

# Networking 101

Maël Auzias

ENSIBS - UBS

September 2015



Figure: [teaching.auzias.net](http://teaching.auzias.net)

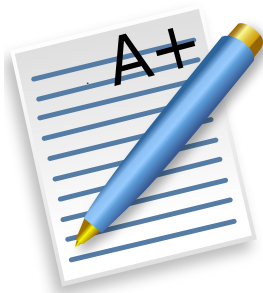
# Course details

## Objectives

- ▶ How do *computers* communicate?
- ▶ What are the mechanisms **under** an HTTP request or a telegram message?
- ▶ Networks are all around us, better study them!



## Course details



### Evaluation

- ▶ Short test at the end of each lesson
- ▶ Project
- ▶ Final exam (1 hour)
- ▶ All equal weighting

### Material

- ▶ Slides available at [teaching.auzias.net](https://teaching.auzias.net) (github too)

# Presentation Outline

Introduction

Physical

Data Link

Network

Transport

## Definitions and presentation

- ▶ **Network:** an **interconnected** group or system
- ▶ **Internet:** world wide **interconnected system of networks**  
RFC791 (September 1981)
- ▶ **IP:** Internet **Protocol** provides the functions necessary to deliver a package of bits from a source to a destination over a network
- ▶ **(world wide) Web: network** consisting of a collection of Internet websites using HTTP

## Definitions and presentation

- ▶ **HTTP:** Hypertext Transfer **Protocol**, application-level protocol for distributed, collaborative, hypermedia information systems [draft HTTP2 \(July 2014\)](#)
- ▶ **FTP:** File Transfer **Protocol** promotes sharing of files, encourages the use of remote computers [RFC959 \(October 1985\)](#)
- ▶ **RFC:** Request For Comments (Internet Draft (ID), RFC, Internet Standard)

## Definitions and presentation

- ▶ **Router:** network **hardware** providing routing services
- ▶ **Routing:** **algorithm processed** to decide where to forward a packet
- ▶ **Forwarding:** **action** of moving a packet from one NIC to another
- ▶ **NIC:** Network Interface Card
- ▶ **Switch (hub):** network **hardware** connecting systems using packet switching
- ▶ **Packet switching:** forward-like method regardless of the content (destination-based)
- ▶ **NAT:** Network Address Translation, router modifying IP address into another IP address (PAT).

## Definitions and presentation

- ▶ **Node (network):** any entity that can send packets to/receive packets from a network through a NIC
- ▶ **Client: computer** able to send requests to a server
- ▶ **Request: application message** destined for a server (*order*)
- ▶ **Server: computer** able to respond to a client's requests
- ▶ **Response: application message** destined for a client (*result*)
- ▶ **Fat client: application** where most functions are processed by the client itself
- ▶ **Thin client: application** where most functions are carried out on a central server



## Network classification

- ▶ **BAN:** Body Area Network
- ▶ **PAN:** Personal Area Network
- ▶ **(W)LAN:** (Wireless) Local Area Network (home, office, school or airport)
- ▶ **MAN:** Metropolitan Area Network, can cover a whole city
- ▶ **WAN:** Wide Area Network cover a broad area (Internet)

# Topologies

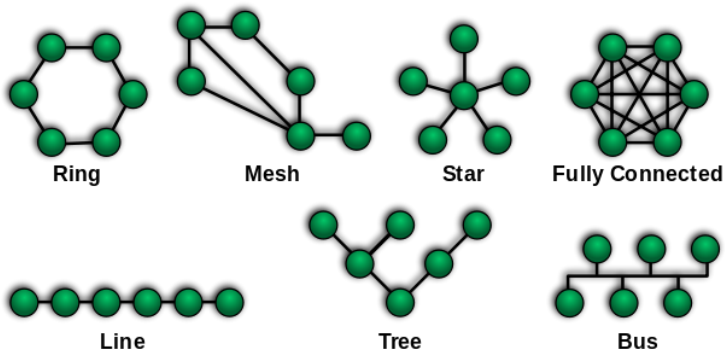


Figure: [upload.wikimedia.org](http://upload.wikimedia.org)

## Topologies

- ▶ **Point-to-point:** two entities directly connected to each other (tunnel).
- ▶ **Ring:** data go around the ring, unidirectional way network.
- ▶ **Mesh:** all nodes cooperate in the distribution of data in the network<sup>1</sup>.
- ▶ **Star:** all messages go through the same central node, reducing network failure.
- ▶ **Fully connected:** all nodes are connected to all other nodes.
- ▶ **Line:** bidirectional link between two nodes. Node can only send packet going through its neighbors.
- ▶ **Bus:** all nodes are connected to the same media. Only one can send a packet at a time, which all others then receive.
- ▶ **Tree:** hierarchical topology, such as a binary tree.

---

<sup>1</sup>[Hong Kong protesters used a mesh network to organize \(2014\)](#)

## Bonus

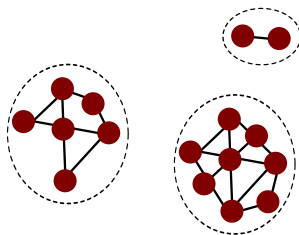


Figure: Disconnected MANET illustration

## Bonus

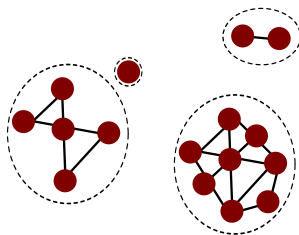


Figure: Store-carry-and-forward

## Bonus

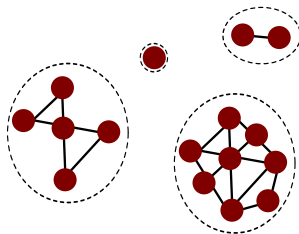


Figure: Store-carry-and-forward

## Bonus

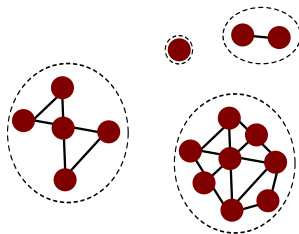


Figure: Store-carry-and-forward

## Bonus

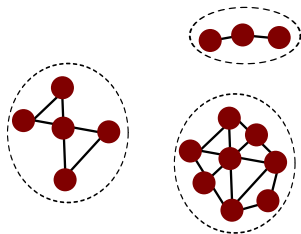


Figure: Store-carry-and-forward



## HTTP request/response example

Enter [getbootstrap.com](https://getbootstrap.com) in your browser

## HTTP request/response example

Enter [getbootstrap.com](http://getbootstrap.com) in your browser

Source	Destination	Protocol	Length	Info
192.168.0.48	208.67.222.222	DNS	76	Standard query 0x4797 A getbootstrap.com
208.67.222.222	192.168.0.48	DNS	108	Standard query response 0x4797 A 192.30.252.154 A 192.30.252.153

Figure: DNS request/response

# HTTP request/response example

Enter [getbootstrap.com](http://getbootstrap.com) in your browser

Source	Destination	Protocol	Length	Info
192.168.0.48	208.67.222.222	DNS	76	Standard query 0x4797 A getbootstrap.com
208.67.222.222	192.168.0.48	DNS	108	Standard query response 0x4797 A 192.30.252.154 A 192.30.252.153

Figure: DNS request/response

Source	Destination	Protocol	Length	Info
127.0.0.1	127.0.0.13	TCP	74	36159 > http [SYN] Seq=0 Win=43690 Len=0 MSS=65495 SACK_PERM=1 TSval=12
127.0.0.13	127.0.0.1	TCP	74	http > 36159 [SYN, ACK] Seq=0 Ack=1 Win=43690 Len=0 MSS=65495 SACK_PERM
127.0.0.1	127.0.0.13	TCP	66	36159 > http [ACK] Seq=1 Ack=1 Win=43776 Len=0 TSval=122257 TSecr=12225
127.0.0.1	127.0.0.13	HTTP	356	GET /index.html HTTP/1.1
127.0.0.13	127.0.0.1	TCP	66	http > 36159 [ACK] Seq=1 Ack=291 Win=44800 Len=0 TSval=122259 TSecr=122
127.0.0.13	127.0.0.1	HTTP	354	HTTP/1.1 200 OK (text/html)
127.0.0.1	127.0.0.13	TCP	66	36159 > http [ACK] Seq=291 Ack=289 Win=44800 Len=0 TSval=122259 TSecr=1
127.0.0.1	127.0.0.13	HTTP	357	GET /favicon.ico HTTP/1.1
127.0.0.13	127.0.0.1	HTTP	565	HTTP/1.1 404 Not Found (text/html)
127.0.0.1	127.0.0.13	TCP	66	36159 > http [ACK] Seq=582 Ack=788 Win=45952 Len=0 TSval=122269 TSecr=1

Figure: HTTP request/response

## To read

<https://github.com/alex/what-happens-when>

- ▶ DNS lookup
- ▶ ARP process
- ▶ Opening of a socket
- ▶ TLS handshake
- ▶ HTTP protocol
- ▶ HTTP Server Request Handle

Figure: [acenk90.files.wordpress.com](http://acenk90.files.wordpress.com)

More like this...

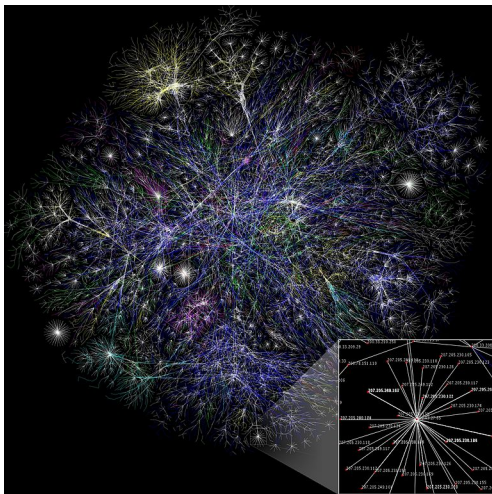


Figure: [wikipedia.org](https://www.wikipedia.org)

## Models overview (OSI and TCP/IP)

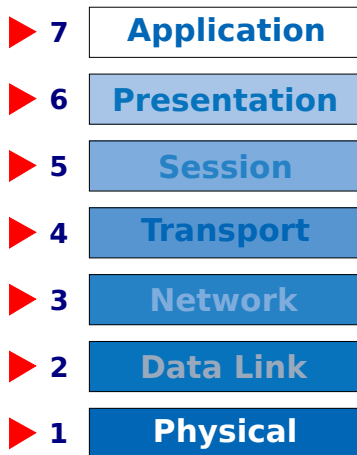
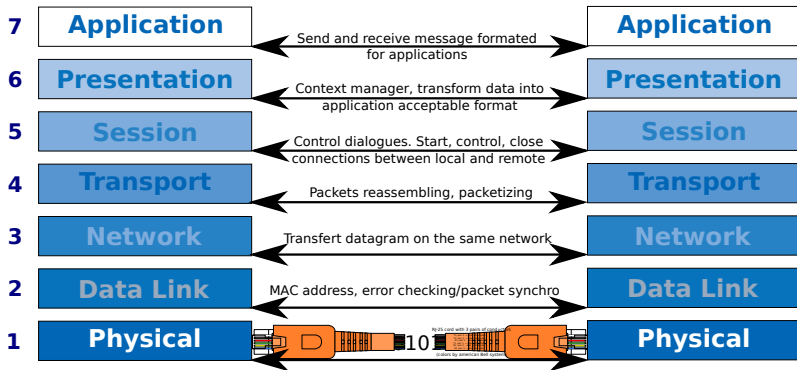


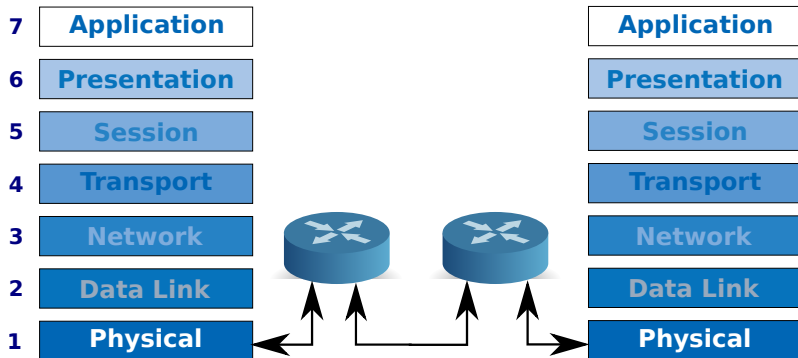
Figure: OSI model

$N^{\text{th}}$  layer communicate with  $N^{\text{th}}$  layer..

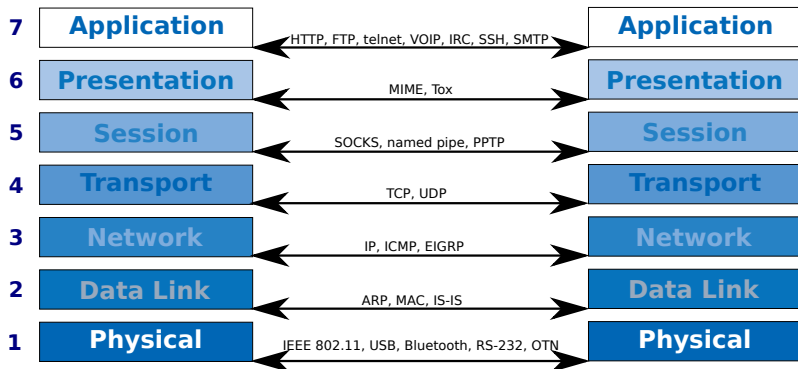




.. thanks to 3<sup>th</sup> layers



## One single protocol, one single layer



# Encapsulation

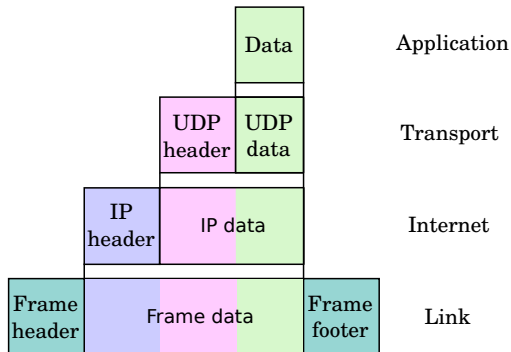


Figure: Encapsulation

# Reading

## Reading list:

- ▶ "Computer Networks" by A Tanenbaum, Andrew S., G ISBN 013162959X
- ▶ <http://nmap.org/book/toc.html>
- ▶ <http://blog.nodenexus.com/2014/11/28/a-shark-on-the-network/>
- ▶ and many many other resources on the Internet freely available<sup>2</sup>! If you can read it, knowledge is reachable<sup>3</sup>!

---

<sup>2</sup>[An Introduction to Computer Networks \(21: Security\)](#) by Peter L Dordal

<sup>3</sup>such as this [example of Wireshark using](#) or [what-happens-when](#)

# Watching

## Watching list:

- ▶ DEF CON 22 Hacking Conference Presentation By Christopher Soghoian - Blinding The Surveillance State <sup>4</sup>
- ▶ any other defcon
- ▶ Mr Robot, that's a good serie!

---

<sup>4</sup>[media.defcon.org](http://media.defcon.org)

# Presentation Outline

Introduction

Physical

Data Link

Network

Transport

# Aims

- ▶ Interface data link layer,
- ▶ (De)Encode,
- ▶ Transmit: 1 after 0 (after 0 or 1, after 0... or 1)

## Hardware medium

- ▶ IEEE 802.3 (a.k.a. Ethernet): <100Gbit/s
- ▶ IEEE 802.11 (a.k.a. Wi-Fi): <50 Mbit/s (802.11ad goes up to 6.75 Gbit/s)
- ▶ IEEE 802.15.1 (a.k.a. Bluetooth): <1 Mbit/s
- ▶ IEEE 802.15.4 (a.k.a. ZigBee): <250 kbit/s
- ▶ IEEE 802.16 (a.k.a. Wi-Max): <40 Mbit/s
- ▶ IEEE 1394 (a.k.a. Firewire): <3200 Mbit/s
- ▶ USB, serial port such as RS-232...



## Hardware medium: IEEE 802.3 (Ethernet)



Figure: RJ45 connector

## Hardware medium: IEEE 802.15.1 (Bluetooth)

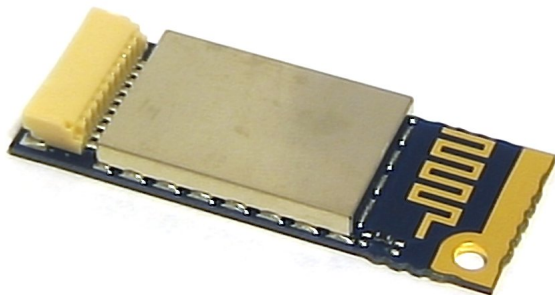


Figure: Bluetooth card

## Hardware medium: IEEE 802.15.4 (ZigBee)

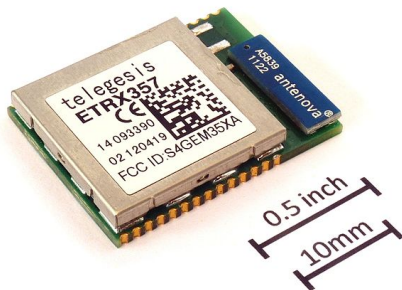


Figure: ZigBee card

## Hardware medium: IEEE 802.16 (Wi-Max)



Figure: Wi-Max antenna

## Hardware medium: IEEE 1394 (Firewire)



Figure: Firewire connector

## Encoding

- ▶ **MLT3 (Multi-Level Transmit):** state changes for 1s over 3 levels, stays in the same state for 0s
- ▶ **AMI (Alternate Mark Inversion):** state 0 for 0s, state  $+/-1$  for 1s
- ▶ **Manchester:** voltage transition (rising/falling edge mean 1/0)
- ▶ **BMC (Biphase Mark Code):** change its state for 1s, stay on the same state for 0s
- ▶ and so on...

## Encoding: Multi-Level Transmit

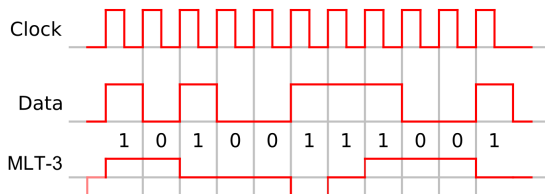


Figure: Multi-Level Transmit

## Encoding: Alternate Mark Inversion

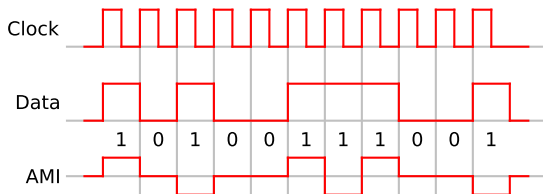


Figure: Alternate Mark Inversion



## Encoding: Manchester

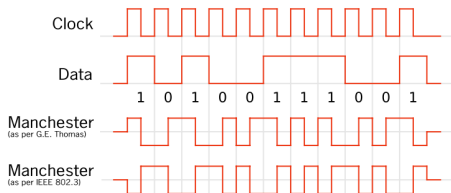


Figure: Manchester

## Encoding: Biphas Mark Code

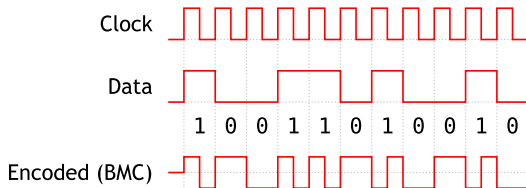


Figure: Biphas Mark Code

# Transmitting

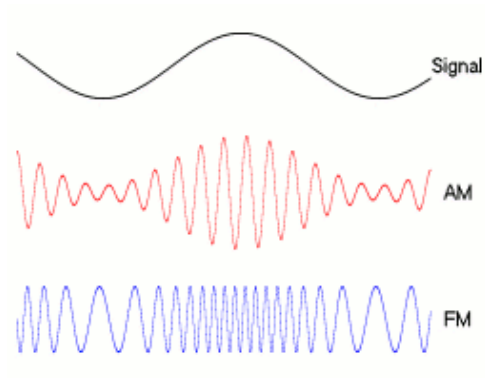


Figure: Amplitude and phase modulation

## Error detection

- ▶ Repetition (hum...)
- ▶ Parity (XOR)
- ▶ Checksum
- ▶ CRC (Cyclic redundancy check): with a polynomial division
- ▶ Hash
- ▶ and so on...

## Error correcting

- ▶ Repetition (again)
- ▶ Hamming
- ▶ MDPC (Multidimensional parity-check code)

## Correction: MDPC

Raw data to send: 0x01 02 03 04

0x01	0x02	0x03
0x03	0x04	0x07
0x04	0x06	

Figure: Data received with MDPC

Data sent (with MDPC): 0x01 02 03 03 04 07 04 06

# Presentation Outline

Introduction

Physical

**Data Link**

Network

Transport

# Aims

- ▶ Interface network layer,
- ▶ Delivery to unique(?) hardware addresses,
- ▶ Framing,
- ▶ Data transfer



## Layer composition (of its two sublayers)

1. Logical Link Control (LLC):
  - ▶ end to end flow control
  - ▶ end to end error control
  - ▶ (transmitting/receiving) protocols, over MAC sublayer, multiplexing
2. Media Access Control (MAC):
  - ▶ physical (hardware) addressing
  - ▶ collision detection and retransmission
  - ▶ data packet scheduling (and queuing)
  - ▶ QoS
  - ▶ VLAN

# Carrier Sense Multiple Access with Collision Avoidance

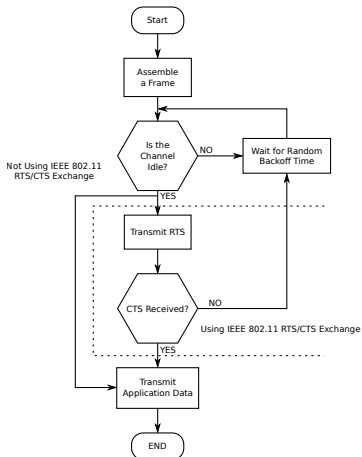


Figure: CSMA CA

## Layer 2 Ethernet packet

MAC dest. (6)	MAC src. (6)	VLAN tag* (4)	Ethertype (2)
Payload (42-1500)		Frame check sequence (4)	

Figure: Layer 2 Ethernet packet

optional, Content (size in bytes)

Ethertype 0x	Protocol
0800	IPv4
0806	ARP
0842	Wake-on-LAN
86dd	IPv6

Figure: Data received with MDPC

## ARP example

<b>0000</b>	ff	ff	ff	ff	ff	ff	fa	ba	00	ab	ab	af	08	06	00	01
<b>0010</b>	08	00	06	04	00	01	fa	ba	00	ab	ab	af	ac	11	22	37
<b>0020</b>	00	00	00	00	00	00	ac	11	00	f9	00	00	00	00	00	00
<b>0030</b>	00	00	00	00	00	00	00	00	00	00	00	00				

Figure: ARP request

MAC address destination MAC address source Ethertype Hardware  
 type Protocol type OpCode (1 request, 2 reply) IP address source  
 IP address destination

## ARP example

<b>0000</b>	ff	ff	ff	ff	ff	ff	fa	ba	00	ab	ab	af	08	06	00	01
<b>0010</b>	08	00	06	04	00	01	fa	ba	00	ab	ab	af	ac	11	22	37
<b>0020</b>	00	00	00	00	00	00	ac	11	00	f9	00	00	00	00	00	00
<b>0030</b>	00	00	00	00	00	00	00	00	00	00	00	00				

Figure: ARP request

MAC address destination MAC address source Ethertype Hardware  
 type Protocol type OpCode (1 request, 2 reply) IP address source  
 IP address destination

## ARP example

<b>0000</b>	fa	ba	00	ab	ab	af	be	be	00	00	eb	eb	08	06	00	01
<b>0010</b>	08	00	06	04	00	01	be	be	00	00	eb	eb	ac	11	00	f9
<b>0020</b>	fa	ba	00	ab	ab	af	ac	11	22	37	00	00	00	00	00	00
<b>0030</b>	00	00	00	00	00	00	00	00	00	00	00	00				

Figure: ARP reply

MAC address destination   MAC address source   Ethertype   Hardware  
 type   Protocol type   OpCode (1 request, 2 reply)   IP address source  
 IP address destination

## ARP example

<b>0000</b>	fa	ba	00	ab	ab	af	be	be	00	00	eb	eb	08	06	00	01
<b>0010</b>	08	00	06	04	00	01	be	be	00	00	eb	eb	ac	11	00	f9
<b>0020</b>	fa	ba	00	ab	ab	af	ac	11	22	37	00	00	00	00	00	00
<b>0030</b>	00	00	00	00	00	00	00	00	00	00	00	00				

Figure: ARP reply

MAC address destination MAC address source Ethertype Hardware  
 type Protocol type OpCode (1 request, 2 reply) IP address source  
 IP address destination

# Presentation Outline

Introduction

Physical

Data Link

**Network**

Transport



# Aims

- ▶ Interface transport layer,
- ▶ Host addressing,
- ▶ End-to-end packet transmission (data link? Connectionless? Switch? Router?),
- ▶ Routing, load balancing

# Concepts

- ▶ IP addressing fundamentals,
- ▶ Classfull IP addressing,
- ▶ Subnet and VLSM (Variable length subnet masks),
- ▶ CIDR (Classless inter-domain routing),
- ▶ Routing,
- ▶ IPv6.

# IP addressing fundamentals

## IP address

32 bits (4x4 bytes)

mask	
Networks part	Host part

Figure: IP address parts

# IP addressing fundamentals

## Masks

- ▶ Separates **network** and **host** bits,
- ▶ MSB are **always** ones and then zeros! 255.254.255.0 is not possible,
- ▶ Indicates how many bits are used for the **network** part:
  - ▶ A 8-bit **mask** leaves 24 bits for the **hosts**,
  - ▶ A 16-bit **mask** leaves 16 bits for the **hosts**,
  - ▶ A 24-bit **mask** leaves 8 bits for the **hosts**,
  - ▶ A N-bit **mask** leaves 32-N bits for the **hosts**.
- ▶ Two different **masks** (differences seen further on):
  - ▶ Network **mask**,
  - ▶ Subnet **mask**.

# IP addressing fundamentals

## IP address

32 bits (4x4 bytes)

Networks part	Host part

Figure: IP address parts and mask

# IP addressing fundamentals

## IP address

32 bits (4x4 bytes)

ones mask	zeros mask
Networks part	Host part

Figure: IP address parts and mask

# IP addressing fundamentals

## Is that an address?

- ▶ Network address,
- ▶ Hosts,
- ▶ Broadcast address.

## Within the same network

- ▶ All addresses have the same **network** bits,
- ▶ Network address has zeros for **host** bits:  $x.x.x.0^*$ ,
- ▶ All **hosts** have different **host** bits:  $x.x.x.[0-1]^*$ ,
- ▶ Broadcast address has ones for **host** bits:  $x.x.x.1^*$ .

## IP addressing fundamentals

Mask /24 254 hosts	255 11111111	255 11111111	255 11111111	0 00000000
Network address	192 11000000	168 10101000	1 00000001	0 00000000
First host	192 11000000	168 10101000	1 00000001	1 00000001
Last host	192 11000000	168 10101000	1 00000001	254 11111110
Broadcast address	192 11000000	168 10101000	1 00000001	255 11111111

Figure: IP address example 1



## IP addressing fundamentals

Mask /16 65.534 hosts	255 11111111	255 11111111	0 00000000	0 00000000
Network address	172 10101100	64 01000000	0 00000000	0 00000000
First host	172 10101100	64 01000000	0 00000000	1 00000001
Last host	172 10101100	64 01000000	255 11111111	254 11111110
Broadcast address	172 10101100	64 01000000	255 11111111	255 11111111

Figure: IP address example 2

## IP addressing fundamentals

**Formula:** how many **hosts** with an N-bit mask?

$2^{32-N} - 2$ , the  $-2$  moves out network and broadcast addresses which are not **hosts**.

- ▶ 24-bit **mask**:  $2^{32-24} - 2 = 2^8 - 2 = 254$  **hosts**
- ▶ 16-bit **mask**:  $2^{32-16} - 2 = 2^{16} - 2 = 65.534$  **hosts**
- ▶ 8-bit **mask**:  $2^{32-8} - 2 = 2^{24} - 2 = 16.777.214$  **hosts**

# IP addressing fundamentals

## Public addresses

- ▶ Most IP addresses
- ▶ Registered ISP and large organizations inherit blocks of public addresses from IANA<sup>5</sup>
- ▶ Usage of unregistered public addresses is forbidden.

## Private addresses

- ▶ Private addresses are A, B and C classes (not all, see after)
- ▶ No registration needed
- ▶ Not routed across the Internet
- ▶ Proxy, NAT and private addresses solved IPv4 shortage.

---

<sup>5</sup>Internet Assigned Numbers Authority

## Classful IP Addressing

Class	A	B	C
First octet	1 - 126	128 - 191	192 - 223
First octet 0b	0*	10*	110*
Network mask	255.0.0.0 /8	255.255.0.0 /16	255.255.255.0 /24
IP addresses range	1.0.0.0 126.0.0.0	128.0.0.0 191.255.0.0	192.0.0.0 223.255.255.0
Private range	10.0.0.0 10.255.255.255	172.16.0.0 172.31.255.255	192.168.0.0 192.168.255.0
Number of hosts	16.777.214	65.534	254

Figure: Three main classes

Where did 127.0.0.0/8 go ?!

## Classful IP Addressing

### Class D

- ▶ First octet: 224 - 239
- ▶ First octet pattern: 1110\*
- ▶ These IP addresses are multicast addresses.

### Class E

- ▶ Everything left
- ▶ Experimental class.

# Classful IP Addressing

## Reserved addresses

- ▶ 0.0.0.0 used in routing (seen further)
- ▶ 127.0.0.0/8: loopback addresses (127.0.0.1 - 127.255.255.254).

## Classful IP Addressing

- ▶ Class A (16 m-addresses) and B (65 k-addresses) are too large!
- ▶ Class C (254 addresses) is manageable. A and B are not, and then not fully utilized... That's a waste of IP addresses!

Means to limit the number of nodes on a network (regardless of the class) and, thus, improve the manageability, are needed. Three means for it:

- ▶ Subnet,
- ▶ VLSM (Variable Length Subnet Mask),
- ▶ CIDR (Classless Inter-Domain Routing).

## Subnet and VLSM

- ▶ Class A (16 m-addresses) and B (65 k-addresses) are too large!
- ▶ Class C (254 addresses) is manageable. A and B are not, and then not fully utilized... That's a waste of IP addresses!



## Subnet and VLSM

Mask /16 65.534 hosts	255 11111111	255 11111111	0 00000000	0 00000000
Network address	172 10101100	64 01000000	0 00000000	0 00000000
First host	172 10101100	64 01000000	0 00000000	1 00000001
Last host	172 10101100	64 01000000	255 11111111	254 11111110
Broadcast address	172 10101100	64 01000000	255 11111111	255 11111111

Figure: IP address example 2

## Subnet and VLSM

Mask /12 1.048.574 hosts	255 11111111	240 11110000	0 00000000	0 00000000
Network address	172 10101100	64 01000000	0 00000000	0 00000000
First host	172 10101100	64 01000000	0 00000000	1 00000001
Last host	172 10101100	79 01001111	255 11111111	254 11111110
Broadcast address	172 10101100	79 01001111	255 11111111	255 11111111

Figure: IP address example 3

## Subnet and VLSM

Mask /10 4.194.302 hosts	255 11111111	192 11000000	0 00000000	0 00000000
Network address	172 10101100	64 01000000	0 00000000	0 00000000
First host	172 10101100	64 01000000	0 00000000	1 00000001
Last host	172 10101100	127 01111111	255 11111111	254 11111110
Broadcast address	172 10101100	127 01111111	255 11111111	255 11111111

Figure: IP address example 4

## Subnet and VLSM

Mask /31 0 host	255 11111111	255 11111111	255 11111111	254 11111110
Network address	172 10101100	64 01000000	0 00000000	254 11111110
First host	172 10101100	64 01000000	0 00000000	? 1111111?
Last host	172 10101100	64 01000000	255 00000000	? 1111111?
Broadcast address	172 10101100	64 01000000	255 00000000	255 11111111

Figure: IP address example 5

## Subnet and VLSM

Mask /30 2 hosts	255 11111111	255 11111111	255 11111111	252 11111100
Network address	172 10101100	64 01000000	0 00000000	252 11111100
First host	172 10101100	64 01000000	0 00000000	253 11111101
Last host	172 10101100	64 01000000	255 00000000	254 11111110
Broadcast address	172 10101100	64 01000000	255 00000000	255 11111111

Figure: IP address example 6

	Netmask	CIDR	hosts
255.255.255.255	11111111.11111111.11111111.11111111	/32	Unusable
255.255.255.254	11111111.11111111.11111111.11111110	/31	Unusable
255.255.255.252	11111111.11111111.11111111.11111100	/30	2
255.255.255.248	11111111.11111111.11111111.11111000	/29	6
255.255.255.240	11111111.11111111.11111111.11110000	/28	14
255.255.255.224	11111111.11111111.11111111.11100000	/27	30
255.255.255.192	11111111.11111111.11111111.11000000	/26	62
255.255.255.128	11111111.11111111.11111111.10000000	/25	126
255.255.255.0	11111111.11111111.11111111.00000000	/24	254
255.255.254.0	11111111.11111111.11111110.00000000	/23	510
255.255.252.0	11111111.11111111.11111100.00000000	/22	1.022
255.255.248.0	11111111.11111111.11111000.00000000	/21	2.046
255.255.240.0	11111111.11111111.11110000.00000000	/20	4.094
255.255.224.0	11111111.11111111.11100000.00000000	/19	8.190
255.255.192.0	11111111.11111111.11000000.00000000	/18	16.382
255.255.128.0	11111111.11111111.10000000.00000000	/17	32.766
255.255.0.0	11111111.11111111.00000000.00000000	/16	65.534
255.254.0.0	11111111.11111110.00000000.00000000	/15	131.070
255.252.0.0	11111111.11111100.00000000.00000000	/14	262.142
255.248.0.0	11111111.11111000.00000000.00000000	/13	524.286
255.240.0.0	11111111.11110000.00000000.00000000	/12	1.048.574
255.224.0.0	11111111.11100000.00000000.00000000	/11	2.097.152
255.192.0.0	11111111.11000000.00000000.00000000	/10	4.194.302
255.128.0.0	11111111.10000000.00000000.00000000	/9	8.388.606
255.0.0.0	11111111.00000000.00000000.00000000	/8	16.777.214
254.0.0.0	11111110.00000000.00000000.00000000	/7	33.554.430
252.0.0.0	11111100.00000000.00000000.00000000	/6	67.108.862
248.0.0.0	11111000.00000000.00000000.00000000	/5	134.217.726
240.0.0.0	11110000.00000000.00000000.00000000	/4	268.435.454
224.0.0.0	11100000.00000000.00000000.00000000	/3	536.870.910
192.0.0.0	11000000.00000000.00000000.00000000	/2	1.073.741.822
128.0.0.0	10000000.00000000.00000000.00000000	/1	2.147.483.646
0.0.0.0	00000000.00000000.00000000.00000000	/0	IP space

# CIDR

## Classless Inter-domain Routing?

- Wait! What is routing?

## Routing Principles

Algorithms are processed to decide where to forward a packet

### Any router must

- ▶ know where any packet should be directed
- ▶ send directly the packets to the destination if the router and the destination are on the same (sub)network

### Any node

- ▶ on any network can communicate directly with all the nodes within the same network
- ▶ can connect to any node using its gateway
- ▶ needs to be aware of its gateway to communicate with nodes on other networks



## Routing Principles

### Route

- ▶ Destination
- ▶ Gateway (next hop)
- ▶ Masks
- ▶ Metric
- ▶ Interface

```
>sudo route -n
Kernel IP routing table
Destination      Gateway         Genmask         Flags Metric Ref    Use Iface
0.0.0.0          192.168.0.254  0.0.0.0         UG    0      0        0 eth0
192.168.0.0      0.0.0.0        255.255.255.0   U     0      0        0 eth0
```

Figure: Routing table

# Routing Principles

```
>sudo route -n
Kernel IP routing table
Destination      Gateway          Genmask         Flags Metric Ref    Use Iface
0.0.0.0          192.168.0.254   0.0.0.0         UG    0      0      0 eth0
192.168.0.0      0.0.0.0         255.255.255.0   U      0      0      0 eth0
```

Figure: Routing table

## 0.0.0.0 ?

- ▶ Default destination
- ▶ Default (sub)network(s)
- ▶ Default route
- ▶ Default gateway

# Routing Principles

## Example

what would the routing table of this router look like?

# Routing Principles

Static or dynamic ?

We will see this later

## CIDR

Combine 2+ networks' into one bigger to ease routing.

### Classless Inter-domain Routing?

- ▶ Can a routing table having both (192.168.0.0/24, E0), (192.168.1.0/24, E0), (10.0.0.0/8, S0) be shorten?
- ▶ Can a routing table having both (192.168.0.0/24, E0), (192.168.1.0/24, E0), (192.168.8.0/24, E0), (10.0.0.0/8, S0) be shorten?
- ▶ Can a routing table having both (192.168.0.0/24, E0), (192.168.4.0/24, E0), (192.168.1.0/24, E1), (10.0.0.0/8, S0) be shorten?

## Routing Protocol

- ▶ RIP: Routing Information Protocol
- ▶ OSPF: Open Shortest Path First
- ▶ EIGRP: Enhanced Interior Gateway Routing Protocol

# Routing Protocol

## RIP v1

- ▶ Classful routing
- ▶ Periodic updates (30 sec) ..
- ▶ ..by broadcasting (!)
- ▶ Metric is hop-count (max = 15, infinite = 16)
- ▶ Timer (180 sec) to tag route as invalid (metric = 16)
- ▶ no subnet, no VLSM, no CIDR, no router authentication

# Routing Protocol

## RIP v2

- ▶ Classless routing
- ▶ Multicast (224.0.0.9)
- ▶ VLSM support
- ▶ Route summarization
- ▶ "Authentication" (MD5)

RIPng is the next RIP version for support of IPv6



## Routing Protocol

1. Router coming online broadcasts Request message
2. RIP Routers send **broadcasts** Response messages with their routing table
3. When Update timers (from other routers) expire, its routing table<sup>6</sup> is sent again
4. When Invalid timer expires, the metric of the route is set to 16 (unreachable)
5. When Flush timer expires, the 16-metric routes are removed from the routing table
6. When a new router (or new metric) is sent, a Hold-down timer is started to stabilize the network.

---

<sup>6</sup>not always the whole table

# Routing Protocol

## OSPF

- ▶ Classless
- ▶ IPv4 and IPv6
- ▶ VSLM
- ▶ CIDR
- ▶ Build a topology of the network
- ▶ Dijkstra
- ▶ Metric =  $f(\text{hop-count, bandwidth, link reliability})$
- ▶ Subdivided into area (a 32-bit number)
- ▶ Multicast
- ▶ Authentication support (update only from trusted routers)

# Routing Protocol

## EIGRP

- ▶ Enhanced IGRP (to support classless routing)
- ▶ IPv4 and IPv6
- ▶ VSLM
- ▶ CIDR
- ▶ Build a topology of the network
- ▶ Dijkstra
- ▶ Metric =  $f(\text{bandwidth, load, delay, reliability})$
- ▶ Authentication support

## IPv6 - Aims

- ▶ Support billions of hosts (even with inefficient IP addressing)
- ▶ Reduce routing table size
- ▶ Simplified protocol to allow routers to process packets faster
- ▶ Better security
- ▶ Better real-time QoS
- ▶ Better multicast diffusion (scope)
- ▶ Able to move without changing IP address
- ▶ Give the protocol the ability to evolve
- ▶ Give the protocol the ability to coexist with newer version

## IPv4 vs IPv6

- ▶ not compatible
- ▶ IPv4 address: 4 octets, IPv6: 16 octets ( $2^{128} = 3 \times 10^{138}$ )
- ▶ Packet Header, IPv6: 7 fields, IPv4:13 (faster to process)
- ▶ IP options: some required options are now optional (faster to process)
- ▶ Notation:
  - ▶ 8000:0000:0000:0000:0123:4567:89AB:CDEF
  - ▶ 8000::0123:4567:89AB:CDEF
  - ▶ ::192.168.2.3
- ▶ Unicast address format:

bits	48 (or more)	16 (or fewer)	64
field	routing prefix	subnet id	interface identifier

Figure: Unicast IPv6 address format

# IPv4 vs IPv6

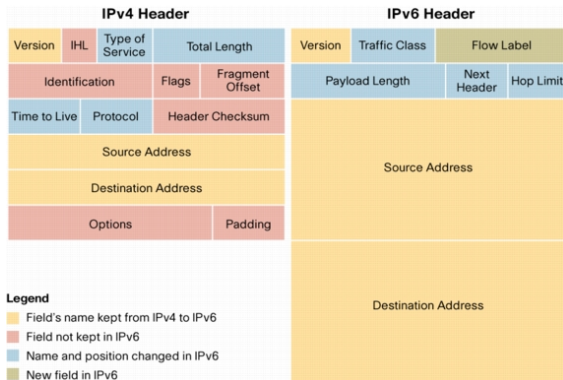


Figure: IPv4 and IPv6 headers (www.cisco.com)

## IPv6 - Header

- ▶ **Version (4 bits):** 0b0110
- ▶ **Traffic class (8 bits):** 6-MSB for differentiated services<sup>7</sup>, 2-LSB for ECN<sup>8</sup>
- ▶ **Flow label (20 bits):** routers are supposed to use the same path for the same flow (thus, destination do not need to re-order packets)
- ▶ **Payload length (16 bits):** packet length minus its header length

---

<sup>7</sup>multimedia or http

<sup>8</sup>Explicit Congestion Notification (RFC 3168)

## IPv6 - Header

- ▶ **Next header (8 bits):** specifies the transport layer protocol, also indicates (if any) extension header that follows.
- ▶ **Hop limit (8 bits):** Hop count (discussion was to use a duration instead, but router implementations would be much more complex)

### Optional IPv6 headers offer the possibility to

- ▶ specify the route of the datagram
- ▶ include authentication data
- ▶ include fragmentation parameters
- ▶ and so on...



## IPv6 - Anecdotes

- ▶ IPv6 address length could have been 8 bytes, or 20 bytes, or even variable
- ▶ Hop count max value (255) is considered, by some, not enough
- ▶ Removing IPv4 checksum is *as safe as removing brakes from a car*
- ▶ Different national laws on encryption disallow a real secure transport layer

## IPv6 - Adoption

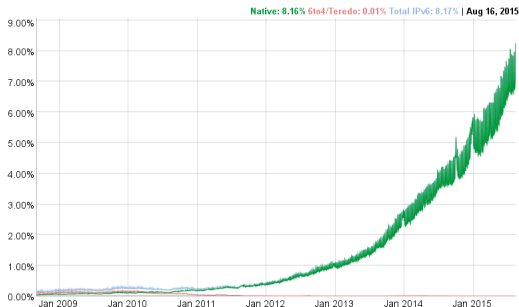


Figure: IPv6 adoption (among Google users)<sup>9</sup>

- ▶ **2014** Belgium: 28%, USA and Germany: 11%
- ▶ **2015** Belgium: 36%, USA: 21% and Germany: 18%

<sup>9</sup><https://www.google.com/intl/en/ipv6/statistics.html>

# Presentation Outline

Introduction

Physical

Data Link

Network

Transport

## Aims

- ▶ Interface session layer,
- ▶ Reliable end-to-end communication,
- ▶ Order and reassemble received packets (if needed),
- ▶ Flow control,
- ▶ Congestion avoidance (if supported by protocol),
- ▶ Multiplexing

# Application identification

## Socket address

- ▶ Node identification is made by IP address,
- ▶ Application identification is made by node identification..
- ▶ .. and a port. Number between 0 and 65535. (1-1024: root privilege)
  - ▶ ip.ad.dr.ess:port

Port	Protocol
21	FTP
22	SSH
23	Telnet
25	SMTP
80	HTTP
443	HTTPS
465	SMTPS
631	IPP
1194	OpenVPN
3128, 8080	Web Proxy
9418	git
23399	Skype

Figure: Default port for well known protocol

# TCP header

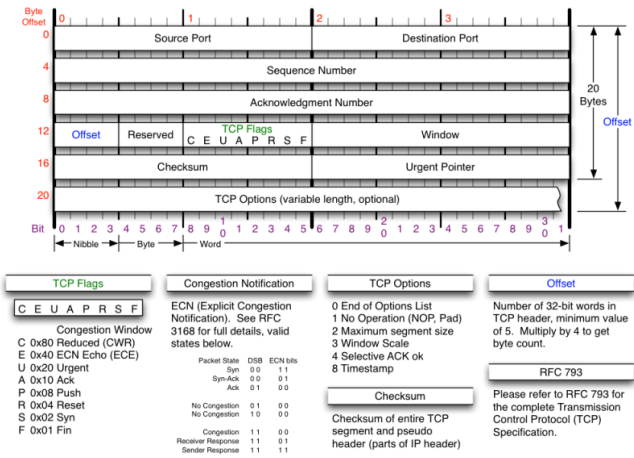


Figure: [nmap.org](http://nmap.org): TCP header

# UDP header

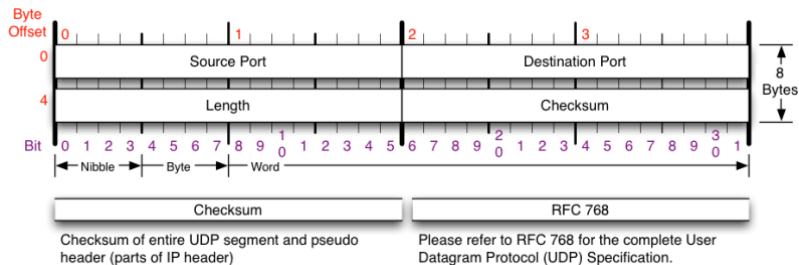


Figure: [nmap.org](http://nmap.org): UDP header



## Socket Primitives (TCP)

Order	Primitive	Meaning
1	SOCKET	Creates a new communication endpoint
2	BIND	Links local IP address to the socket
3	LISTEN	Signs up for incoming connections
4	ACCEPT	Blocking call till a connection attempt occurs
-	CONNECT	<b>Tries</b> to connect to another communication endpoint
-	SEND	Sends data through the established connection
-	RECEIVE	Receives data through the established connection
last	CLOSE	Releases the connection

Figure: TCP primitives

A socket does not have an IP address until it is bound, just an allocation in the transport entity. A server must listen before any client can connect.

## What are these ?

- ▶ **Frame:** Physical layer representation
- ▶ **Datagram:** UDP<sup>10</sup> or IP packet (IP datagram, UDP datagram)
- ▶ **Segment:** TCP data unit
- ▶ **PDU:** Protocol Data Unit, generic term.
- ▶ **Fragment:** Any data unit **fragmented**

---

<sup>10</sup>User **Datagram** Protocol

I hope you liked it and learnt something new !



Figure: [teaching.auzias.net](http://teaching.auzias.net)