Computer Networks - *Xarxes de Computadors*

Outline

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

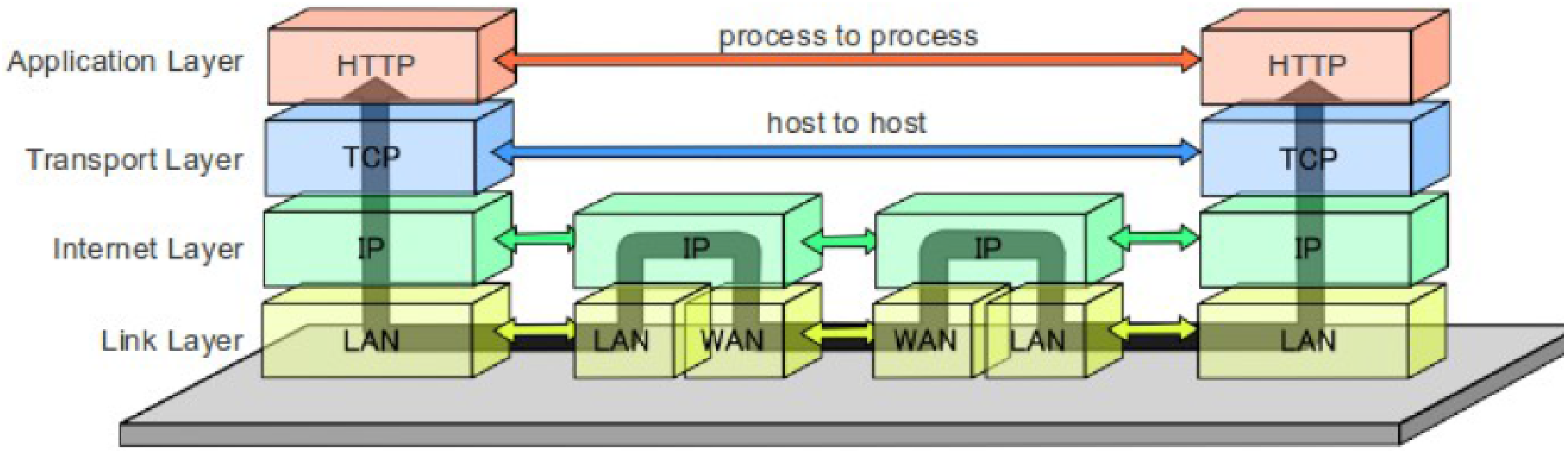
These slides are based on the set of slides provided by Llorenç Cerdà for this course. They include some modifications and some new slides.

Local Area Networks, LANs

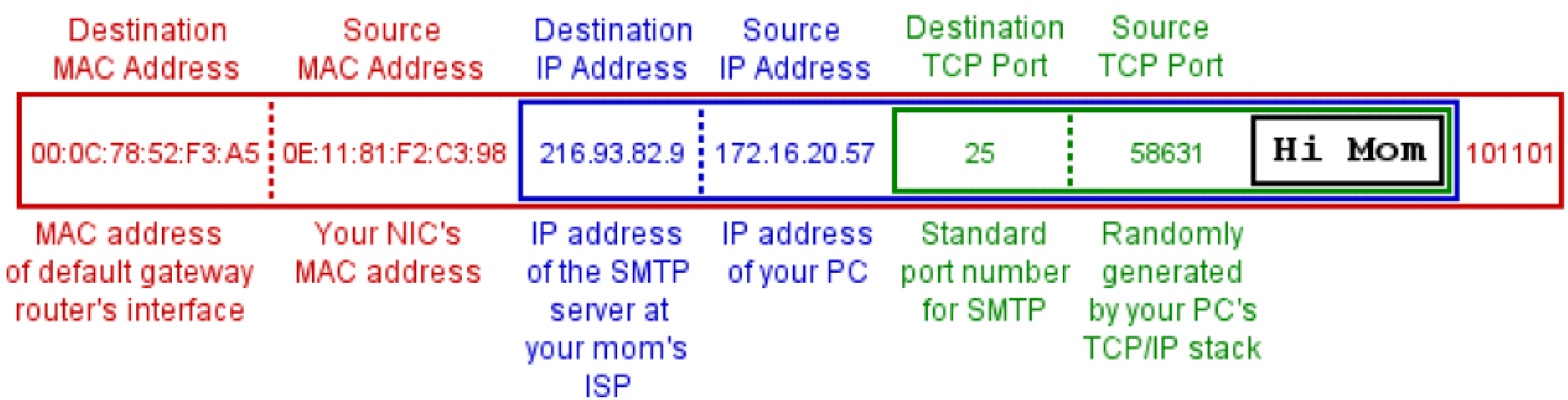
Outline

- **Introduction**
- IEEE LAN Architecture
- Ethernet
- Ethernet Switches
- Wireless LANs

Data Flow of the Internet Protocol Suite



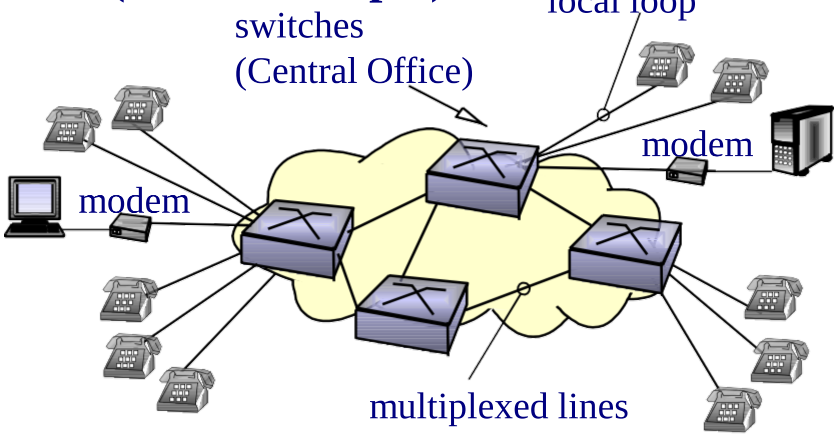
Outgoing E-mail Frame



Introduction – WAN and LAN differences

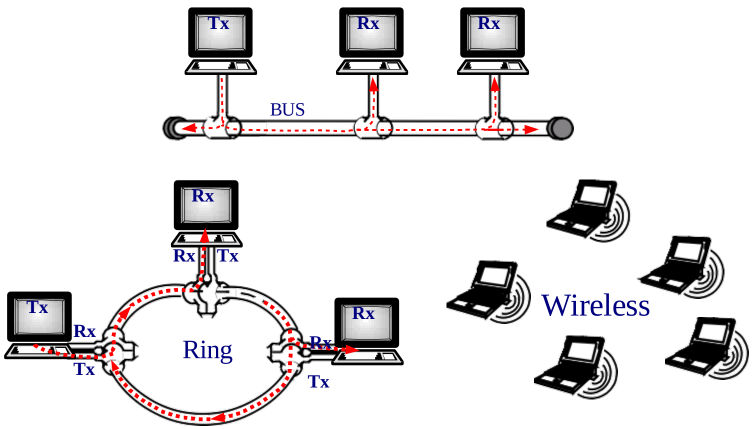
- WANs:
  - Main goal: scalability.
  - Switched network with mesh topology.
- LANs:
  - Multy-access network with shared media.
  - A Medium Access Control (MAC) protocol is needed.

WAN (PSTN example)



Switched media

LANs

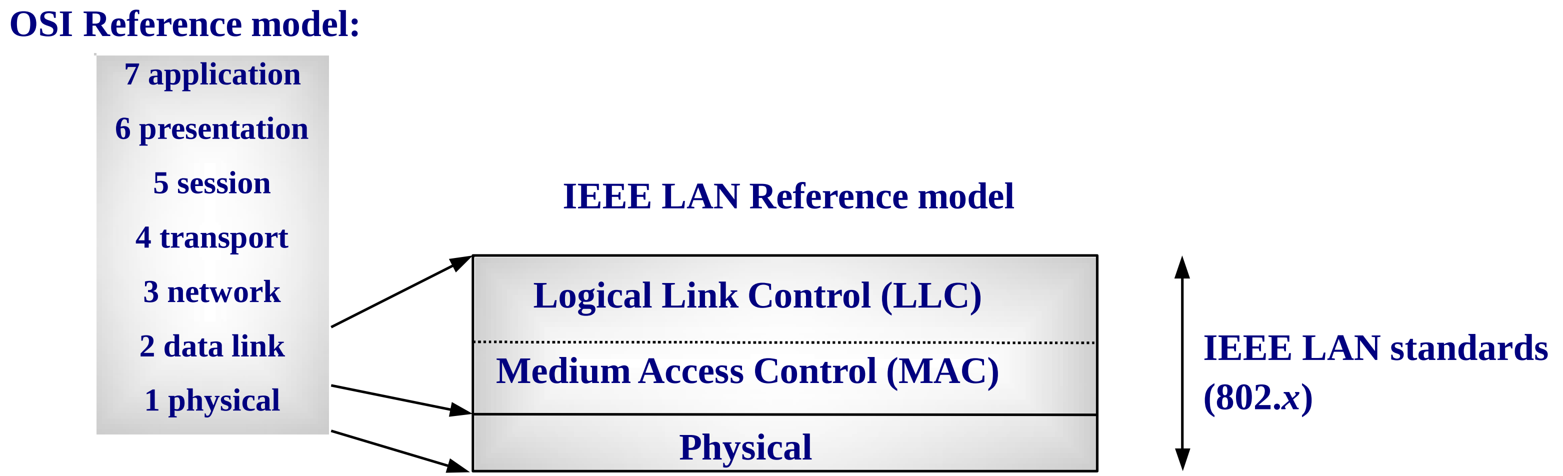


Shared media

Outline

- Introduction
- **IEEE LAN Architecture**
- Ethernet
- Ethernet Switches
- Wireless LANs

IEEE LAN Architecture



- LLC sublayer (802.2):
  - Common to all 802.x MAC standards.
  - Define the interface with the upper layer and specifies several services (operational modes):
    - (i) unacknowledged connectionless, (ii) connection oriented, (iii) acknowledged connectionless.
- MAC sublayer:
  - Define the medium access protocol. It is different for each LAN technology.

IEEE LAN Architecture – IEEE 802 standards (some)

802.1 LAN/MAN architecture

802.2 Logical Link Control (LLC)

802.3 Ethernet

802.4 Token Bus

802.5 Token Ring

802.6 MAN (DQDB)

802.8 FDDI

802.11 WiFi: Wireless LANs.

802.15 Personal Area Networks or short distance wireless networks (WPAN)

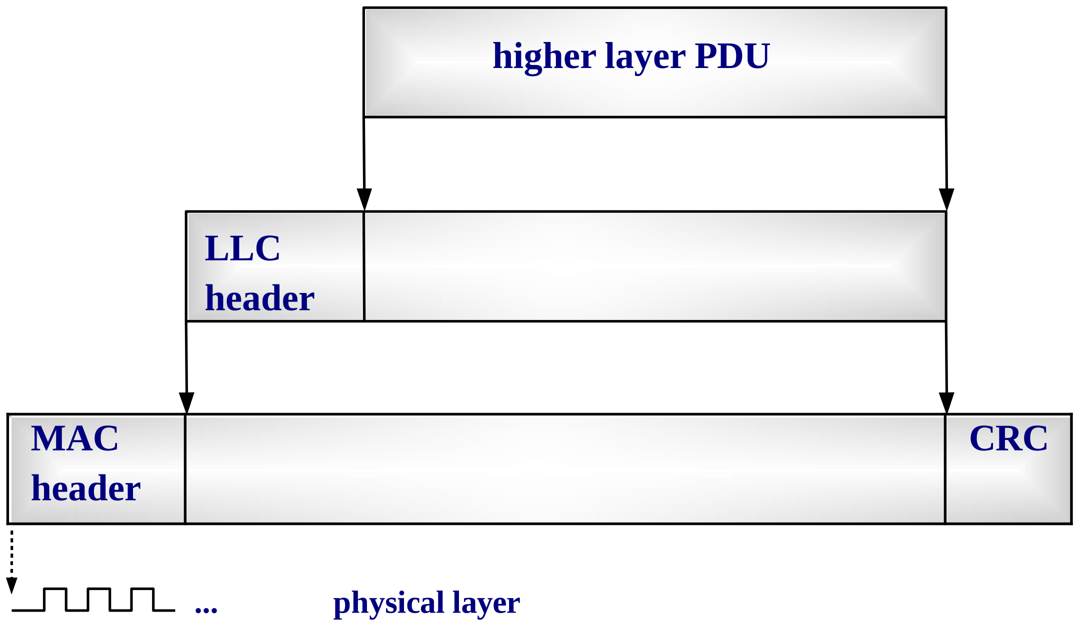
802.15.1 Bluetooth

802.15.4 Low data rate and low cost sensor devices

802.16 WiMAX: broadband Wireless Metropolitan Area Networks.

See: http://grouper.ieee.org/groups/802/1, 2, …

IEEE LAN Architecture – LAN encapsulation



IEEE LAN Architecture – LLC header

3 / 4 bytes

```
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 bits
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Destination SAP| Source SAP    | Control       /
|               |               | 8 or 16 bits  /
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

- Service Access Point (SAP): Identifies the upper layer protocol.
- Control: Identifies the frame type. It can be 8 or 16 bits long, 8 bits for unnumbered frames (used in connectionless modes).

SAP (hex)	Protocol
06	ARPANET Internet Protocol (IP)
08	SNA
42	IEEE 802.1 Bridge Spanning Tree Protocol
98	ARPANET Address Resolution Protocol (ARP)
AA	SubNetwork Access Protocol (SNAP)
E0	Novell Netware
F0	IBM NetBIOS
FF	Global LSAP

SNAP: used in TCP/IP

Example of some IEEE SAP values.

Ethernet – Frames

- Ethernet II (DIX):

```
+-----------+-----------+----------+-----------+-----------+----------+
|Preamble   |Destination|Source MAC|Frame type | Payload   | CRC      |
|(8 bytes)  |MAC Address|Address   |(2 bytes)  |(46 to     |(4 bytes) |
|           |(6 bytes)  |(6 bytes) |           |1500 bytes)|          |
+-----------+-----------+----------+-----------+-----------+----------+
```

- IEEE 802.3

```
+-----------+-----------+----------+-----------+-----------+----------+
|Preamble   |Destination|Source MAC|Length of  | Payload   | CRC      |
|(8 bytes)  |MAC Address|Address   |the frame  |(46 to     |(4 bytes) |
|           |(6 bytes)  |(6 bytes) |(2 bytes)  |1500 bytes)|          |
+-----------+-----------+----------+-----------+-----------+----------+
```

- Preamble: Give time to detect, synchronize and start reception.
- Type: Identifies the upper layer protocol (IP, ARP, etc. RFC 1700, Assigned numbers). This value is always > 1500.
- Length: Payload size (0~1500).

Ethernet – IEEE Sub-Network Access Protocol (SNAP)

- Allows the specification of protocols, and vendor-private identifiers, not supported by the 8-bit 802.2 Service Access Point (SAP) field.
- It is used to encapsulate TCP/IP protocols over IEEE 802.2 (LLC) with OUI=0x000000 and Type equal to the RFC 1700 (used for DIX).

802.3 SNAP Frame

```
+-------+------+------+------+--------+------+-----------+----------+
| MAC   | DSAP | SSAP |Contr.|  OUI   | Type |upper layer| CRC      |
| 802.3 | 0xAA | 0xAA | 0x03 |0x000000|2bytes| PDU       |(4 bytes) |
+-------+------+------+------+--------+------+-----------+----------+
```

LLC header (3 bytes) **SNAP header (5 bytes)** **≤ 1492**

- The MSS used by TCP would be of 1460 if DIX encapsulation is used, and 1452 if IEEE is used.

Outline

- Introduction
- IEEE LAN Architecture
- **Ethernet**
- Ethernet Switches
- Wireless LANs

Ethernet – Introduction

- Designed by Bob Metcalfe at Xerox in mid-70s.
- Initially was commercialized by Digital, Intel and Xerox consortium (DIX).
- Ethernet was standardized by IEEE (802.3) in 1983.
- Nowadays Ethernet is the leading LAN technology. There are numerous Ethernet standards with different transmission mediums, and line bitrates.

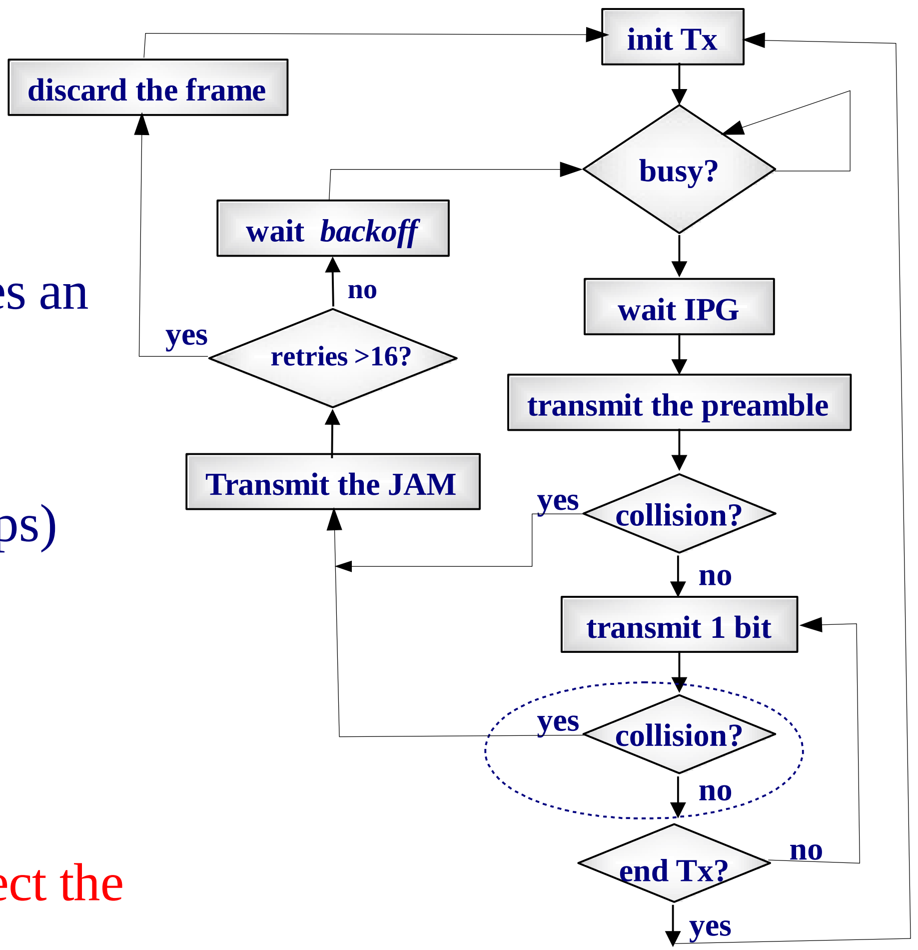
Types of MACs

- Token Passing:
  - Only the station having the token can transmit. After transmission the token is passed to another station.
  - Examples: FDDI and Token-Ring
- Random:
  - There is no token. Instead, there is a non null collision probability. In case of collision, the frame is retransmitted after a random *backoff* time.
  - Examples: Ethernet

Carrier Sense Multiple Access/Collision Detection (CSMA/CD)

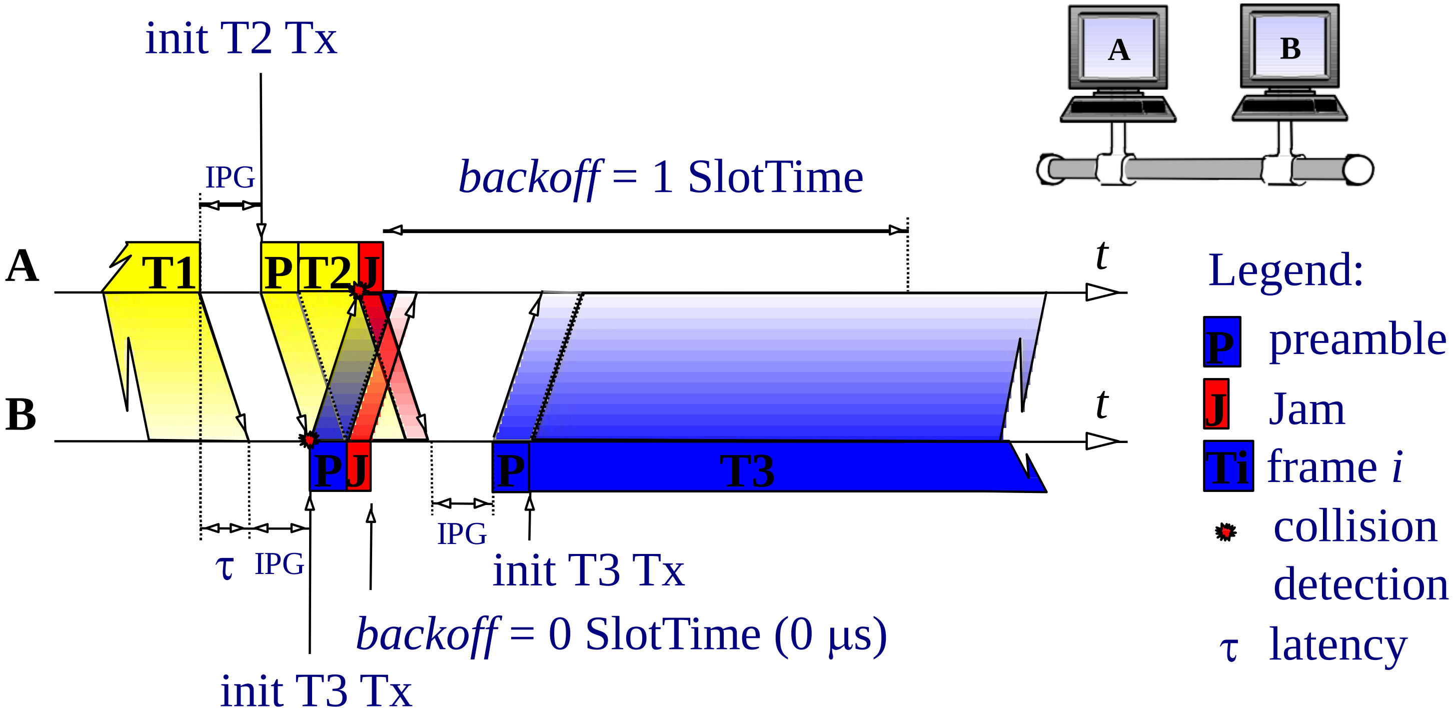
- Is a random MAC where the stations "listen" the medium (*carrier sense*) before transmission.
- When the medium is becomes free the frame is transmitted immediately, and the medium is listened to detect collisions.
- In case of collision, the frame is retransmitted after a random *backoff* time.

- Inter Packet Gap (IPG): 96 bits.
- JAM: 32 bits pattern that produces an erroneous CRC.
- *backoff* = $n\ T_{512}$
- T_{512}: *Slot Time* (51,2 μs at 10 Mbps)
- n = random$\{0, 2^{\min\{N, 10\}}-1\}$,
    - N: maximum number of retransmission of the same frame (1, 2…)
- The transmitting station must detect the collision (no ack is sent).



Ethernet – Collision example

- Stations A y B have frames ready to Tx:



NOTE: The preamble is not interrupted in case of collision, and the JAM is Tx immediately after.

x*Base*y

Line bitrate:

- 10: 10 Mbps
- 100: 100 Mbps
- 1000: 1000 Mbps (1 Gbps)
- 10G: 10 Gbps

Base band signal.
Broad: translated band signal.

Various meanings:

- Number: Maximum segment distant in hundreds of m.
- Reference to the medium type:
  - T: UTP
  - F: Optical Fiber
  - Other:
  - T4: Uses 4 UTP pairs.
  - TX: Full Duplex
  - ...

Ethernet – Different Ethernet Standards (some)

Commercial name	bps	Standard	year	Name	Cabling	UTP/OF Pairs	Connector	Codification	segment distance*	
									Half duplex	Full duplex
Ethernet	10Mbps	802.3	1983	10Base5	Coax-thick	-	AUI	Manchester	500m	n/a
		802.3a	1985	10Base2	Coax-thin	-	BNC	Manchester	185m	n/a
		802.3i	1990	10BaseT	UTP-cat.3	2	RJ45	Manchester	100m	100m
		802.3j	1993	10BASE-FL	FO	2	SC	on/off Manchester	2000m	>2000m
Fast Ethernet	100Mbps	802.3u	1995	100BaseTX	UTP-cat.5	2	RJ45	4B/5B	100m	100m
		802.3u	1995	100BaseFX	FO	2	SC	4B/5B	412m	2000m
		TIA/EIA-785	1999	100BaseSX	FO/led	2	SC	4B/5B	300m	300m
Gigabit-Eth.	1Gbps	802.3z	1998	1000BaseSX	FO	2	SC	8B/10B	275-316m	275-550m
		802.3z	1998	1000BaseLX	FO	2	SC	8B/10B	316m	550-10000m
		802.3z	1998	1000BaseLH	FO	2	SC	8B/10B	n/a	100km
		802.3ab	1999	1000BaseT	UTP-cat. 5e	4	RJ45	PAM5	100m	100m
10Gigabit-Eth.	10Gbps	802.3ae	2002	10GBASE-CX4	InfiniBand	4	CX4	8B/10B	n/a	15m
		802.3ae	2002	10GBASE-SR	FO	2	SC	64B/66B	n/a	26-300m
		802.3ae	2002	10GBASE-LR	FO	2	SC	64B/66B	n/a	10km
		802.3ae	2002	...	FO	2	SC	...	n/a	...

*With OF the distance depends on the OF type.

Ethernet – Different Ethernet Standards: after 10BaseT

All standards use UTP o OF (except 10GBaseCX4):

- Fast Ethernet (1995). 100BaseTX: UTP-cat 5
- Gigabit Ethernet (1998). 1000BaseT: UTP-cat 5e
- 10Gigabit Ethernet (2002). Uses optical fiber. The only copper standard is Infiniband with segment size ≤ 15m.

NIC 10/100 – RJ45
10BaseT-100BaseTX
$11.99

NIC 10/100/1000 - SC
10BaseFL-100BaseFX-1000Base-SX
$151

NIC 10Gbps – CX4
10GBaseCX4
$795

Infiniband cable with CX4 connectors

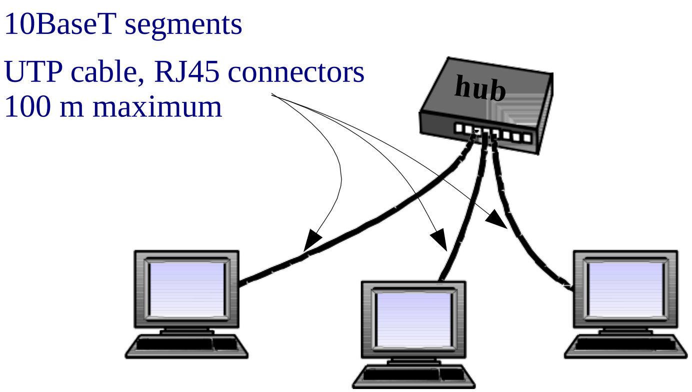
Outline

- Introduction
- IEEE LAN Architecture
- Ethernet
- **Ethernet Switches**
- Wireless LANs

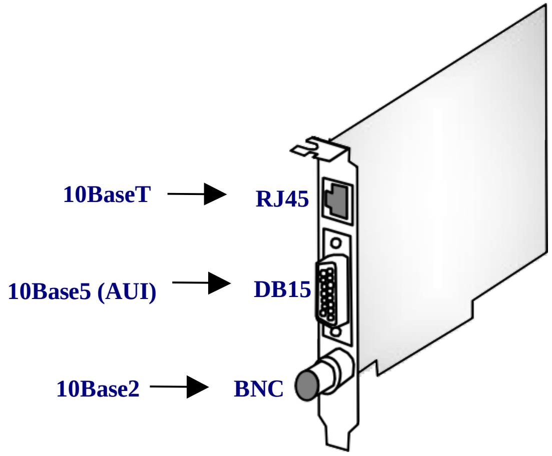
Ethernet – Different Ethernet Standards: 10BaseT

1990. Cable UTP-cat 3.

- Hub: Is a multi-port repeater (layer 1).
- The signal received in 1 port is retransmitted by all the others.



Transceivers
AUI-BNC/AUI-RJ45



NIC “combo”:
Supports 10Base5, 10Base2, 10BaseT

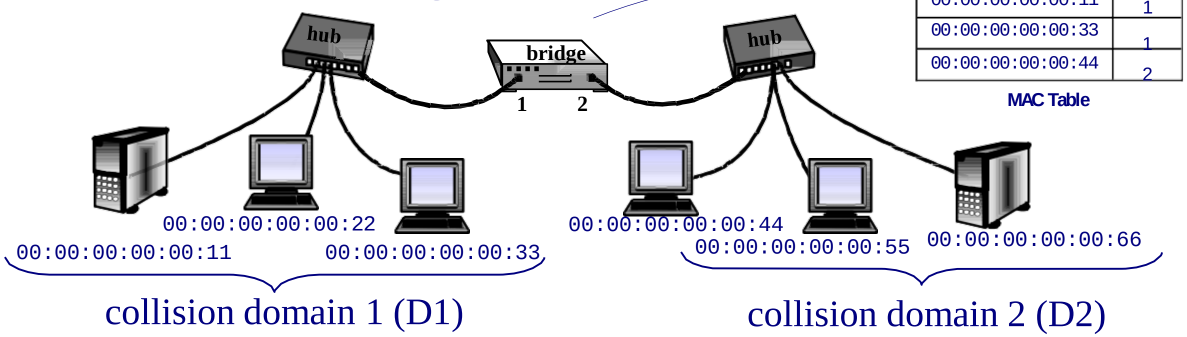
Ethernet Switches - Introduction

- Hub problem: If many stations are connected, may be inefficient due to collisions.
- Solution: bridges and switches.
- Ethernet bridge:
  - “plug and play” layer 2 device.
  - In each port there is a NIC in “promiscuous” mode: Capturing all frames.
  - The source address is used to “learn” which MAC is present in each port (MAC table). Each entry has the MAC and the port numbers.
  - The destination MAC is used to decide whether the frame needs to be retransmitted by another port.
  - Isolates the “collision domain”.

Ethernet Switches - Bridges

MAC address	Port
00:00:00:00:00:11	1
00:00:00:00:00:33	1
00:00:00:00:00:44	2

MAC Table



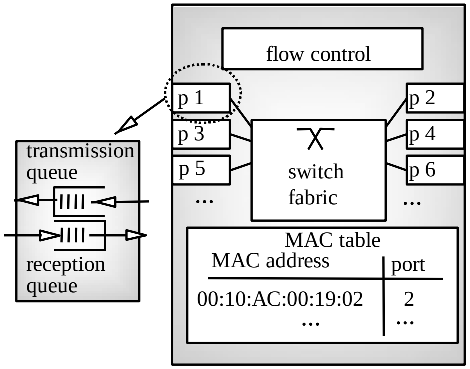
How the bridge works:

- If a frame is received with a source address not in the MAC table, it is added (*learning bridge*).
- If a frame from D1 is received with a destination address that: (i) is in D2, (ii) it is not in the table, (iii) it is broadcast: It is sent into D2 (*flooding*).
- If it is received a frame from D1 addressed to another station from D1, it is discarded (*filtering*).
- The entries have an *aging timer*. Each time an entry is used, it is refreshed. If the aging timer expires, the entry is removed.

Advantages:

- Segments the collision domain (less collisions).
- Clients in D1 and D2 can simultaneously send frames to their servers.

Ethernet Switches - Switch Architecture




```
Switch#show mac-address-table
Address            Dest Interface
-----------------------------------
00D0.5868.F583     FastEthernet 2
00E0.1E74.6ADA     FastEthernet 1
00E0.1E74.6AC0     FastEthernet 1
0060.47D5.2770     FastEthernet 3
00D0.5868.F580     FastEthernet 5
```

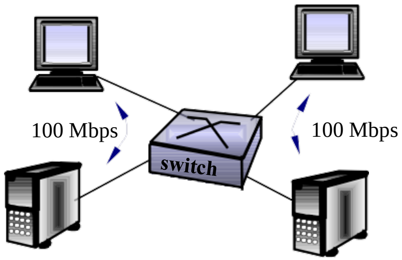
MAC Table in a CISCO Switch

Edge and *backbone* CISCO switches.

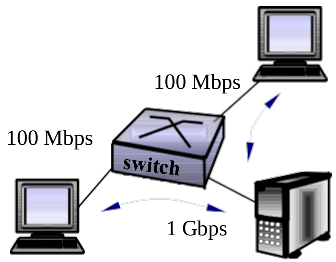
How the switch works:

- It is equivalent to a "multiport bridge".
- When a frame is received with a source address not in the table, it is added.
- If a frame is received with a destination address: (i) not in the table, (ii) broadcast or multicast: copy the frame in all transmission buffer of the other ports (flooding).
- If a frame is received with the address from another port: It is switched as fast as possible the the transmission buffer of that port.
- If receives a frame addressed to another station from the same port, it is discarded (filtering).

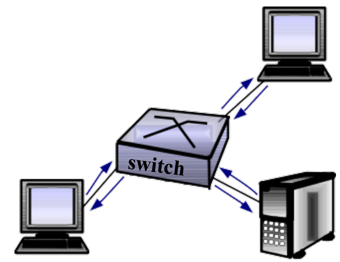
Ethernet Switches - Switch Capabilities



Simultaneous Transmissions



Ports with Different bitrates



Full Duplex Ports

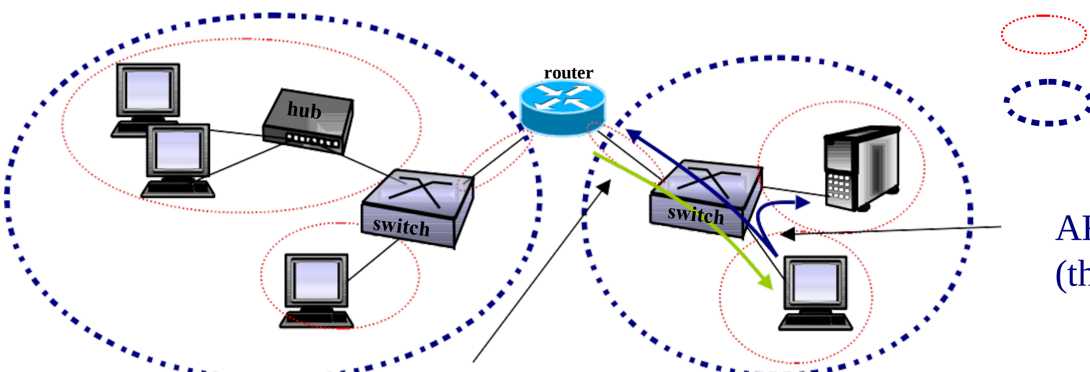
- Each port is different a collision domain (less collisions).
- Different ports can be simultaneously Tx/Rx.
- Ports can have different bitrates.
- Ports may be full-duplex (if only one host is connected).
- There can be ports in half or full duplex mode simultaneously.
- Link aggregation: Bitrate can be increased by aggegating several links, which behave as a slingle one (*etherchannel* in CISCO).
- Security: Stations can only capture the traffic of their collision domain.

Ethernet – Half Duplex and full-duplex

- Half Duplex: Using CSMA/CD only one NIC can be simultaneously transmitting into the medium.
- Full Duplex: When 2 Ethernet NICs are connected point-to-point, some Ethernet standards allow a full-duplex Tx, .
- Ethernet NICs have an auto-negotiation mechanism to detect the full-duplex availability.
- In full-duplex mode Ethernet NICs deactivate CSMA/CD (no collisions can occur).

Ethernet Switches - Broadcast and Collision Domains

- Broadcast Domain: Set of stations that will receive a broadcast frame sent by any of them.
- Unless Virtual LANs are used, a switch does not segment the broadcast domain.
- A router segments the broadcast domain.
- The broadcast reachability is important because allows reaching stations having one hop connectivity (with ARP).



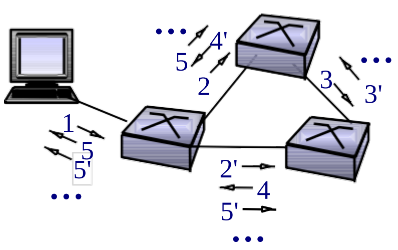
ARP request (broadcast) requesting an @IP (the router @IP)

ARP reply (unicast)

ARP cannot solve an @IP out of the broadcast domain.
In order to leave the broadcast domain a router is required.

Ethernet Switches – Spanning Tree Protocol (STP)

- The basic principle of the “layer 2 routing” done by Ethernet switches is based on having a unique port to forward the frame towards the destination. Therefore, loops are not allowed.
- In practice loops can appear because:
  - They are introduced by accident.
  - The are desirable to have redundant path (fault tolerance).
- If loops are introduced without protection a *broadcast storm* is produced, and the network blocks:



Frames multiply and remain turning indefinitely in the loop!

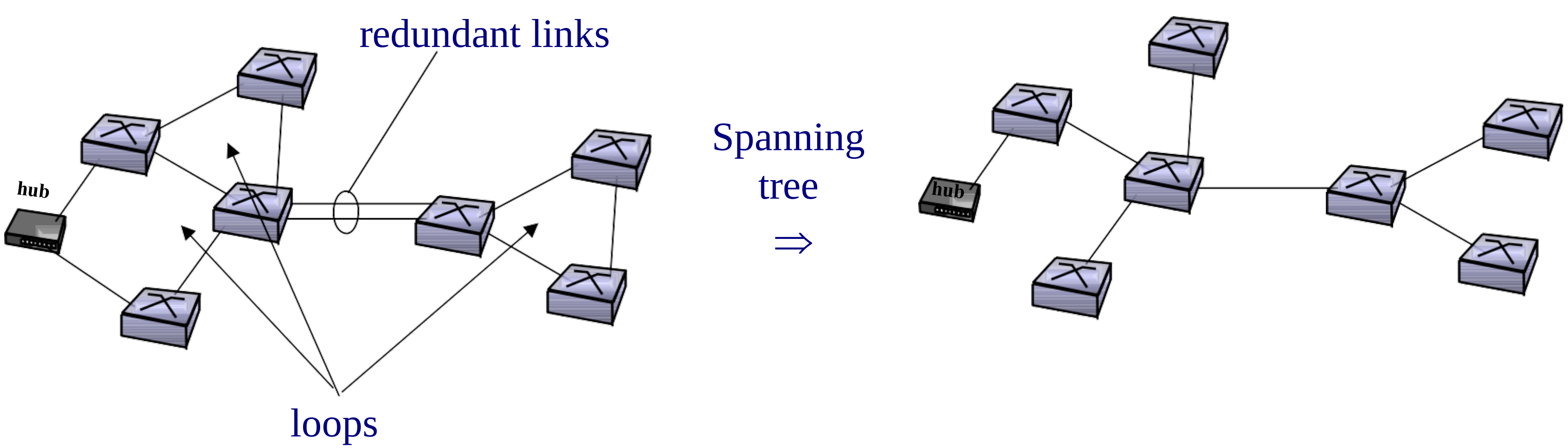
Other problems:
- Reception of duplicated frames
- MAC Tables instability

⇓

Solution: IEEE 802.1D Spanning Tree Protocol (STP)

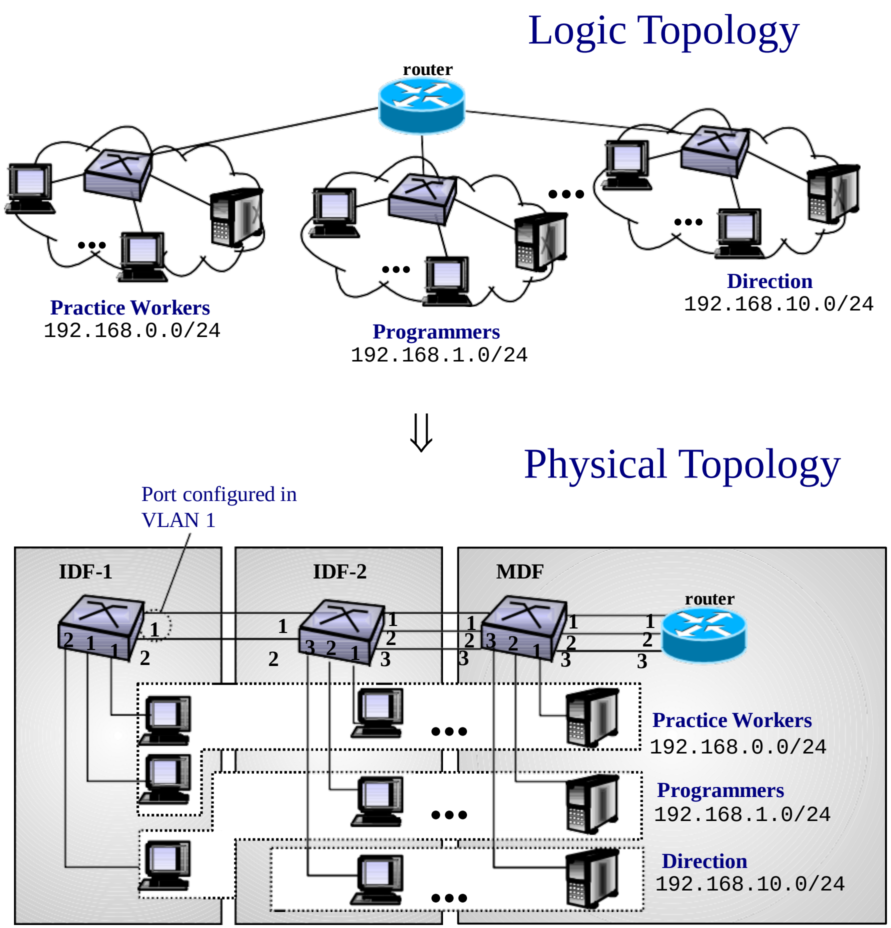
Ethernet Switches – Spanning Tree Protocol (STP)

- STP goal: Build a loop free topology (STP-tree) with optimal paths. The ports that do not belong to the STP tree are blocked.
- The switches send 802.1D messages to their neighbors to build up the STP-tree. If the topology changes (e.g. due to a link failure), a new STP-tree is setup.



Ethernet Switches – Virtual LANs, VLANs

- Motivation:
- Grouping related servers and hosts in different broadcast domains.
- How VLANs work:
- Each switch port belongs to a VLAN.
- The switch isolates different VLANs: The switch flooding is done only towards the ports of the same VLAN. Each VLAN is equivalent to a different physical switch.
- A router is needed to send traffic to a different VLAN.



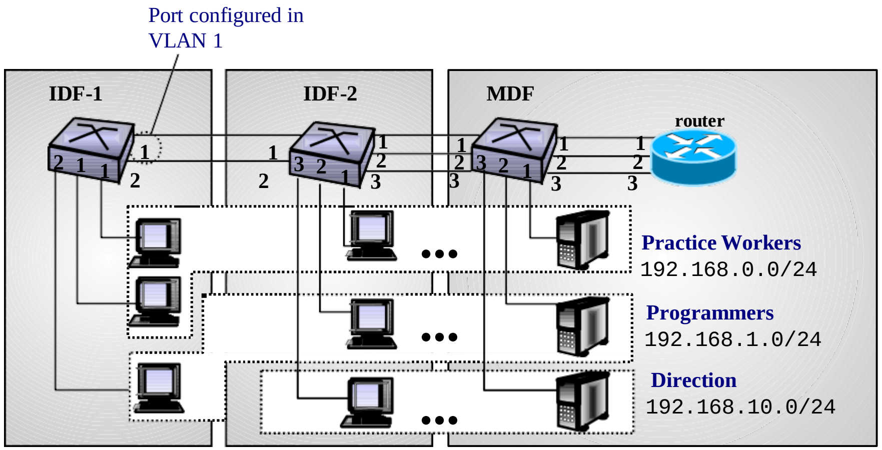
Ethernet Switches – Virtual LANs, VLANs

- Advantages:
- Flexibility of the physical placement of the devices.
- Facilitates network growth.
- Facilitates the network management: Changing the topology, adding new subnetworks, moving ports from one network to another.

- NOTE: Since each VLAN is a different broadcast domain, usually a different STP instantiation is used for each VLAN. Thus, a different STP-tree is build in each VLAN.

Ethernet Switches – VLAN Trunking

- Problem:
- Why connecting several ports between the same devices?
- Trunking:
- The port configured as trunk belongs to several VLANs (maybe all).
- The traffic sent in one VLAN is also sent to the trunk the VLAN belongs to.
- A tagging mechanism is used in the trunk to discriminate the traffic from different VLANs.



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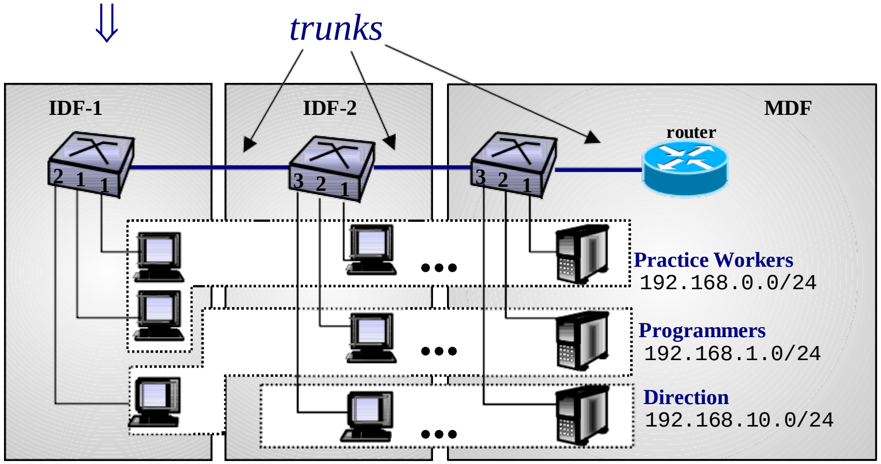


Ethernet Switches – VLAN Trunking

- Trunking Protocols: IEEE-802.1Q

```
+-----------+-----------+----------+---------+---------+---------+-----------+----------+
|Preamble   |Destination|Source MAC| TPID    | TCI     |Length of| Payload   | CRC      |
|(8 bytes)  |MAC Address|Address   |         |         |the frame|(46 to     |(4 bytes) |
|           |(6 bytes)  |(6 bytes) |(2 bytes)|(2 bytes)|(2 bytes)|1500 bytes)|          |
+-----------+-----------+----------+---------+---------+---------+-----------+----------+
```

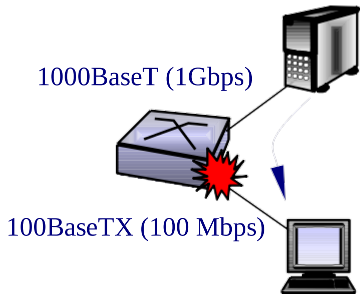
IEEE-802.3 frame with the 802.1Q *tag*.

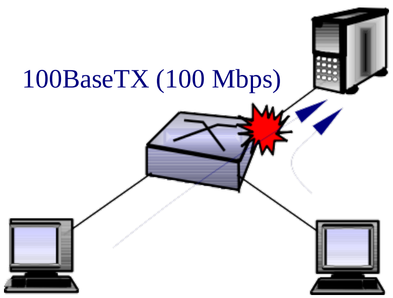
Legend:

- *Tag Protocol Identifier* (TPID): Field with the hexadecimal value 8100 for an Ethernet frame.
- *Tag Control Information* (TCI): Contains several fields. The most important is the VLAN ID (12 bits), which identifies the VLAN.

Ethernet Switches – Flow Control

- Switch Flow Control: Consists of adapting the rate at which the switch receives the frames, and the rate at which the switch can send them.
- Examples:



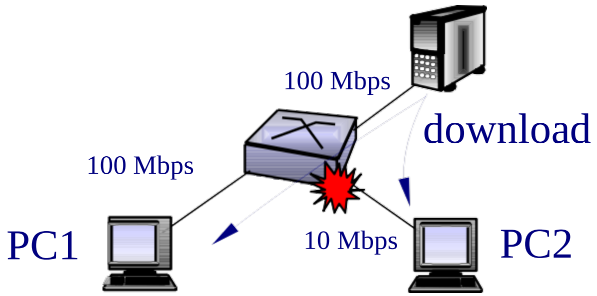


If no flow control is used, frames could be lost by buffer overflow.

- Flow control techniques (back pressure):
  - Jabber signal (half duplex): The switch sends a signal into the port which need to be throttled down, such that CSMA see the medium busy.
  - Pause frames (full duplex): The switch send special *pause frames*. These frames have an integer (2 bytes) indicating the number of slot-times (512 bits) that the NICs receiving the frame must be silent.

Ethernet Switches – Problems of Flow Control

- Flow Control can introduce inefficiencies (*head of line blocking*):

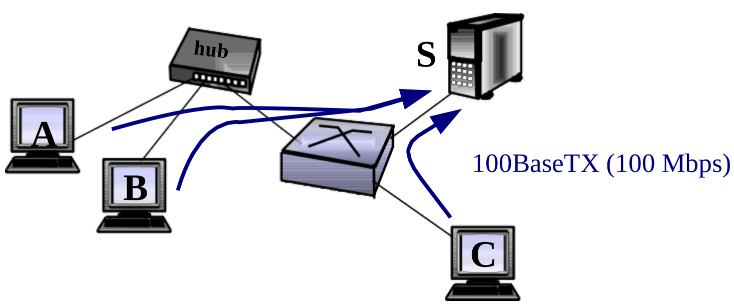


The slow link may trigger the flow control and send pause frames towards the server, causing under-utilization of the switch-server link.

- We would expect a download of approximately 90 Mbps for PC1 and 10 Mbps for PC2. However, the flow control can make the PC1 throughput to be significantly lower. Switches allow disabling the flow control in a link
If flow control is disabled, traffic is assumed to be controlled by TCP.
- If not otherwise stated, we shall assume an *ideal* flow control in the problems, which allow achieving the maximum throughput.

Ethernet Switches – Line bitrate sharing

- Hub: If the hub is the bottleneck for all the active ports, the capacity is equally shared between all ports where frames are transmitted.
- Switch: If one congested port is the bottleneck for all ports sending traffic to it, the port bit rate is equally shared between all ports sending traffic to it.
- Example:



  - If A, B and C simultaneously transmit to S:
    throughput C ≈ 100 Mbps / 2 = 50 Mbps
    throughput A = throughput B ≈ (100 Mbps / 2) / 2 = 25 Mbps

Outline

- Introduction
- IEEE LAN Architecture
- Ethernet
- Ethernet Switches
- **Wireless LANs**

Wireless LANs (WLANs) – Brief WLAN History

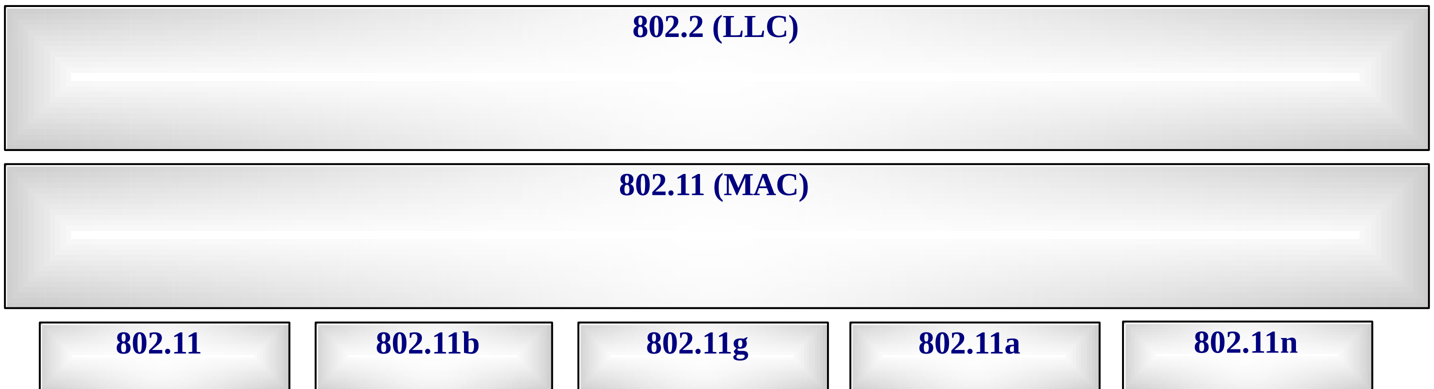
- 1971: Prof. Norman Abramson develops ALOHANET for the University of Hawaii
- 1990: many companies develop proprietary WLANs products.
- 1996: ETSI approves HIPERLAN/1 and
- 1997: IEEE approves 802.11
- Late 90 and 2000: Wi-Fi Alliance, tremendous growth of 802.11 products.
- 1999: 802.11a, 802.11b. 2003: 802.11g. 2009: 802.11n...

802.11 indoor APs

802.11 NICs

802.11 outdoor

Wireless LANs (WLANs) – 802.11

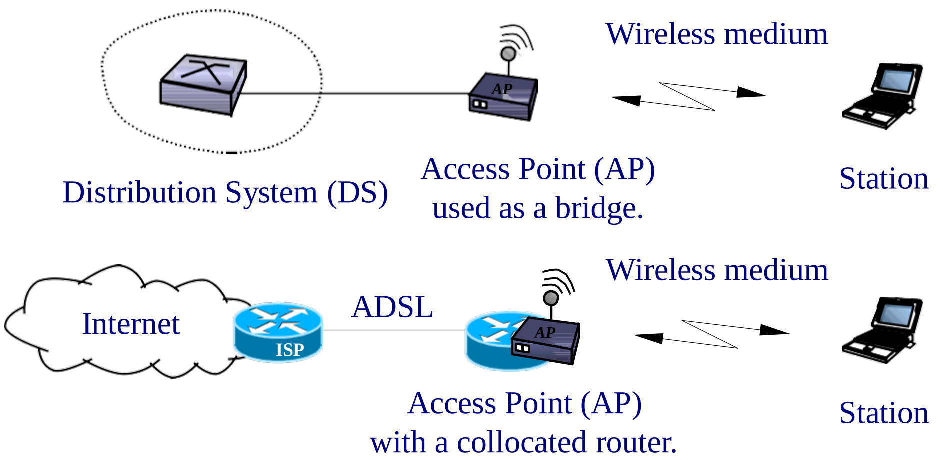


Standard	*Bitrate*	*ISM band*
802.11	1, 2 Mbps	2.4 GHz
802.11b	up to 11 Mbps	2.4 GHz
802.11a	up to 54 Mbps	5 GHz
802.11g	up to 54 Mbps	2.4 GHz
802.11n	up to 600 Mpbs	2.4 or 5 GHz

- ISM: Industrial Scientific and Medical. No licence required for non commercial usage.

Wireless LANs (WLANs) – 802.11 Components

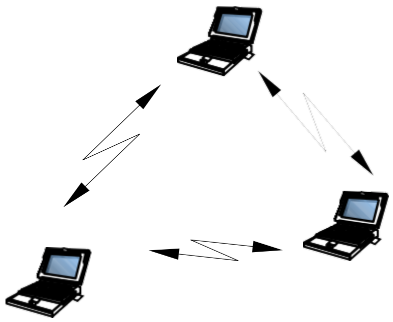
- Distribution System (DS):
  - Used by APs to exchange frames with one another and with wired networks. (e.g. an ethernet switch).
- Access Point (AP)
  - Simplify communication between stations.
  - All transmissions go through the AP.
  - APs are bridges and may have a collocated router.



Wireless LANs (WLANs) – 802.11 Components

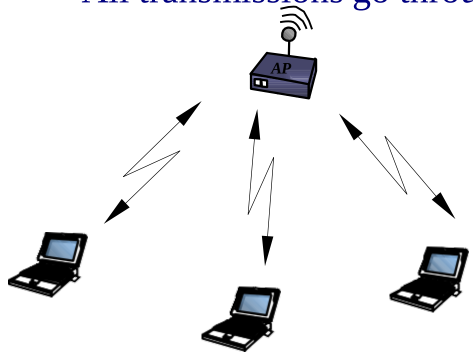
- Basic Service Set (BSS)
  - Set of stations communicating with each other.
  - Are identified by: (i) a Service Set identifier (SSID), or Network name: String with <32 characters; and (ii) a BSS Identifier (BSSID): 48 bits number.
  - If the network is composed of more than 1 BSS it is called Extended Service Set (ESS).

Independent BSS, IBSS (*ad-hoc mode*)

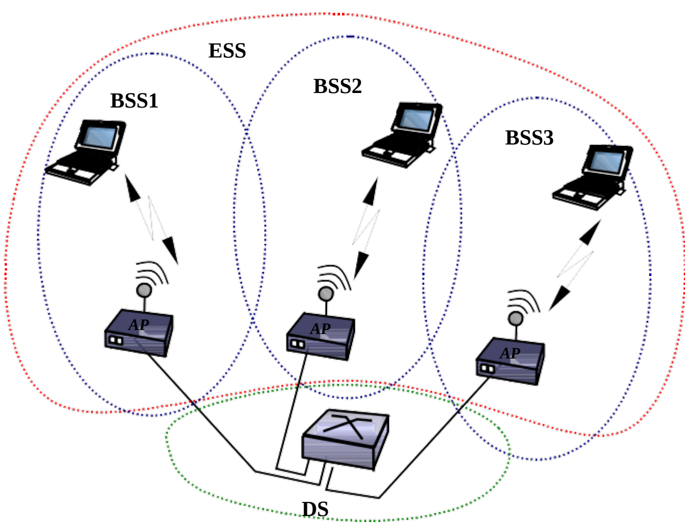


Infrastructure BSS (*infrastructure mode*)

- An station must associate with an AP.
- All transmissions go through the APs.



Extended Service Set (ESS)



Wireless LANs (WLANs) – 802.11 MAC

- Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA): In contrast to CSMA/CD, always waits a random backoff before Tx. Acks are needed to detect whether a transmitted frame collided.
- CSMA/CD is not used because collisions can hardly be detected in wireless (because in the antenna the Tx power is orders of magnitude higher than Rx power).

Wireless LANs (WLANs) – 802.11 Addresses

- Designed to be compatible with ethernet.
- Use non overlapping ranges with ethernet.
- The frame may have up to 4 addresses. The meaning of the addresses is specified by the bits to-DS and from-DS of the control.
- The BSSID is always present to identify frames belonging to the BSS

2	2	6	6	6	2	6	Variable: 0-2312	4
Frame Control	Duration	**Address 1**	**Address 2**	**Address 3**	Seq Ctrl	**Address 4**	Payload	FCS

Generic frame format

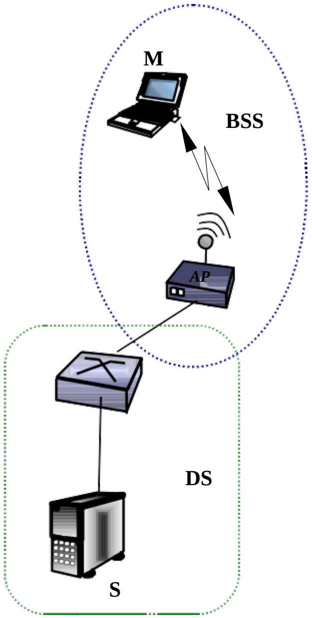
Wireless LANs (WLANs) – 802.11 Addresses

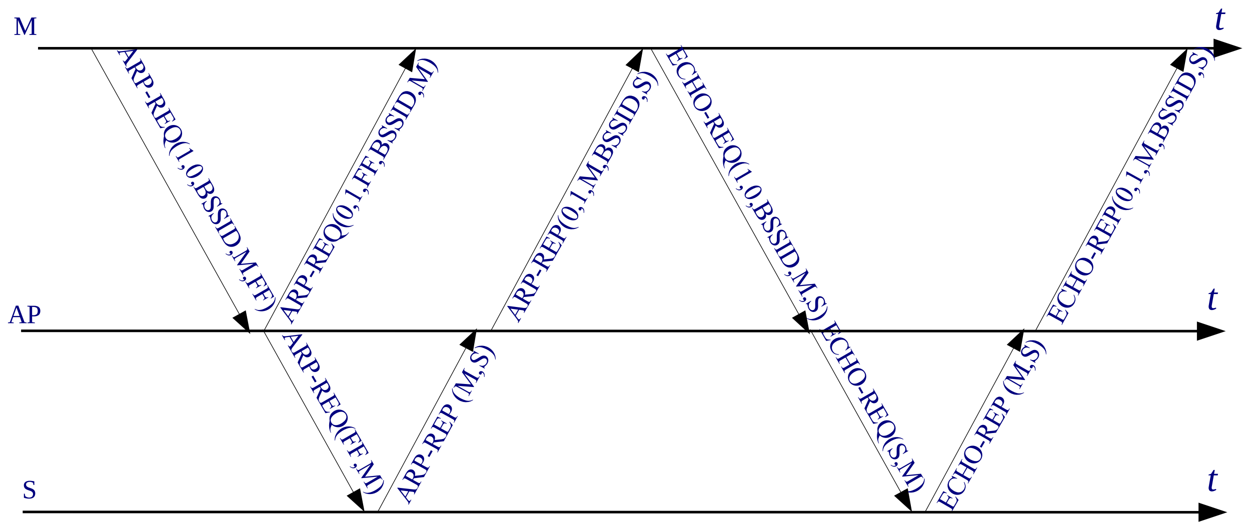
Scenario	Usage	to-DS	from-DS	Address1	Address2	Address3	Address4
STA→STA	Ad-hoc	0	0	DA	SA	BSSID	-
STA→AP	Infrastructure	1	0	BSSID	SA	DA	-
AP→STA	Infrastructure	0	1	DA	BSSID	SA	-
AP→AP	WDS	1	1	RA	TA	DA	SA

Legend: Destination Address (DA), Source Address (SA), Receiver Address (RA), Transmitter Address (TA), Wireless Distribution System (WDS)

Example:

M# ping S



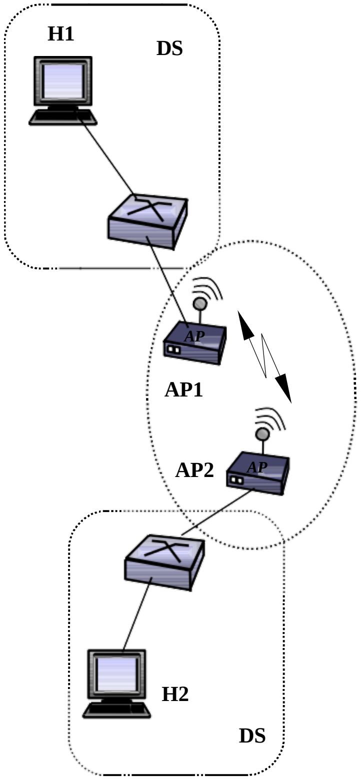


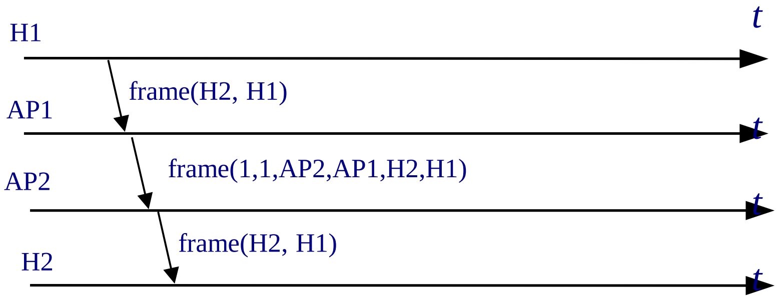
Legend, frames 802.11:
MESSAGE-TYPE(to-DS, from-DS, Address1, Address2, Address3)
Legend, frames ethernet:
MESSAGE-TYPE(destination address, source address)
FF is the broadcast address

Wireless LANs (WLANs) – 802.11 Addresses

Scenario	Usage	to-DS	from-DS	Address1	Address2	Address3	Address4
STA→STA	Ad-hoc	0	0	DA	SA	BSSID	-
STA→AP	Infrastructure	1	0	BSSID	SA	DA	-
AP→STA	Infrastructure	0	1	DA	BSSID	SA	-
AP→AP	WDS	1	1	RA	TA	DA	SA

Legend: Destination Address (DA), Source Address (SA), Receiver Address (FA), Transmitter Address (TA) , Wireless Distribution System (WDS)

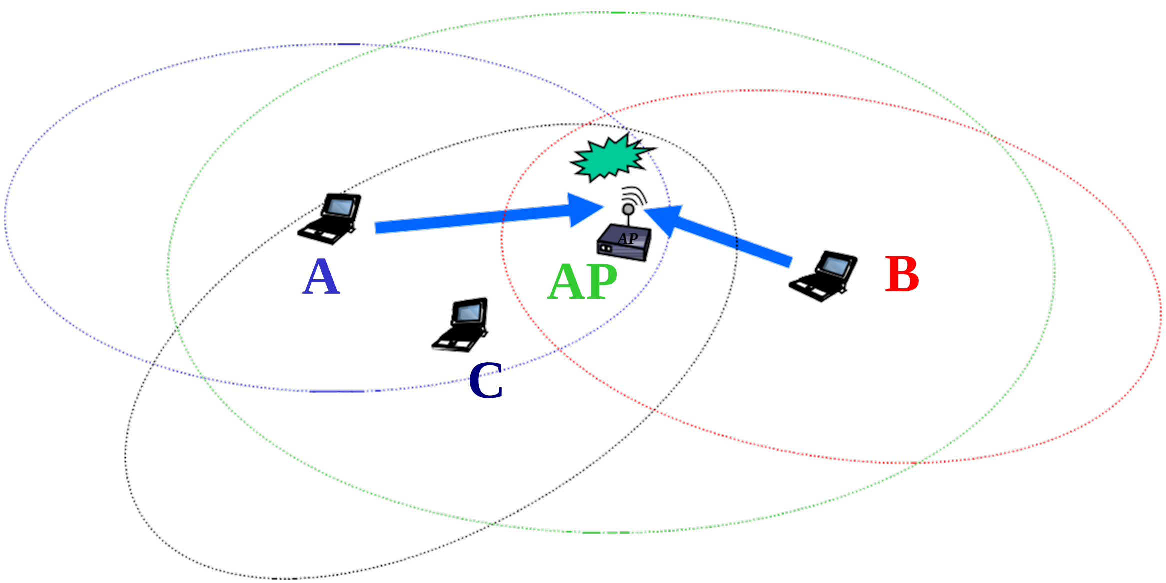




Legend, frames 802.11:
frame(to-DS, from-DS, Address1, Address2, Address3, Address4)
Legend, frames ethernet:
frame(destination address, source address)

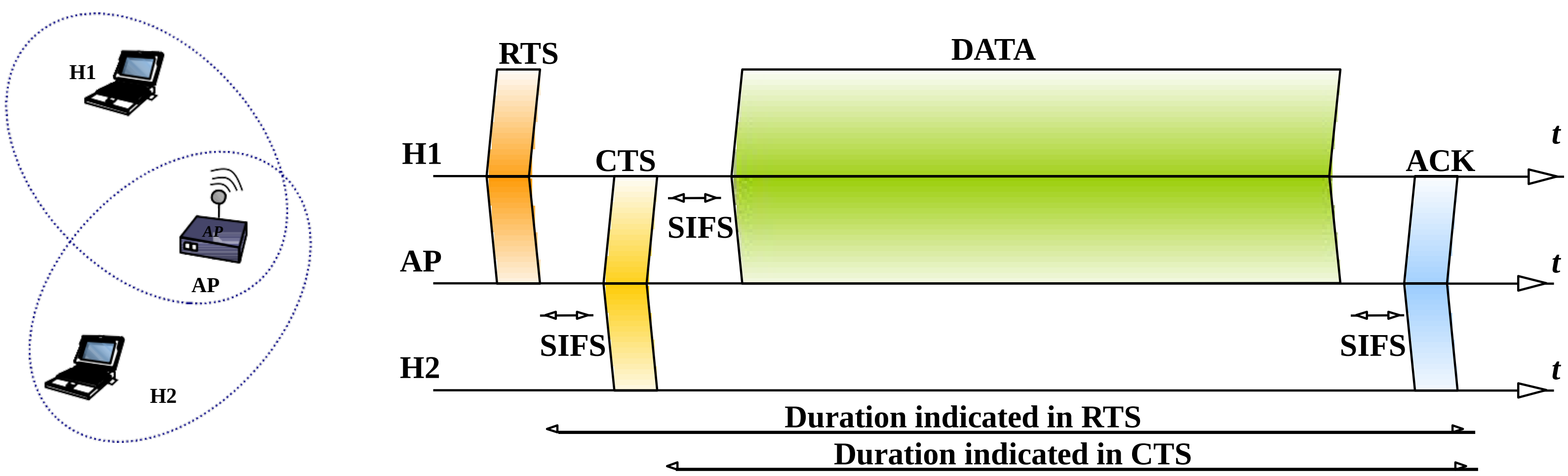
Wireless LANs (WLANs) – Hidden Node Problem

- Node A is in coverage with AP and C
- A and B cannot hear each other
- When A transmits to AP, B cannot detect the transmission using the carrier sense mechanism
- If B transmits, a collision will occur at AP



Wireless LANs (WLANs) – 802.11 RTS/CTS

- Optional mechanism to solve the hidden node problem.



- RTS is sent using the basic access mechanism.
- Upon receiving a RTS/CTS, the station set the Network Allocation Vector (NAV) to the indicated duration. While the NAV is non zero, the virtual carrier sensing indicates that the medium is busy.
- RTS/CTS is only used for unicast Tx.
- There is a threshold indicating the minimum frame size for using RTS/CTS.