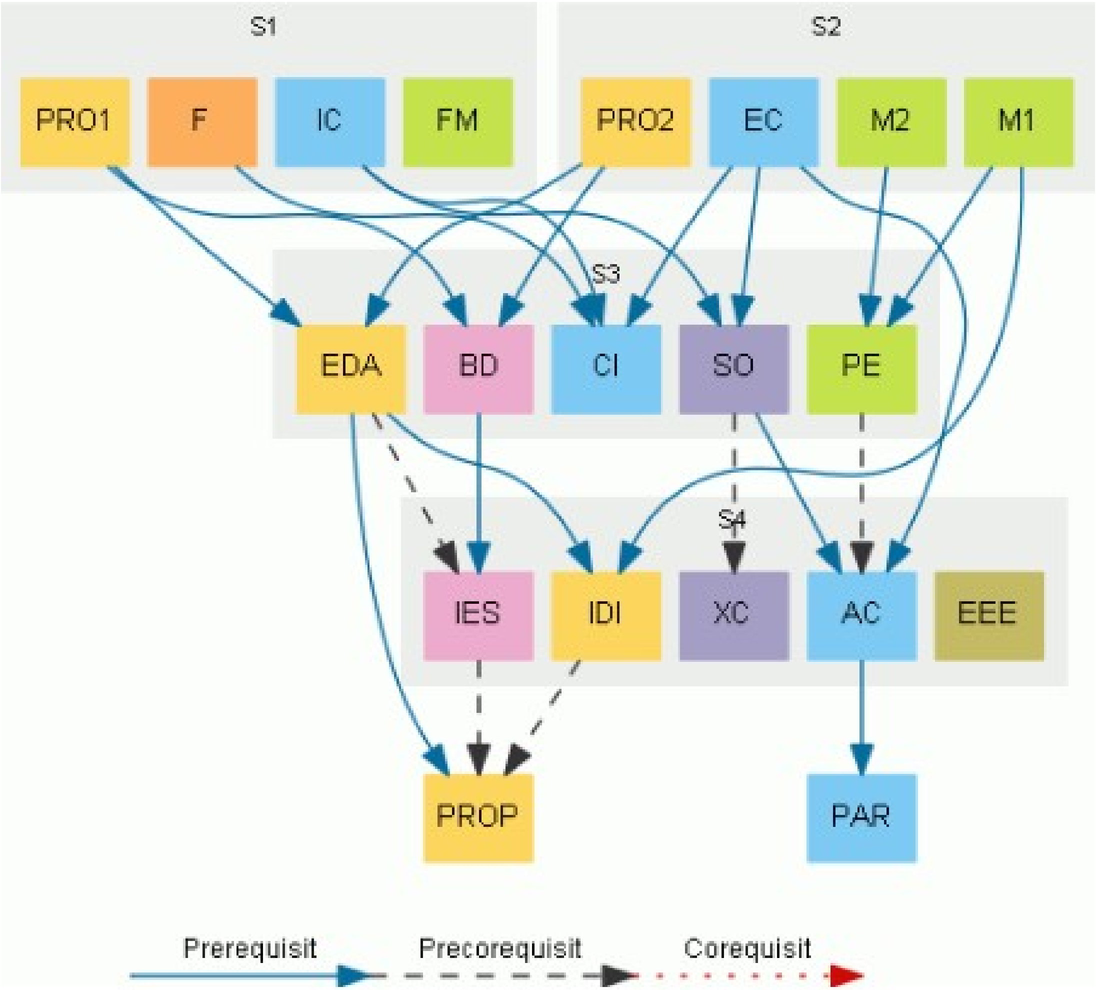
- Roger Baig Viñas roger.baig+xc@upc.edu
- Office hours (*consultes*): on demand, requests via e-mail (D6-105)

Teaching resources

- Public websites:
  - https://studies.ac.upc.edu/FIB/grau/XC/
    - Term's specific info: Read it carefully
  - https://www.fib.upc.edu/en/studies/bachelors-degrees/bachelor-degree-informatics-engineering/curriculum/syllabus/XC
    - General info
- FIB's intranet (*Racó*): https://raco.fib.upc.edu/
  - Subject: Several notifications during the semester (labs, exams, etc.)
  - Lectures: One single notification updated frequently
    - Study guidelines
    - Slides
      - » Consolidated slides will include `_final` in the file name
      - » Public and possibly outdated https://people.ac.upc.edu/rbaig/XC/index.html

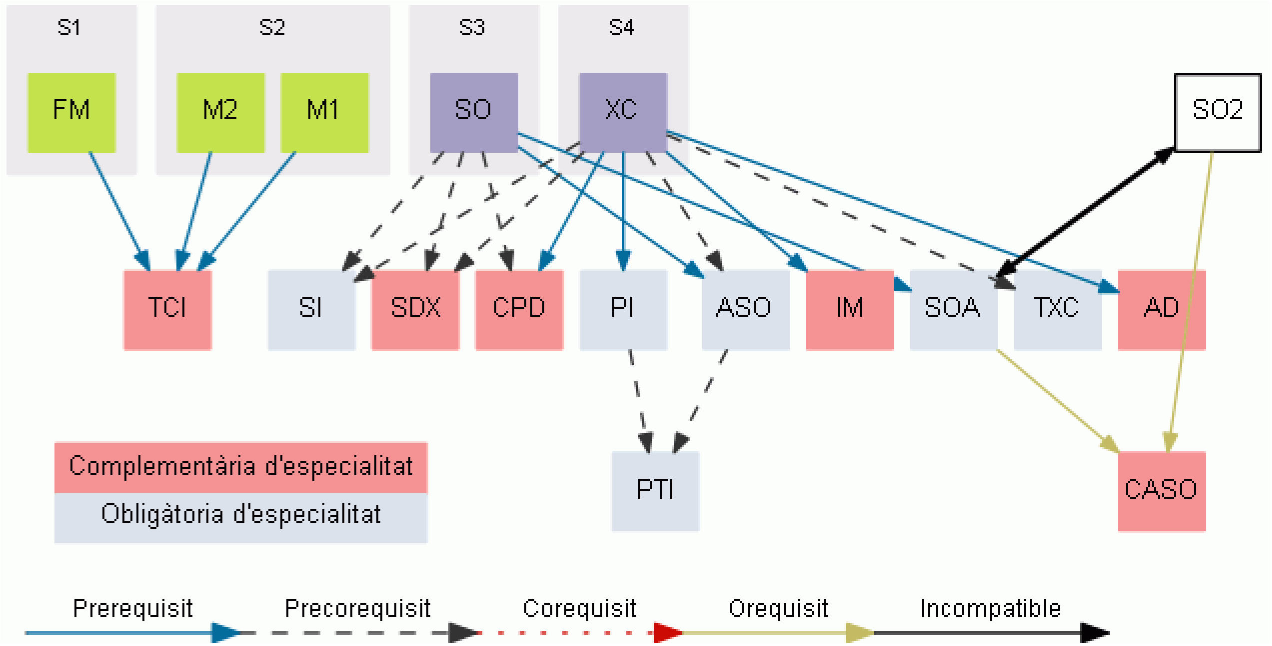
General information

GEI - Assignatures obligatòries



General information

GEI – Especialitat
Tecnologies de la informació



General information

Course Organization

- 2+1h lectures/week: theory + problems
  - Print the problems manual (available in the *Racó*)
  - Try to do the problems beforehand
    - Usually the problems solved will be announced in the previous lectures
  - Tracking problems (*exercicis de seguiment*)
    - Exercises proposed during the lectures
      One per unit, except two for Unit 2
    - Must be delivered within the next 48h
    - Can only be delivered through the R*acó*
      - » Where: *"Pràctiques"* left frame
      - » Accepted file formats: plain text (.txt), PDF, PNG, JPG
      - » Mandatory file names: `Surename1_Surename2_Name_seguiment{1,2,3,4,5}.ext`
  - Find textbooks and related links at the subject's web page

General information

Course Organization (cont.)

- Laboratory 7 sessions of 2h on selected weeks
  - Schedule: see subject's website (starts at 4th week)
  - Bring the manual printed in paper (@ Repography & *racó*)
  - Study and prepare sessions before hand
  - Submit the report at the beginning of the session
  - Minicontrol held at the end of each session (if reported submitted)

General information

Evaluation

NF = 0.30 * NL + 0.70 * NT

- NF = Final grade
- NL = Laboratory = 0.5 * CL + 0.5 * EL
  - CL = Minicontrols average grade
  - EL = Laboratory final exam grade
- NT = Theory grade = 0.3 * max(C1, EF) + 0.7 * EF
  - C1 = Partial exam grade
  - EF = Final exam grade
    - IP's problem grade: max(C1, EF_IP) ⇒ can be skipped (⇒ C1 grade)

Bonus (<u>only if NF>1</u>)

NFinc = NF + max(0, min(1, (NF-5)/2) * B)

- NFinc = Final grade incremented
- B = Tracking problems delivery rate out of 4

General information

Work plan

- 6 credits ECTS (152 hours)
  - Lectures: ~39 hours
  - Laboratories: ~14 hours
  - **Self-study**: 100 hours ⇒ ~1.5 of self-study hours per 1 lecture/lab hour!!
- Lectures: 13 weeks in total
  - Unit 1: Introduction — 1 week
  - Unit 2: IP networks — 5 weeks
  - Unit 3: LANs — 2 weeks
  - Unit 4: TCP (transport) — 3 weeks
  - Unit 5: Applications — 2 weeks
- Exams
  - Partial (*Control*) — 08/04/2024 10:30-12:30 — Units: 1, 2
  - **Final (*Examen final*)** — **19/06/2024 15:00-17:45** — Units: all
  - Only non-programmable calculators allowed

General information

Work plan

- Missed with a justified cause:
  - Laboratories
    - Contact the subject's coordinator in advance (llorenc.cerda@upc.edu) to attend another group
  - Partial exam
    - The second chance exam is the final exam
  - Final exam
    - A second chance exam will be arranged

General information

Objectives

- Identify main network functions at each level
- Identify client-server applications and associated ports
- Predict protocol operation and messages for web, e-mail, DNS apps
- Interpret documents (HTML)
- Interpret IP header fields, IP fragmentation, auxiliary protocols ARP, ICMP
- Interpret and deduce routing table content, predict RIP routing protocol behaviour and messages
- Design IP network address allocation, public and private addresses and NAT
- Design the basic configuration of a firewall (NAT, access lists and tunnels).
- Differentiate TCP and UDP and interpret header TCP segments and UDP datagrams

Source: https://www.fib.upc.edu/en/studies/bachelors-degrees/bachelor-degree-informatics-engineering/curriculum/syllabus/XC

General information

Objectives (cont.)

- Create time diagrams to model protocol behaviour in TCP
- Predict TCP flow, congestion control, window (buffers), segment transfer, congestion window, slow-start, congestion-avoidance algorithms
- Estimate the effective traffic rate for a TCP connection in different conditions (lags, link transmission speeds, segment losses, etc.)
- Represent time diagrams representing MAC protocols for the local area networks studied.
- Determine the active flow control in local area network, traffic distribution in a topology (hubs, switches, routers), distinguish collision and broadcast domains, configure VLANs/ trunks and its network topology
- Identify bottlenecks in a local area network and calculate the effective flow rate for different traffic conditions.

Source: https://www.fib.upc.edu/en/studies/bachelors-degrees/bachelor-degree-informatics-engineering/curriculum/syllabus/XC

Computer Networks - *Xarxes de Computadors*

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Unit 1: Introduction

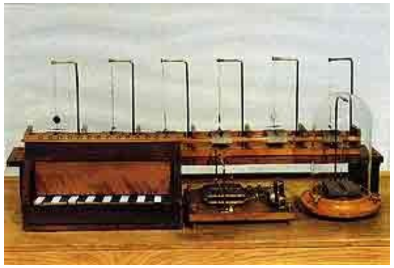
Outline

- **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

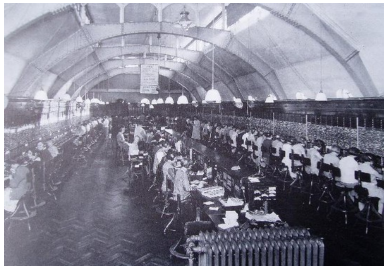
- 1830: Telegraph
- 1866: First transatlantic telegraph cable
- 1875: Alexander Graham Bell invented the telephone
- 1951: First commercial computer
- 1960: Concept of Packet-Switching.
- 1960s: ARPANET project, origins of the Internet.
- 1972: First International and commercial Packet-Switching Network,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



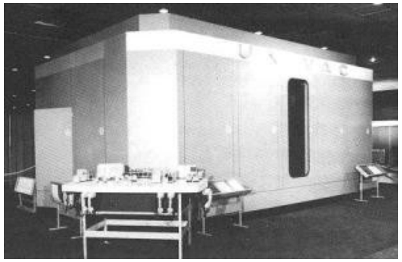
Pavel Shilling Telegraph, 1832.

New York Telephone Cabling, 1888

Major Telegraph Lines, 1891.



Telephone Central Office in London, 1926



UNIVAC: First commercial computer, 1951

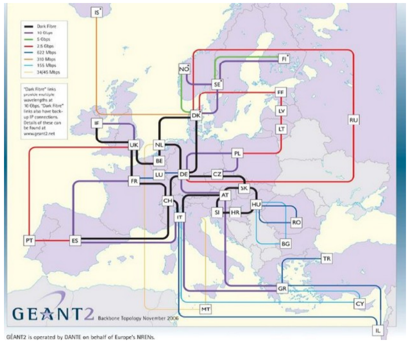
Today's Networking Equipment.

Source: wikipedia

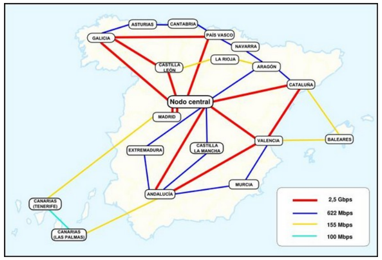
Unit 1: Introduction

Brief History of the Internet

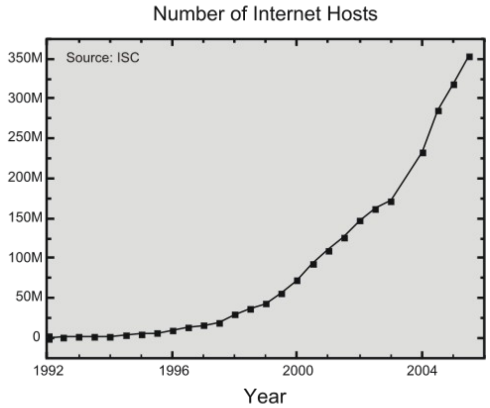
- 1966: Defense Advanced Research Projects Agency (DARPA). ARPANET project.
- ARPANET connected Universities, research labs and military centers. Military portion separated in 1983.
- 1970s: End-to-end reliability was moved to hosts, developing TCP/IP. TCP/IP was ported to UNIX Berkeley distribution,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



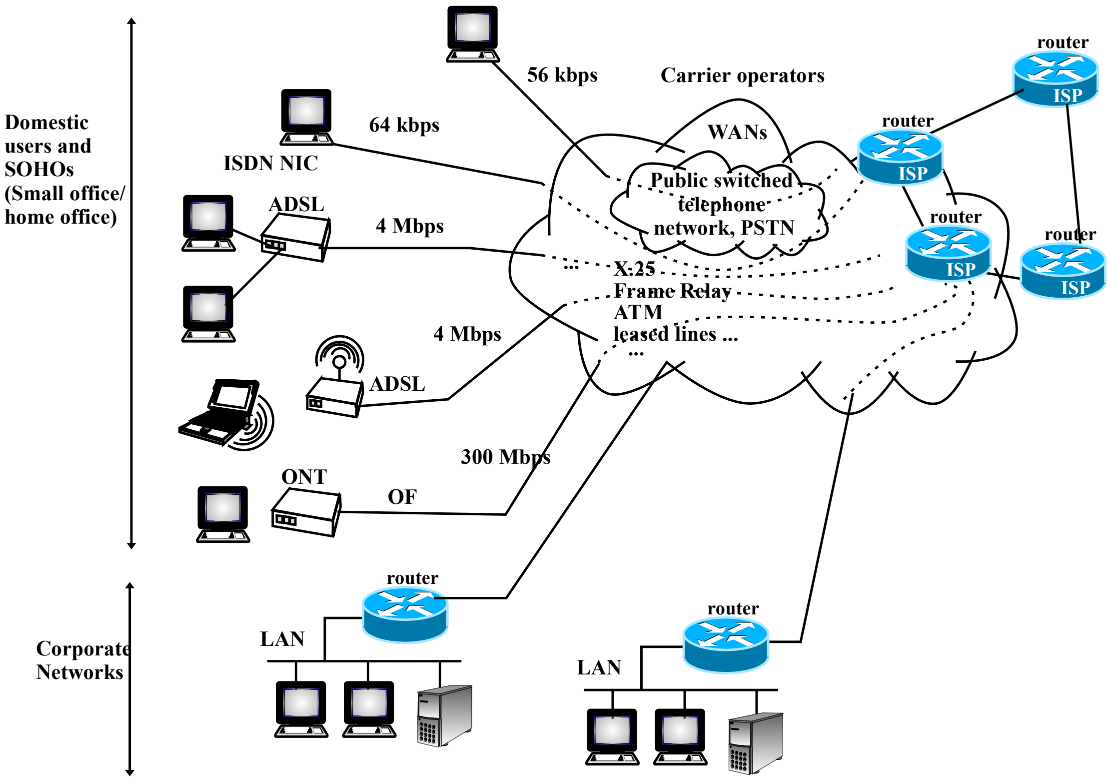
Unit 1: Introduction

Outline

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

Unit 1: Introduction

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

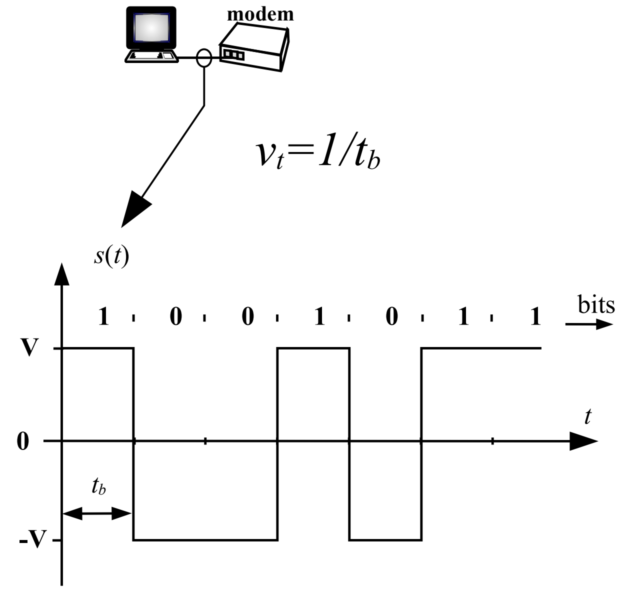


Unit 1: Introduction

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}



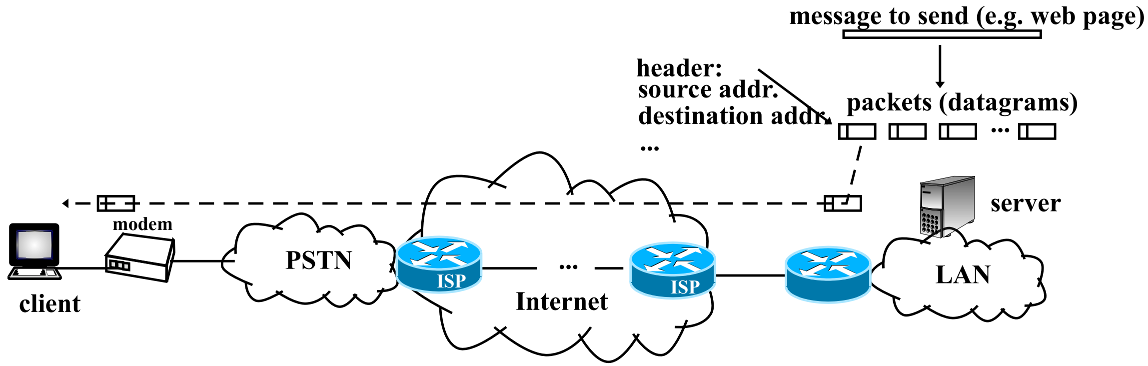
NRZ signal

- 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, ...

Unit 1: Introduction

Types of Switching

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



Datagram packet- switching

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

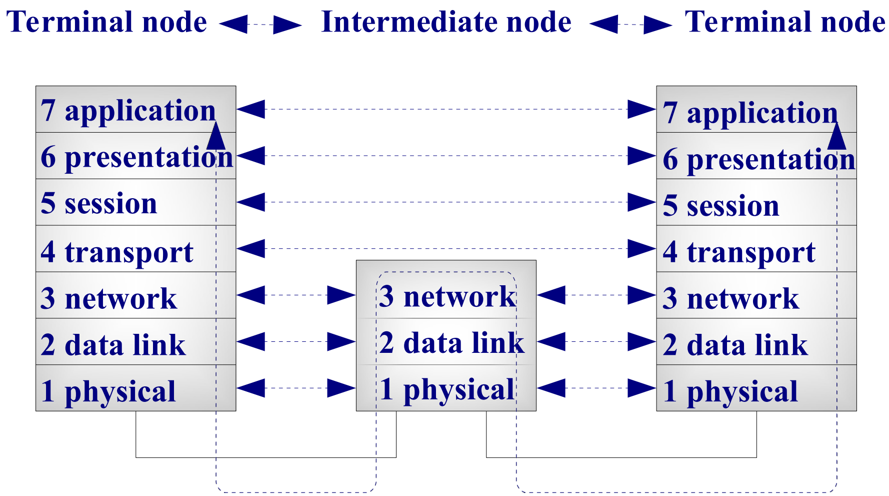
Standardization Bodies

- 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

Unit 1: Introduction

ISO Open Systems Interconnection (OSI) Reference Model

- *Layers or Levels*: Physical or Layer 1 (L1), ...
- Peer layers
  - communicate using a *protocol*.
  - exchange *Protocol Data Unit* (PDU), which consists of a *header* and *payload*.
- Protocols from different layers are independent.
- Layer *i* offers services (e.g. send a datagram to a given address) to layer *i+1*: *Service Access Points* (SAP).



Brief description of Layers:

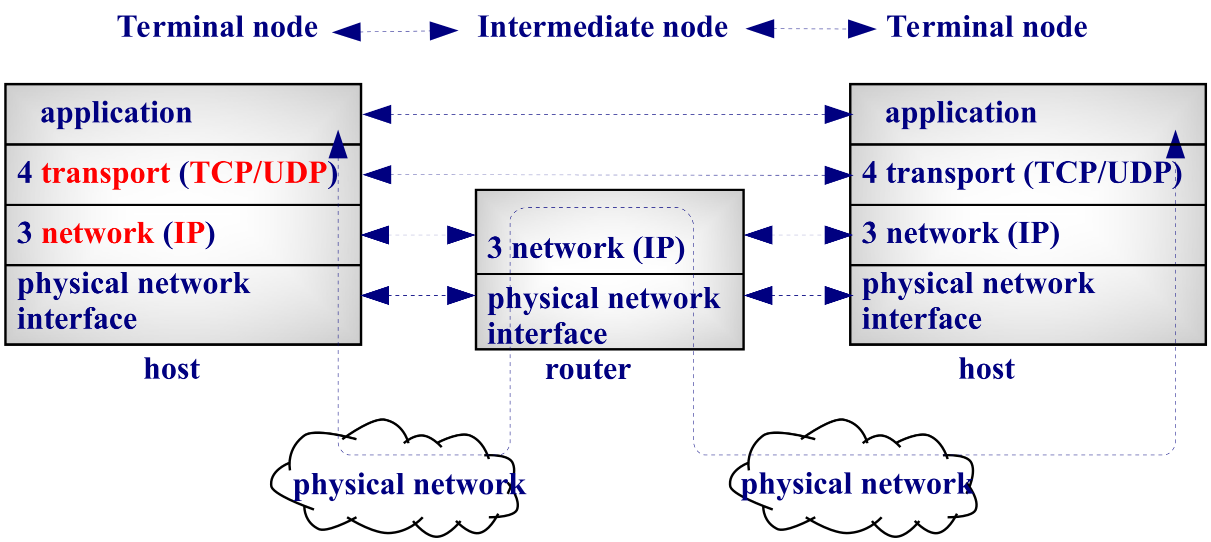
7. Application: Processes using network services (web, email...)
6. Presentation: Encoding of text, numbers...
5. Session: “Login” type service.
4. Transport: End to end data transfer.
3. Network: Routing.
2. Data link: Structured transport of bits.
1. Physical: Electric and mechanical.

*Internet jargon: Layer 8: the user.

Unit 1: Introduction

TCP/IP Architecture

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

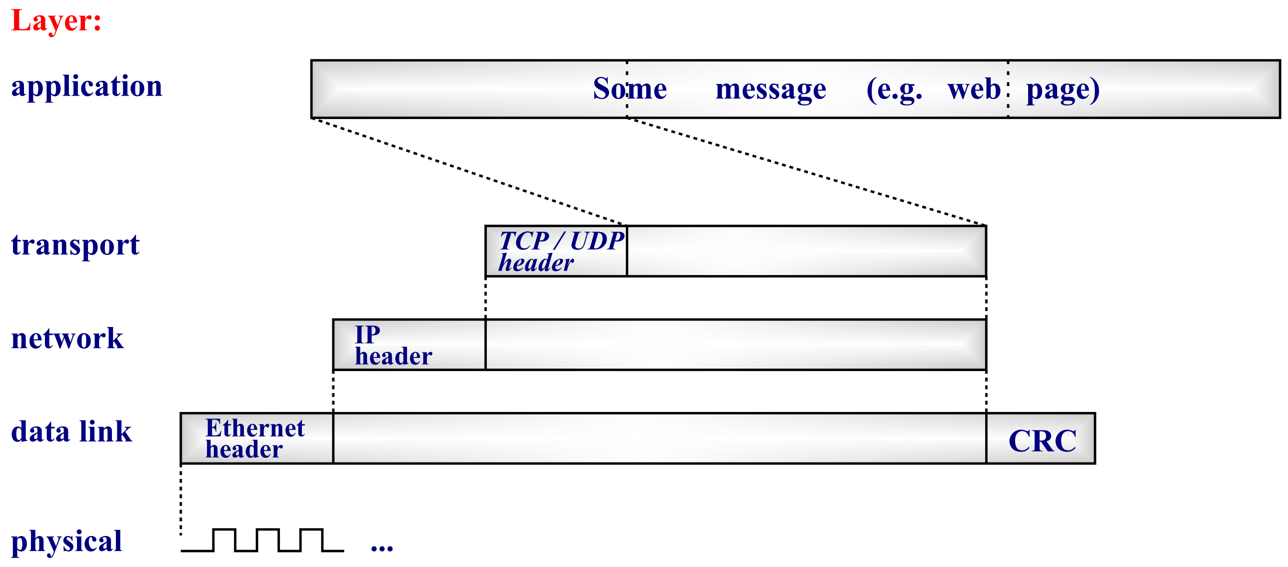


Physical network (Internet jargon): Any network that transport datagrams (not the OSI physical layer!)

Unit 1: Introduction

Segmentation & Encapsulation

- Each layer adds/remove the PDU header.



Unit 1: Introduction

PDU names

TCP/IP		
Layer	***TCP***	***UDP***
Transport	*Segment*	*Datagram*
Network	*Packet**	
Data link	*Frame*	

* Sometimes also called *datagram*

OSI	
Layer	
4 Transport	*Segment*
3 Network	*Packet*
2 Data link	*Frame*
1 Physical	*Symbol (bit)*

Unit 1: Introduction

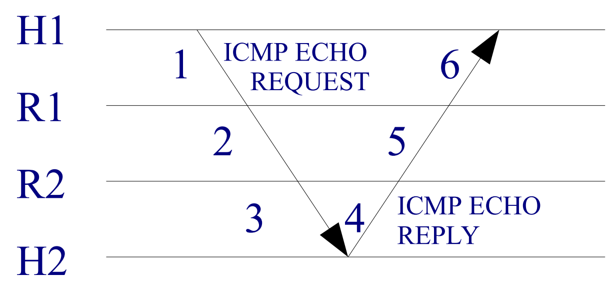
Example

- Discussion: Just Ethernet header contents are modified over links (hops)
- Description
  - Host 1 is connected to Router 1, Router 1 to Router 2, and Router 2 to Host2
  - Host 1 sends a test packet (ICMP Echo Request) to Host 2 over the network
  - Host 2 replies with 1 packet (ICMP Echo Reply)
  - Physical network interfaces identifiers (Ethernet addresses)
    - Host 1: h1
    - Router 1: r11 and r12
    - Router 2: r21 and r22
    - Host 2: hi
  - Network identifiers (IP addresses)
    - Host 1: H1
    - Host 2: H2
- Question
  - Describe the evolution of the Ethernet headers and IP headers of both packets

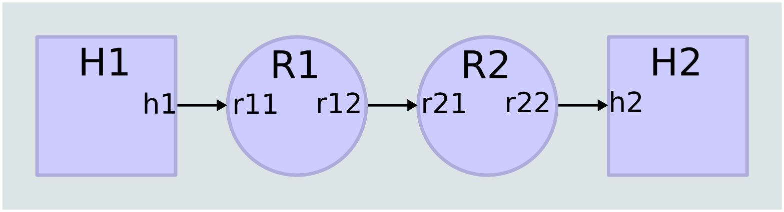
Unit 1: Introduction

Example (cont.)

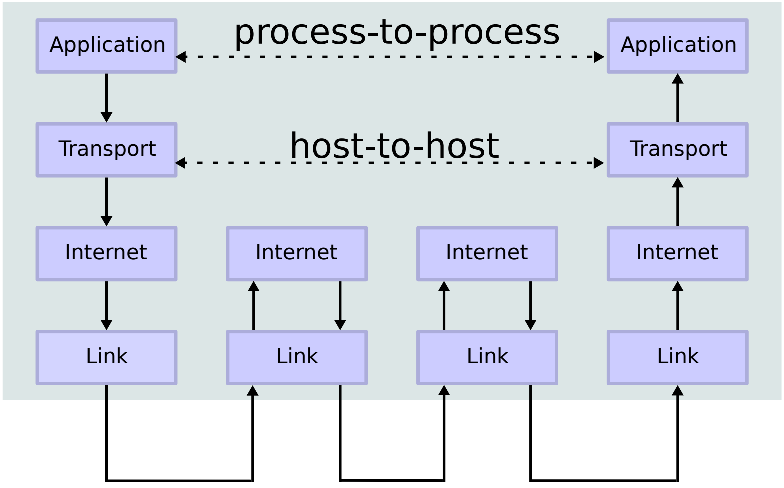
- Solution



Network Topology



Data Flow



		Header			
		Ethernet		IP	
Link	Packe t	src	dst	src	dst
H1-R1	1	h1	r11	H1	H2
R1-R2	2	r12	r21	H1	H2
R2-H2	3	r22	h2	H1	H2
H2-R2	4	h2	r22	H2	H1
R2-R1	5	r21	r12	H2	H1
R1-H1	6	r11	h1	H2	H1

Unit 1: Introduction

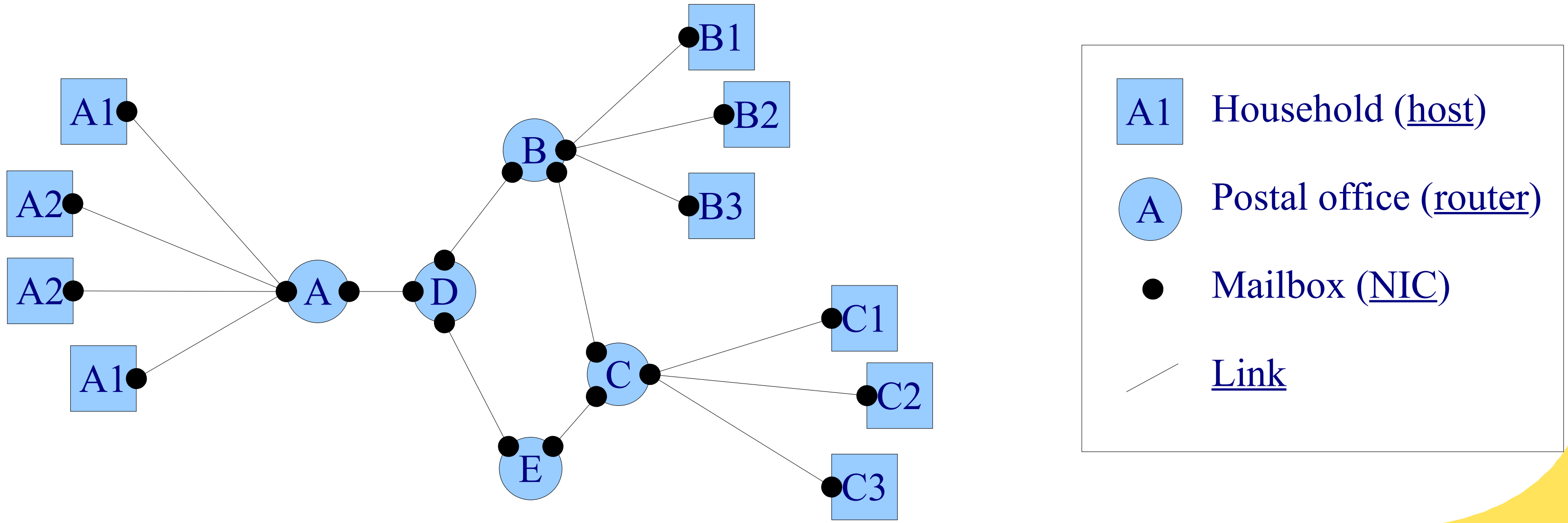
Analogy: The postal service

- Network topology

Each postal office is only connected to:

- A few other postal offices
- The postal offices are connected through dedicated mailboxes (point-to-point)
- The households they serve through a single common mailbox (point-to-multi-point)

Any household can reach any other through at least one multi-hop path



Unit 1: Introduction

Analogy: The postal service (cont.)

- Application layer We want to share a 87 pages long book with a friend
  - the book is the message (it is what only matters to our friend and us)
  - The only mean for sharing it is through the postal service

- Transport layer The receiver (our friend) limits the envelopes' capacity to 10 pages (larger envelops do not fit in her mailbox)
  - We have to split the book into several segments
  - The message segmentation and reassembly must be done according to the same protocol e.g.:
    - The first page is a special page with the number of the first page and the amount of pages of the segment. The rest of the pages are in sequential order.
  - Thus,
    - Header: 1 page
    - Payload: up to 9 pages
    - Segments required: 10 (9 of 9 pages each + 1 of 6 pages = 87 pages)

Unit 1: Introduction

Analogy: The postal service (cont.)

- Network layer Each house (host) has a mailbox with a unique (postal/IP) address
  - For each envelope:
    - We must write (won't change):
      - » Our postal address → the source IP
      - » Our friend's postal address → the destination IP
    - Put it our mailbox
  - Mailboxes (routing):
    - Push to the transport layer all the pages of letter meant for them (i.e. their IP as destination IP)
    - Selects the best next hop for the rest of letters and put them in the corresponding queue (the explanation follows in the Link layer)
  - PDU; : the letter as a whole
  - Header: the envelope
  - Payload: the wad of papers (i.e. up to 10 per envelope)

Unit 1: Introduction

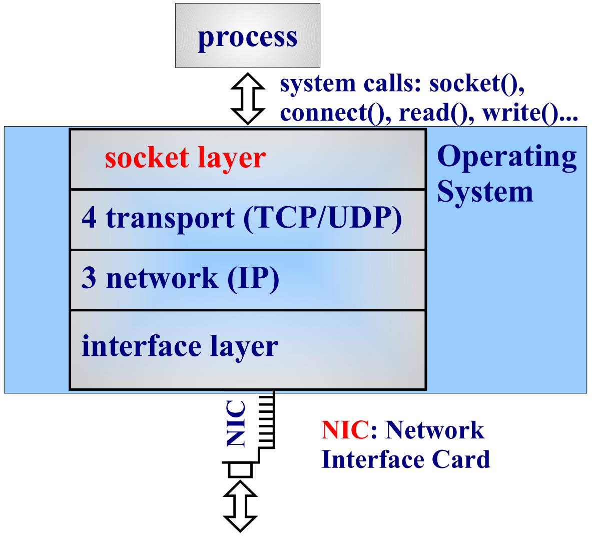
Analogy: The postal service (cont.)

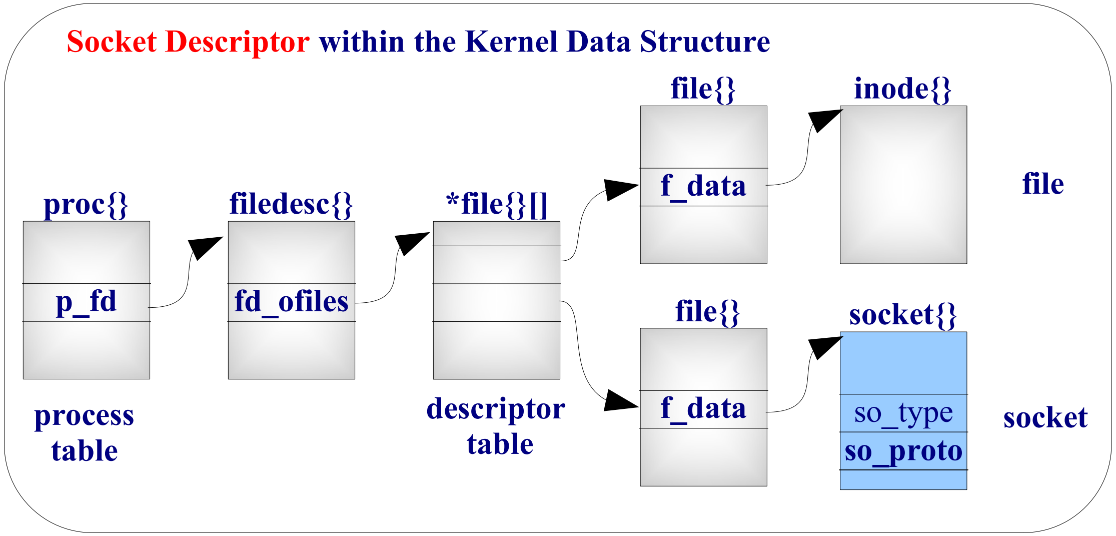
- Link layer
  - Mailboxes (the network interface cards)
    - Only one link: house - closest mail offices
    - Dispatch letters encapsulating them in envelopes with the following information:
      - » Identification code of the mailbox of origin → the source MAC address
      - » Identification code of the mailbox of destination → the destination MAC address
    - Unencapsulate letters on reception (i.e the dst MAC address is theirs)
  - Mail offices (the routers)
    - Two links at least, one of them to a neighboring mail office
    - Routing: must decide to which of the links must enqueue each letter
    - Use the same protocol as the mail boxes
      - » Same code syntax (MAC addresses)
      - » Unencapsule all letters on reception / encapsulate all letters before sending
      - » Can only send to and receive from the neighboring mail offices or their assigned houses
    - *Note: here the analogy breaks a bit because in the postal service usually many envelopes are encapsulated in a single bag but in computer networks packets are encapsulated individually*

Unit 1: Introduction

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.





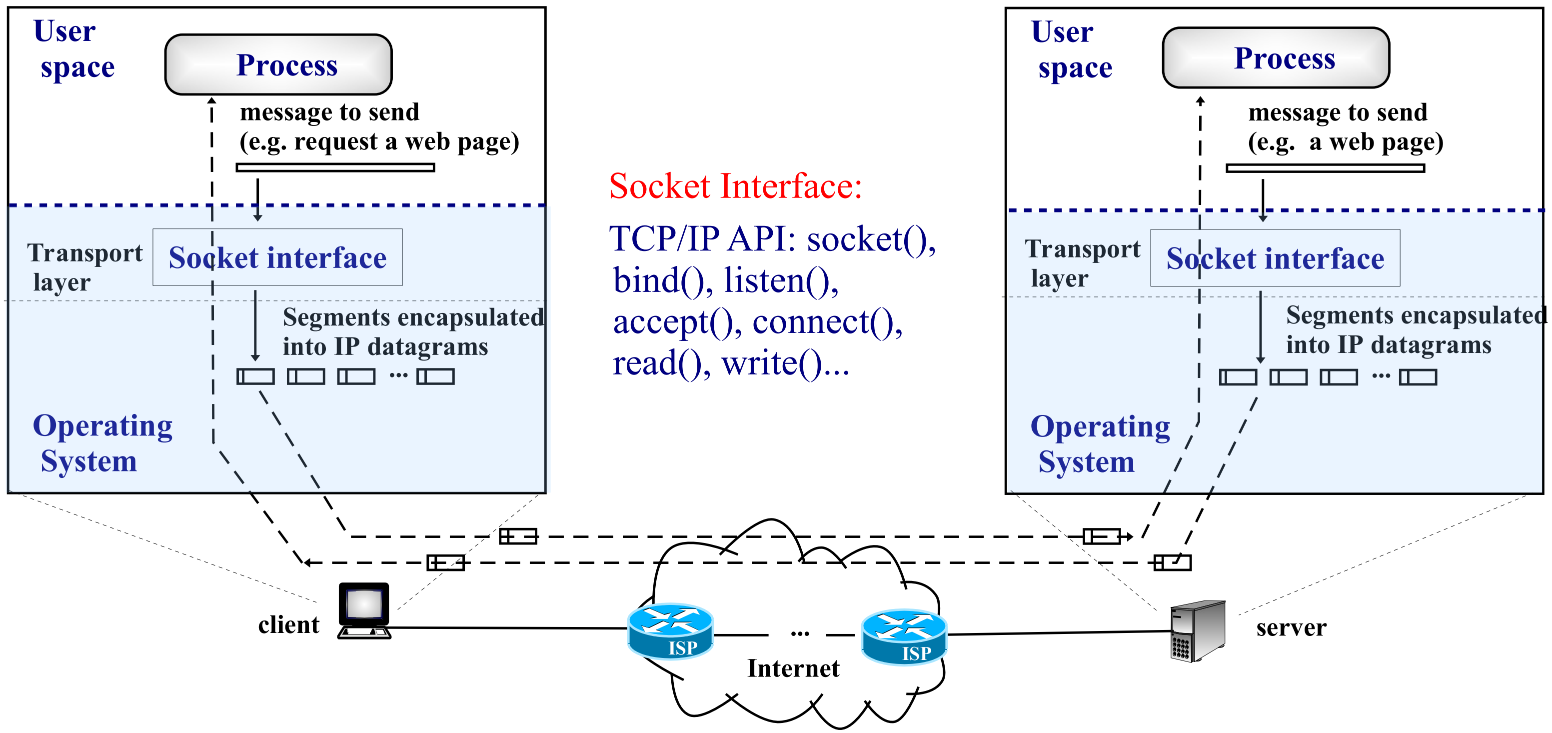
Unit 1: Introduction

Outline

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

Unit 1: Introduction

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



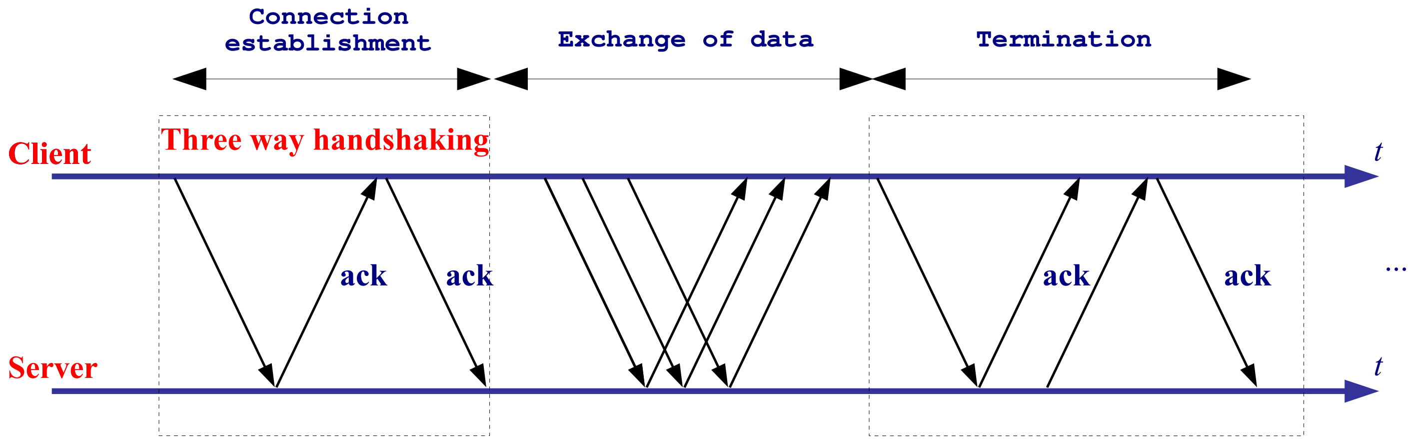
Socket Interface:

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

Unit 1: Introduction

Client Server Paradigm: The Internet Transport Layer

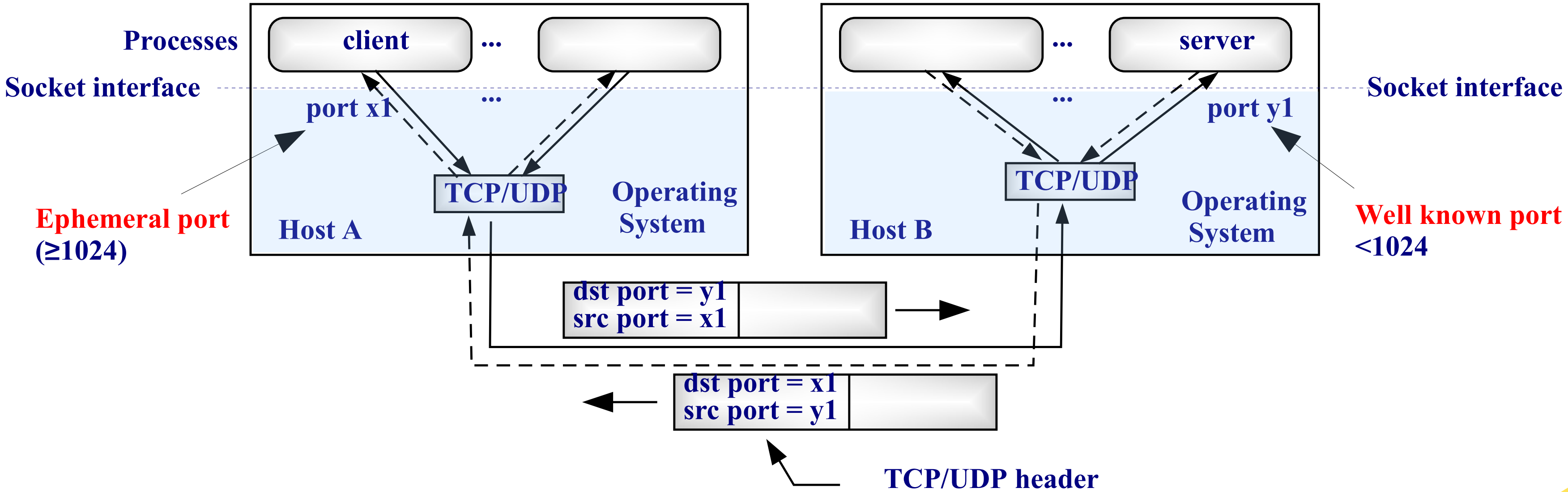
- Two protocols are used at the TCP/IP transport layer: User Datagram Protocol (UDP) and Transmission Control Protocol (TCP).
- UDP offers a *datagram service* (non reliable). It is connectionless.
- TCP offers a reliable service (correct segments are acknowledged, ack, lost segments are retransmitted). It is connection oriented (covered in detail in Unit 3).
- TCP connection:



Unit 1: Introduction

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.



Unit 1: Introduction

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
...
```

Unit 1: Introduction

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
- ...

Unit 1: Introduction

Exercici resolt: 2020t-c1-sol.pdf

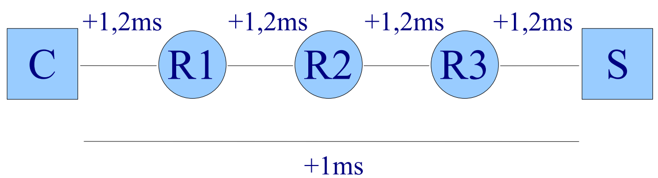
Duració: 1h 30 minuts. El test es recollirà en 25 minuts. ⟶ ~8 preguntes

Test (3,5 punts). Les preguntes valen la mitat si hi ha un error i 0 si hi ha més d'un error a la resposta.

1. El temps de transmissió d'un paquet de 1500 octets a 10 Mbps és 1,2 ms. En un enllaç determinat, el temps de propagació extrem a extrem entre un client i un servidor és d'1 ms. En aquest cas, el retard total extrem a extrem quan no hi ha cap node intermedi és de 2,2 ms.
Si afegim tres routers entre el client i el servidor:

- ☐ El retard mínim extrem a extrem serà 2,2 ms.
- ☐ El retard extrem a extrem serà com a màxim 6,6 ms.
- ☐ El retard mínim extrem a extrem serà 5,8 ms.
- ☐ El retard mínim extrem a extrem serà 4,6 ms.

$$temps\,transmissió = 1500\ octets\ \frac{8\,b}{1\,octet}\ \frac{1\,Mb}{1000000\,b}\ \frac{1}{10\,\frac{Mb}{s}} = 1{,}2\,ms$$



$$retard\ mínim\ extrem\ a\ extrem = 4 * 1{,}2\,ms + 1\,ms = 5{,}8\,ms$$

Unit 1: Introduction

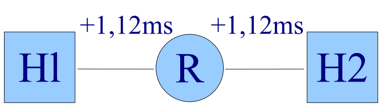
Exercici resolt: 2021t-c1-sol.pdf

2. Dos dispositius estan connectats a través d'un router. Suposem que el temps de propagació extrem a extrem és zero, que el router no afegeix retard a les cues i que la velocitat de transmissió dels enllaços és 10 Mbps.

- ☐ Si el paquet té 1400 octets (bytes) el temps de transmissió del paquet és 0'14ms
- ☐ Si el paquet té 1400 octets (bytes) el temps de transmissió del paquet és 1'12ms.
- ☐ Si el paquet té 1400 octets (bytes) el temps total fins que ha arribat a l'altre extrem és 2'24ms.
- ☐ Si es transmeten dos paquets de 700 octets (bytes) el temps total fins que el segon paquet arriba a l'altre extrem és 1'68ms.

1 pk de 1400 octets

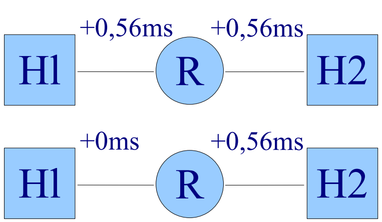
$$temps\,transmissió = 1400\,octets\,\frac{8\,b}{1\,octet}\,\frac{1\,Mb}{1000000\,b}\,\frac{1}{10\,\frac{Mb}{s}} = 1{,}12\,ms$$



$$temps\,total\,extrem\,a\,extrem = 2 * 1{,}12\,ms = 2{,}24\,ms$$

2 pk de 700 octets

$$temps\,transmissió = 700\,octets\,\frac{8\,b}{1\,octet}\,\frac{1\,Mb}{1000000\,b}\,\frac{1}{10\,\frac{Mb}{s}} = 0{,}56\,ms$$



⟶ 0ms pel primer hop del segon paquet perquè es fa en paral·lel al segon hop del primer paquet

$$temps\,total\,extrem\,a\,extrem = 3 * 0{,}56\,ms = 1{,}68\,ms$$

Unit 1: Introduction

Exercicis resolts: 2021t-c1-sol.pdf

3. El model de referència ISO defineix 7 nivells: físic, enllaç de dades, xarxa, transport, sessió, presentació i aplicació.

- ☐ Tots els dispositius d'usuari i els routers de la xarxa gestionen (implementen) els 7 nivells.
- ☐ El model de referència TCP/IP agrupa els nivells de sessió, presentació i aplicació en un únic nivell d'aplicació.
- ☐ Tots els routers gestionen els nivells físic, enllaç de dades, xarxa i transport.
- ☐ El nivell de transport només el gestionen els dispositius d'usuari ("*hosts*").

6. Sobre el model de comunicació client-servidor.

- ☐ Un host pot actuar a la vegada com a client i com a servidor.
- ☐ Els paquets d'una comunicació entre processos client i servidor s'identifiquen amb les adreces IP origen i destinació, els ports de client i de servidor, i el protocol.
- ☐ Un dispositiu pot establir moltes comunicacions com a client amb el mateix servidor i protocol.
- ☐ Un dispositiu amb una única adreça IP pot mantenir simultàniament moltes comunicacions client-servidor amb molts servidors diferents.