Computer Networks - *Xarxes de Computadors*

Outline

- Course Syllabus
- Unit 1: Introduction
- Unit 2. IP Networks
- Unit 3. Point to Point Protocols -TCP
- **Unit 4. Local Area Networks, LANs**
- Unit 5. Data Transmission

Unit 4. Local Area Networks, LANs

Outline

- **Introduction**
- IEEE LAN Architecture
- Random MAC Protocols
- Ethernet
- Ethernet Switches
- Wireless LANs

Unit 4. Local Area Networks, LANs

Introduction – Brief History

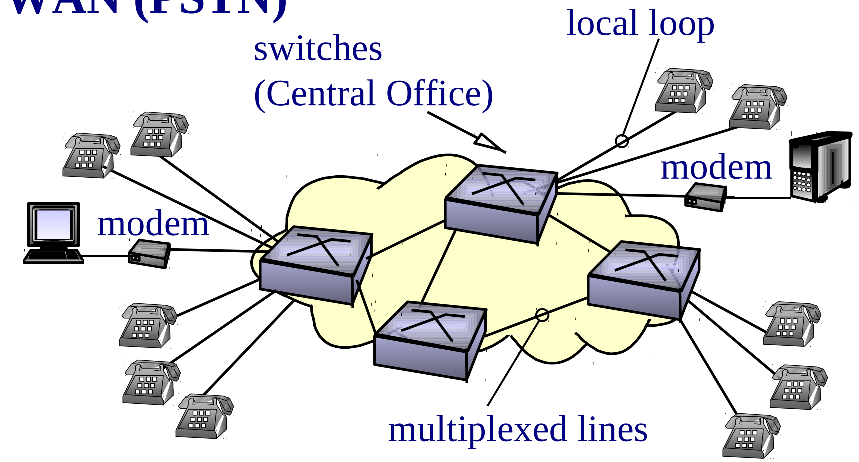
- Before 1970's: Sites had only one central computer, with users accessing via computer terminals with proprietary protocols and low speed lines.
- During the 1970's, the first LANs were created to connect several large central computers: Ethernet, ARCNET, ALOHAnet, etc.
- During the 1980's PCs proliferated and the demand for LAN technologies multiplied. Each vendor typically had its own type of NICs, cabling, and data link and network protocols.
- In 1983 Ethernet was standardized as IEEE 802.3 protocol. Many manufacturers started producing devices for this technology.
- During the 1990's Ethernet and TCP/IP became the leading LAN technology and network protocols.
- In 1999 IEEE 802.11 protocol (wifi) was standardized for Wireless LANs, and it has been an enormous success.

Unit 4. Local Area Networks, LANs

Introduction – WAN and LAN differences

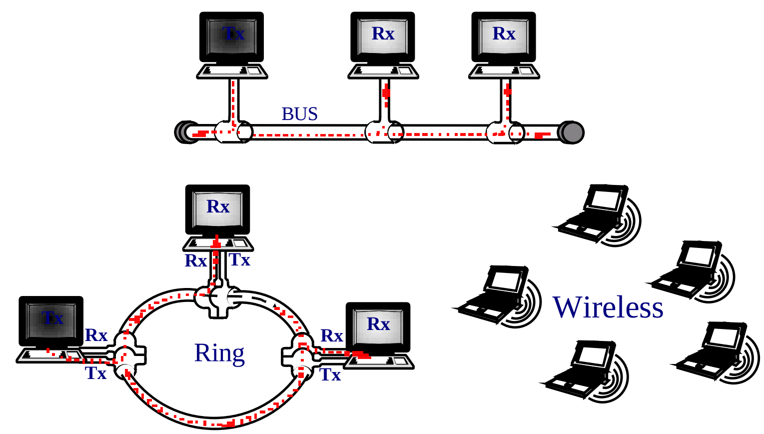
- WANs:
  - Main goal: scalability.
  - Switched network with mesh topology.
- LANs:
  - Multy-access network with shared media.
  - A Medium Access Control (MAC) protocol is needed.

WAN (PSTN)



Switched media

LANs

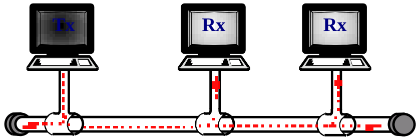


Shared media

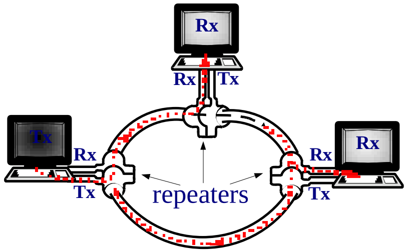
Unit 4. Local Area Networks, LANs

Introduction – LAN topologies

- Traditional LAN designs have used BUS and Ring topologies:
  - BUS: ARCNET, LocalTalk (Apple), Ethernet...
  - RING: Token Ring (IBM), FDDI...
- The standardization and constant evolution of Ethernet have made almost disappear other LAN technologies.



BUS Topology

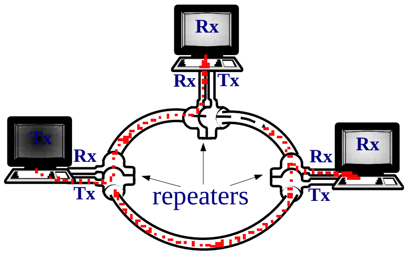


Ring Topology

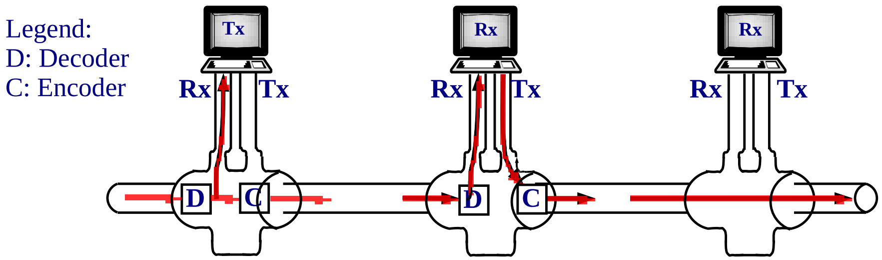
Unit 4. Local Area Networks, LANs

Introduction – Ring Topology

- Stations can be in one of the states:
  - Reception: The repeater decodes the signal and send the bits to the station after some delay *T*. The bits are also encoded and send to the next repeater.
  - Transmission: The same as before, but the bits encoded and send to the next repeater are those received from the station.
  - Short circuit: The repeater is in short circuit (e.g. if no station is connected, or a malfunction occurs).



Ring Topology



Reception State

Transmission State

Short Circuit State

Unit 4. Local Area Networks, LANs

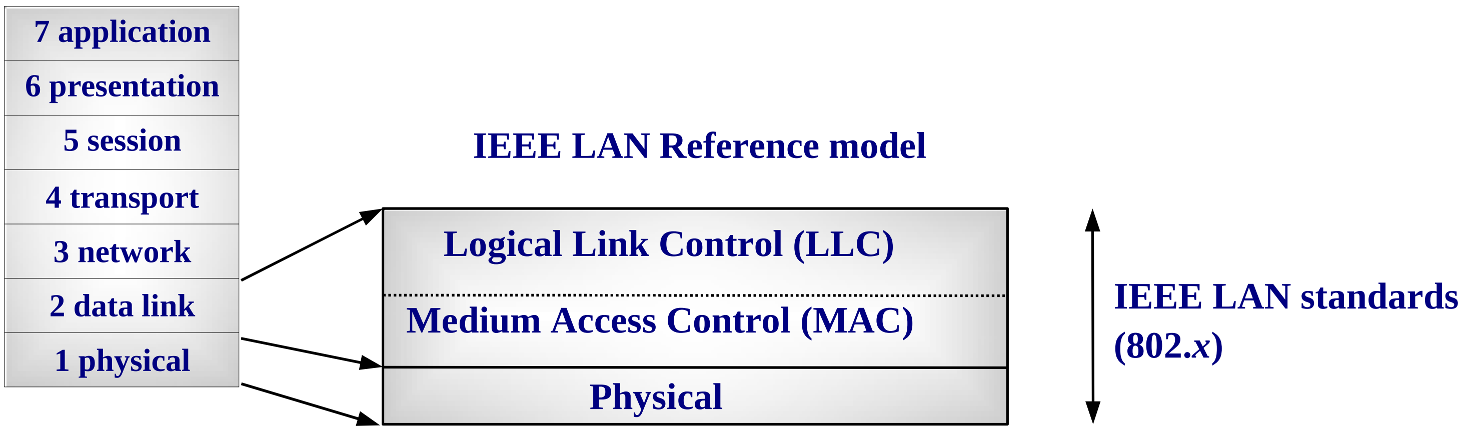
Outline

- Introduction
- **IEEE LAN Architecture**
- Type of MACs
- Random MAC Protocols
- Ethernet
- Ethernet Switches
- Wireless LANs

Unit 4. Local Area Networks, LANs

IEEE LAN Architecture

OSI Reference model:



- 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.

Unit 4. Local Area Networks, LANs

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

802.8 FDDI

802.11 WiFi: Wireless LANs.

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

802.15.1 Bluetooth

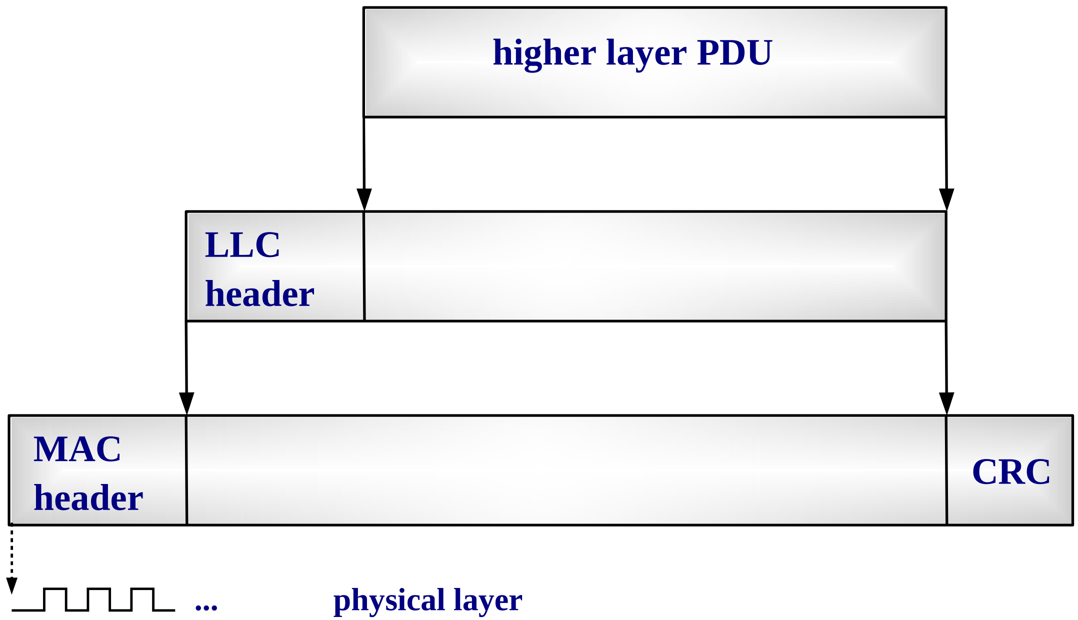
802.15.4 low data rate and low cost sensor devices

802.16 WiMAX: broadband Wireless Metropolitan Area Networks.

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

Unit 4. Local Area Networks, LANs

IEEE LAN Architecture – LAN encapsulation



Unit 4. Local Area Networks, LANs

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	3IEEE 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

Example of some IEEE SAP values.

Unit 4. Local Area Networks, LANs

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- Introduction
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Unit 4. Local Area Networks, LANs

Random MAC Protocols - Type 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.
  - We shall only study random MACs.
  - Example: Ethernet

Unit 4. Local Area Networks, LANs

Random MAC Protocols - Aloha

- Developed in 1970 by professor Norm Abramson. The objective was connecting the central computers of the university campus of Hawaii.
- Aloha is the basis of most random MACs protocols. It is interesting evaluate Aloha because is easy to model mathematically, and the main conclusions apply to other random MACs.

Unit 4. Local Area Networks, LANs

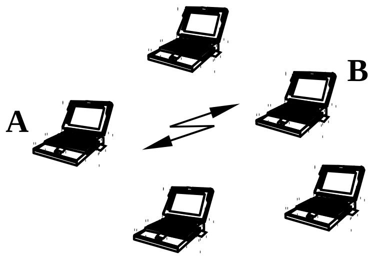
Random MAC Protocols - Aloha

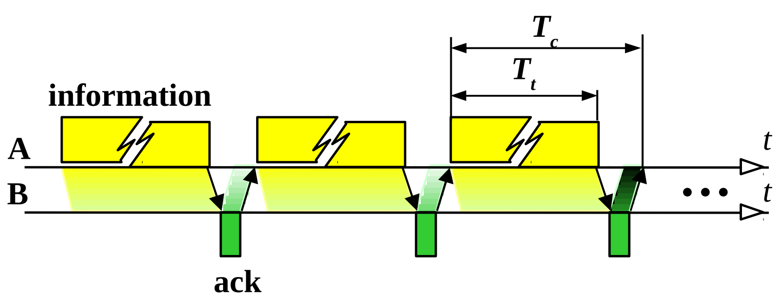
- When a station has a frame ready, transmit immediately.
- After sending a frame, wait for an ack.
- If the ack does not arrive, a time-out occurs and a collision is assumed.
- When a collision is detected, retransmit the frame after a *backoff* time. The backoff is random.

Unit 4. Local Area Networks, LANs

Random MAC Protocols - Aloha

- If only one station transmits:



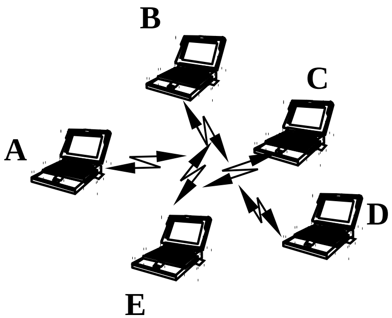


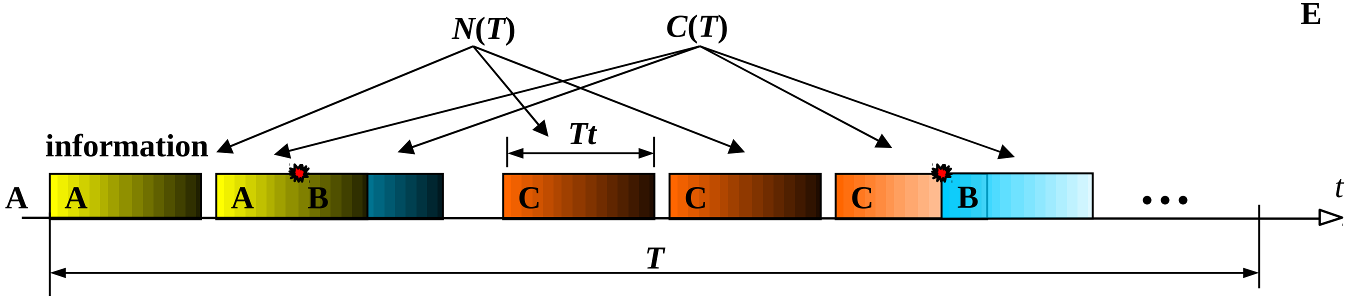
$$E = \frac{T_t}{T_c} \approx 100\,\%$$

Unit 4. Local Area Networks, LANs

Random MAC Protocols – Aloha efficiency

- Many stations transmit. Define:
  - $N(T)$: Number of successful Tx during T.
  - $C(T)$: Number of collisions during T.
  - Tt: Tx time of a frame.





Efficiency: $E = N(T)\, T_t / T$

Offered load: $G = [N(T)+C(T)]\, T_t /T$

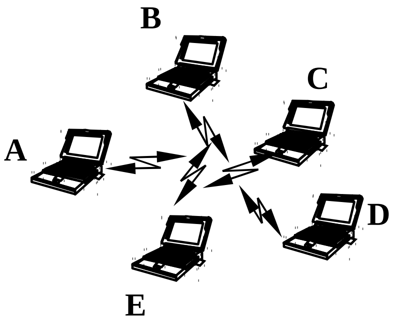
Hipothesis: Poisson arrivals

$$P(n \text{ frames arrive in a time } t/T_t) = \frac{\left(G\frac{t}{T_t}\right)^n}{n!} e^{-G\frac{t}{T_t}}$$

Unit 4. Local Area Networks, LANs

Random MAC Protocols – Aloha efficiency

- Many stations transmit. Define:
  - *N*(*T*): Number of successful Tx during *T*.
  - *C*(*T*): Number of collisions during *T*.
  - *Tt*: Tx time of a frame.



Eficiency: $E = N(T)\, T_t / T$

Offered load: $G = [N(T)+C(T)]\, T_t / T$

Hipothesis: Poisson arrivals

$$P(n \text{ frames arrive in a time } t/T_t) = \frac{\left(G\frac{t}{T_t}\right)^n}{n!} e^{-G\frac{t}{T_t}}$$

$$E = \lim_{T\to\infty} \frac{N(T)\,T_t}{T} = \lim_{t\to\infty} \frac{(N(T)+C(T))\,T_t}{T} \frac{N(t)}{N(T)+C(T)} = G\, P_{suc}$$

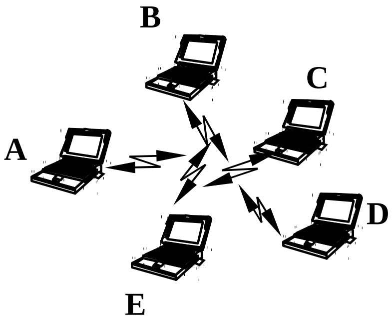
Unit 4. Local Area Networks, LANs

Random MAC Protocols – Aloha efficiency

Eficiency: $E = N(T)\, T_t / T$

Offered load: $G = [N(T)+C(T)]\, T_t / T$

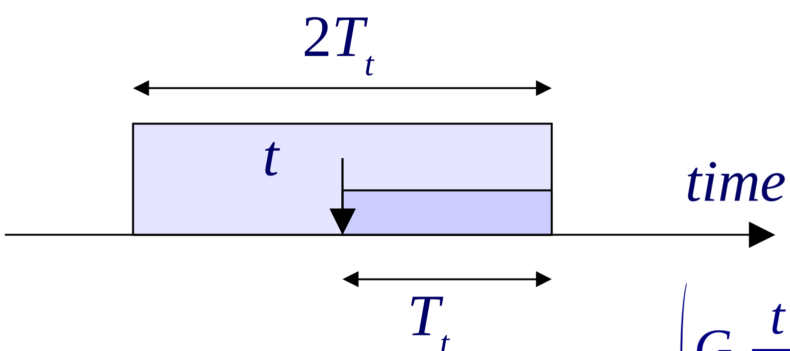
Hipothesis: Poisson arrivals



$$P(n \text{ frames arrive in a time } t/T_t) = \frac{\left(G \frac{t}{T_t}\right)^n}{n!} e^{-G\frac{t}{T_t}}$$

$$E = \lim_{T\to\infty} \frac{N(T)\,T_t}{T} = \lim_{t\to\infty} \frac{(N(T)+C(T))\,T_t}{T} \frac{N(t)}{N(T)+C(T)} = G\; P_{suc}$$

- If a packet is scheduled for Tx at time t, the success probability is the probability of no other Tx occur in the vulnerable interval $[t-T, t+T]$:



$$\Rightarrow E = G\; e^{-2G}$$

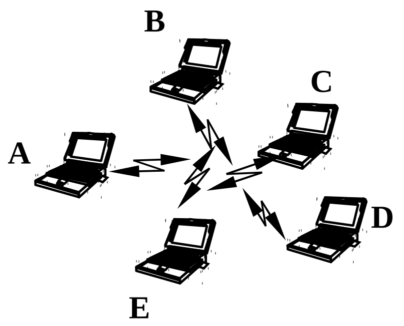
$$P_{suc} = P\{0 \text{ packet is Tx in } 2\,T_t\} = \frac{\left(G\,\frac{t}{T_t}\right)^n}{n\,!} e^{-g\;t}\Big|_{n=0,\,t=2T_t} = e^{-2\;G}$$

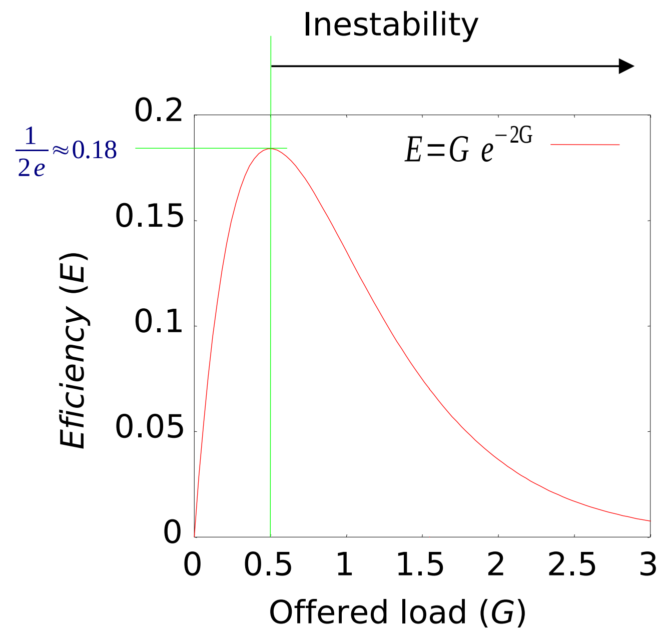
Unit 4. Local Area Networks, LANs

Random MAC Protocols - Aloha

- Many stations transmit.

$$E = G\, e^{-2G}$$





Conclusions:

- The maximum load is only 18%
- After the maximum load is reached the protocol becomes unstable: The higher is the offered load (*G*), the lower is the efficiency (*E*).

Unit 4. Local Area Networks, LANs

Random MAC Protocols – Carrier Sense Multiple Access (CSMA)

- If the transmission time is small compared with the delay, the aloha efficiency can be increased if the stations “listen” the medium (*carrier sense*) before transmission.
- When the medium is becomes free:
  - 1 persistent-CSMA: Transmit immediately. E.g. Ethernet.
  - non persistent CSMA: Wait for an additional random time and listen again before transmission. E.g. Wifi.

Unit 4. Local Area Networks, LANs

Outline

- Introduction
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- **Ethernet**
- Ethernet Switches
- Wireless LANs

Unit 4. Local Area Networks, LANs

Ethernet – Introduction

- Designed by Bob Metcalfe at Xerox in mid-70s.
- Based on Aloha.
- The name Ethernet refers to the idea had in the past that electromagnetic waves propagated into a substance (ether) which filled the space.
- 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. There are several active Ethernet working groups inside IEEE 802.3.

Unit 4. Local Area Networks, LANs

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).

Unit 4. Local Area Networks, LANs

Ethernet – Ethernet addresses

```
      1        2        3        4        4        6     bytes
 0 1 234567 01234567 01234567 01234567 01234567 01234567 bits
+-+-+------+--------+--------+--------+--------+--------+   -> Tx order
|I|U|      #        #        |        #        #        |
|G|L|      #        #        |        #        #        |
+-+-+------+--------+--------+--------+--------+--------+
|<----------- OUI ---------->|<---------- OUA --------->|
```

- Bit I/G (Individual/Group): 0 ⇒ unicast, 1 ⇒ multicast. The broadcast address is FF:FF:FF:FF:FF:FF. RFC-1112, Host extensions for IP multicasting, specifies how to build an Ethernet from an IP multicast address.
- Bit U/L (Universal/Local): 0 ⇒ IEEE address, 1 ⇒ local address. In practice local addresses are rarely used.
- OUI (22 bits) (Organizationally Unique Identifier): IEEE assigns 1 o more OUI to each manufacturer.
- OUA (24 bits) (Organizationally Unique Address): Allows the manufacturer to number 2^{24} NICs.

Unit 4. Local Area Networks, LANs

Ethernet – Representation of Ethernet addresses

```
                1        2        3        4        4        6     bytes
           0 1 234567 01234567 01234567 01234567 01234567 01234567 bits
          +-+-+------+--------+--------+--------+--------+--------+   -> Tx order
          |I|U|      #        #        |        #        #        |
          |G|L|      #        #        |        #        #        |
          +-+-+------+--------+--------+--------+--------+--------+
          |<----------- OUI ---------->|<---------- OUA --------->|
```

- IEEE (`http://standards.ieee.org/regauth/oui/tutorials/lanman.html`):
- *The binary representation of an address is formed by taking each octet in order and expressing it as a sequence of eight bits, least significant bit (lsb) to most significant bit (msb), left to right.*
- The order is changed because each octet is transmitted in the order lsb…msb, but it is written (and seen at in a PC console) in the reverse order (msb…lsb). IP addresses are written in the Tx order, and htonl() is used to convert to network bit order.
- Example:

Transmitted bits:	**0011**	**0101**	**0111**	**1011**	**0001**	**0010**	**0000**	**0000**	**0000**	**0000**	**0000**	**0001**
Binary Representation (msb-lsb):	**1010**	**1100**	**1101**	**1110**	**0100**	**1000**	**0000**	**0000**	**0000**	**0000**	**1000**	**0000**
Hexadecimal representation :	A	C	D	E	4	8	0	0	0	0	8	0

- Notations: AC-DE-48-00-00-80, AC:DE:48:00:00:80, ACDE.4800.0080

Unit 4. Local Area Networks, LANs

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 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**

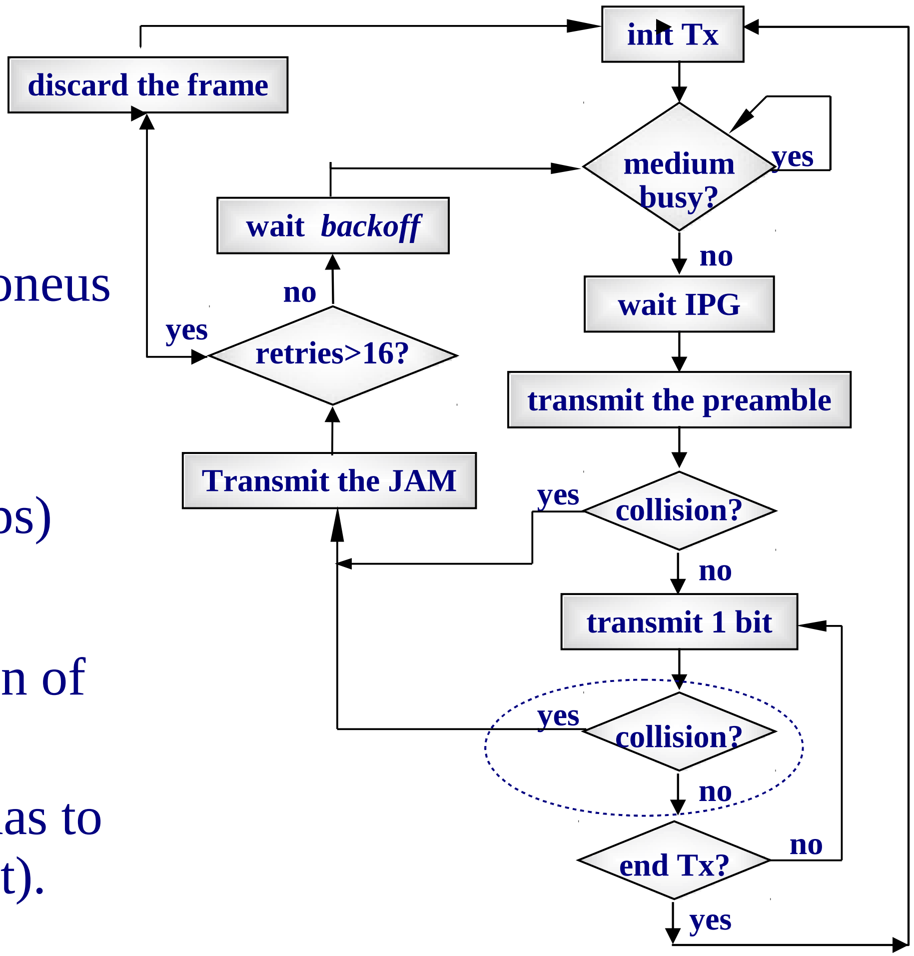
- Note: The MSS indicated by TCP would be of 1460 if DIX, and 1452 if IEEE encapsulation is used.

Unit 4. Local Area Networks, LANs

Ethernet – CSMA/CD Ethernet protocol (simplified)

Legend:

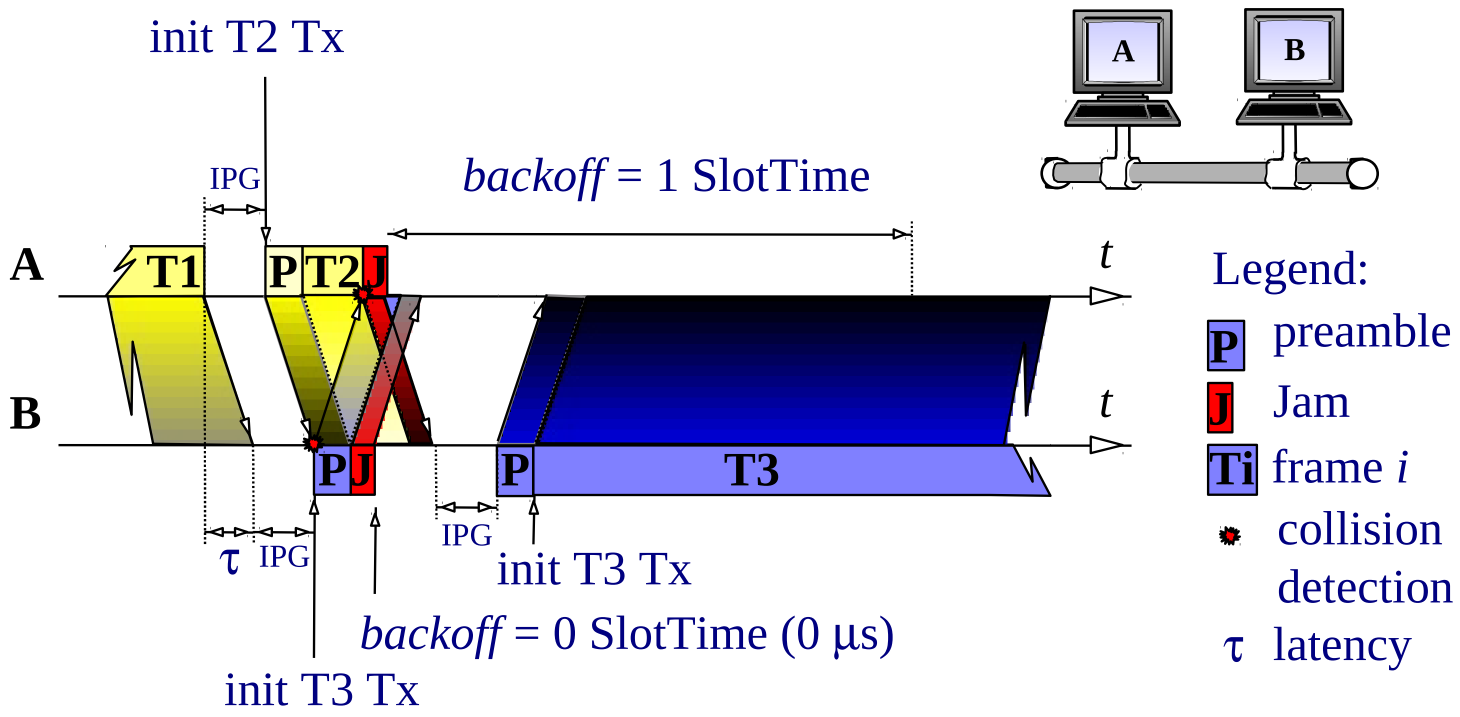
- InterPacket Gap (IPG): 96 bits.
- JAM: 32 bits that produce an erroneus CRC.
- *backoff* = $n\ T_{512}$
- T_{512}: *SlotTime* (51,2 µs at 10 Mbps)
- n = random$\{0, 2^{\min\{N, 10\}}-1\}$,
    - N: number of retransmission of the same frame (1, 2…)
- The station which Tx the frame has to detect the collision (no ack is sent).



Unit 4. Local Area Networks, LANs

Ethernet – Collision example

- Stations A y B have frames ready to Tx:

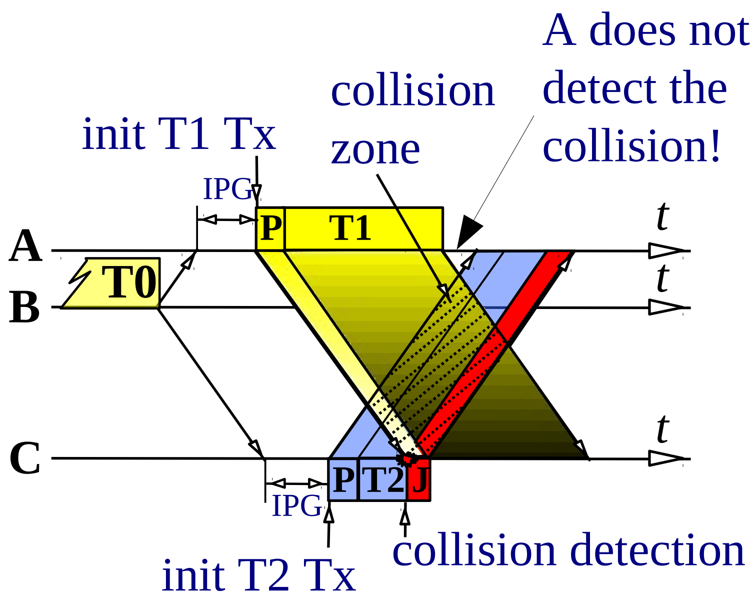


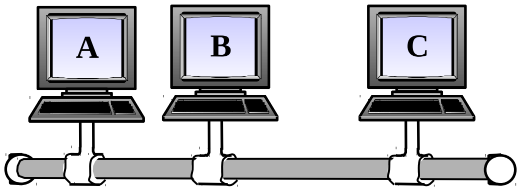
NOTE: The preamble is not interrupted in case of collision, and the JAM is Tx immediately after.

Unit 4. Local Area Networks, LANs

Ethernet – Minimum Frame Size

- Example of a "too small frame"





Legend:
- P preamble
- J Jam
- Ti frame *i*
- collision detection
- τ latency

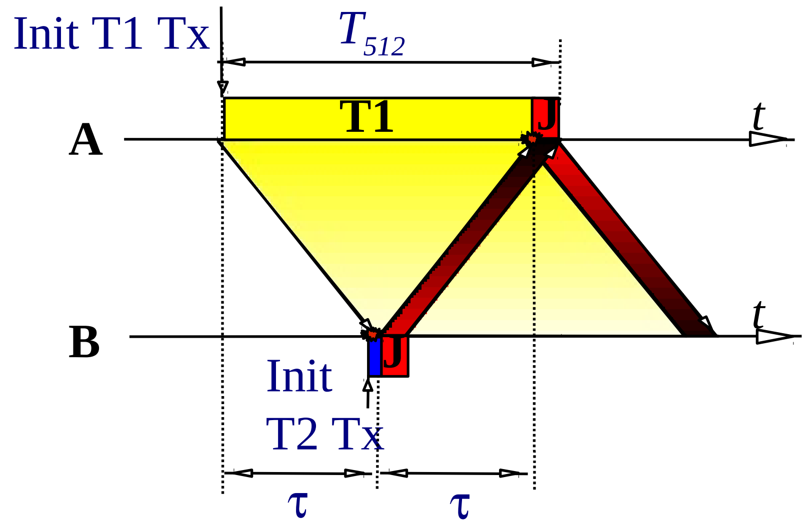
Unit 4. Local Area Networks, LANs

Ethernet – Minimum Frame Size

- The Ethernet payload has to be ≥ 46 bytes, for the ethernet frame size without the preamble to be ≥ 64 bytes (512 bits)
- IEEE standard: The slot time shall be larger than the sum of the Physical Layer round-trip propagation time and the Media Access Layer maximum jam time:

$$T_{512} > 2\,\tau + T_J$$

- Justification:
  If the previous relation holds, station A has time to detect the collision and send the JAM before the end of the frame Tx.



Unit 4. Local Area Networks, LANs

Ethernet – Minimum Frame Size with Gigabit Ethernet

- 512 bits slot time is too restrictive for Gigabit Ethernet (10^9 bps).
- Example, assume $v_p = 2\ 10^8$ m/s and consider only propagation delay:

$$T_{512} > 2\ \tau + T_{JAM} \Rightarrow 512/10^9 > 2\ D/(2x10^8) + 32/10^9 \Rightarrow D < 48\ m$$

- 48 m is too short (we shall see that 100 m is used as maximum Ethernet segment)
- To cope with this, Gigabit Ethernet uses an "extension field", such that the minimum Gigabit Ethernet size is 512 bytes (instead of bits).
- The extension field uses special symbols for its detection and removal.

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

Unit 4. Local Area Networks, LANs

Ethernet – Minimum Frame and full-duplex Ethernet

- As we shall see, some Ethernet standards allow a full-duplex Tx, when Ethernet NICs are connected point-to-point.
- 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).
- Therefore, with full-duplex mode, a minimum frame size is not needed, and Gigabit Ethernet does not add the extension field.

Unit 4. Local Area Networks, LANs

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.

Unit 4. Local Area Networks, LANs

Ethernet – Different Ethernet Standards

Denomination:

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.

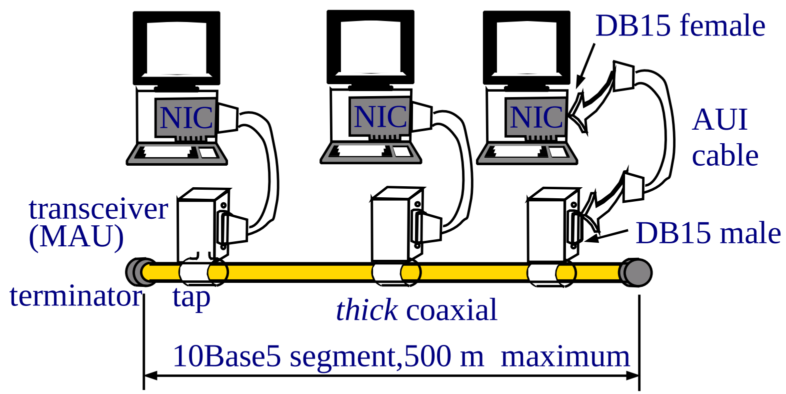
Various meanings:

- 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
  - ...

Unit 4. Local Area Networks, LANs

Ethernet – Different Ethernet Standards: 10Base5

First IEEE Ethernet standard (1983). Now a days is obsolete.



thick coaxial with
N type connectors

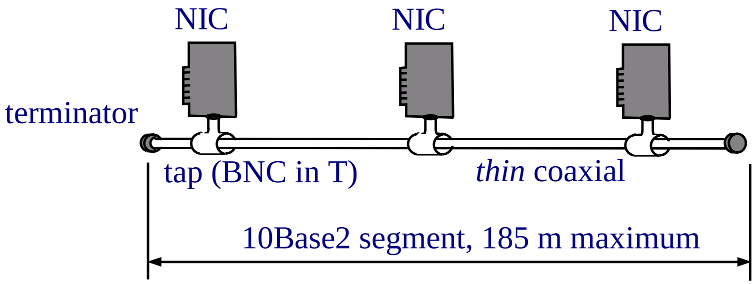
AUI Cable

Transceiver (MAU)

Unit 4. Local Area Networks, LANs

Ethernet – Different Ethernet Standards: 10Base2

1985. Cheaper than 10Base5. Now a days is obsolete.



thin coaxial with BNC connectors

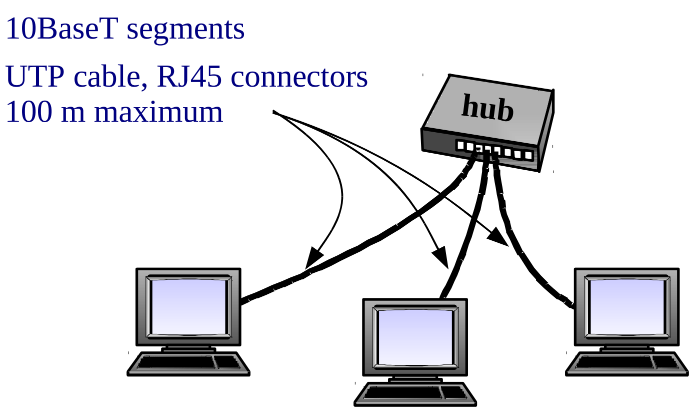
BNC in T

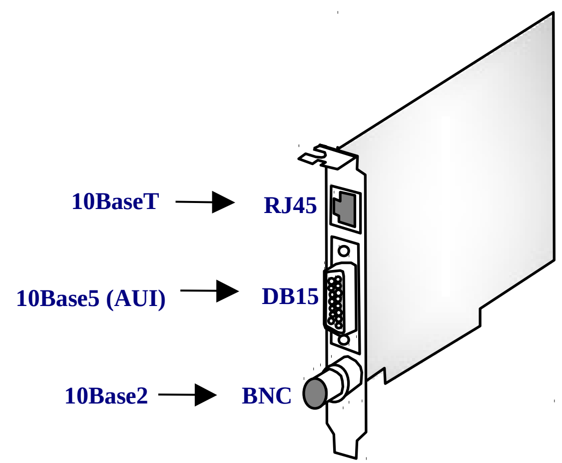
Unit 4. Local Area Networks, LANs

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.





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

Transceivers
AUI-BNC/AUI-RJ45

Unit 4. Local Area Networks, LANs

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). Now the only copper standard is Infiniband with segment size ≤ 15m. It is foreseen a UTP standard-cat.6 –cat.7.

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

Unit 4. Local Area Networks, LANs

Outline

- Introduction
- IEEE LAN Architecture
- Random MAC Protocols
- Ethernet
- **Ethernet Switches**
- Wireless LANs

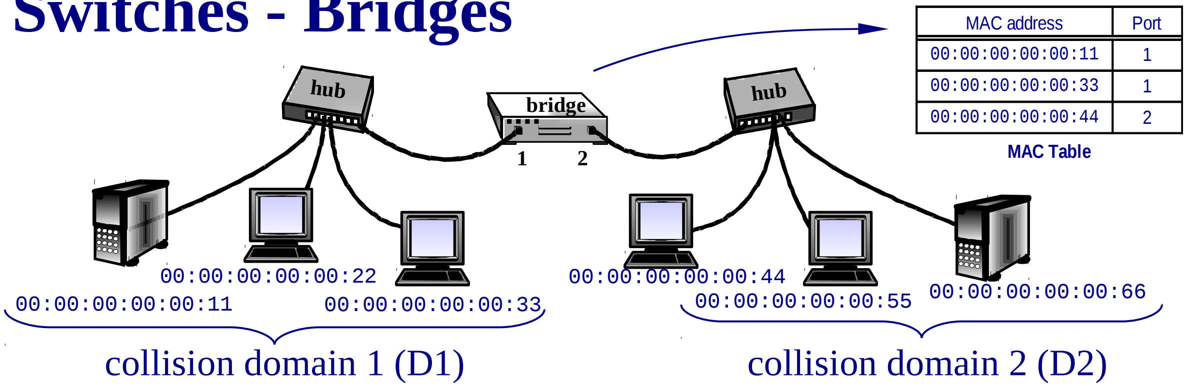
Unit 5. Local Area Networks, LANs

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.
  - Segments the “collision domain”.

Unit 5. Local Area Networks, LANs

Ethernet Switches - Bridges



How the bridge works:

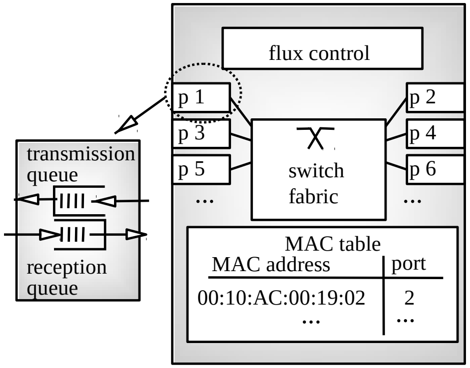
- If a frame is received with a source address on in the MAC table, it is added (*learning bridge*).
- If a frame from D1 is received with a destination address: (i) is in D2, (ii) it is not in the table, (ii) it is broadcast: It is sent into D2 (*flooding*).
- If it is received a frame from D1 addressed 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 access their servers.

Unit 5. Local Area Networks, LANs

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

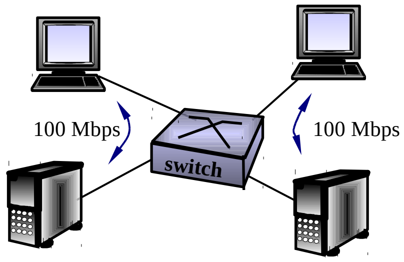
Edge and *backbone* CISCO switches.

How the switch works:

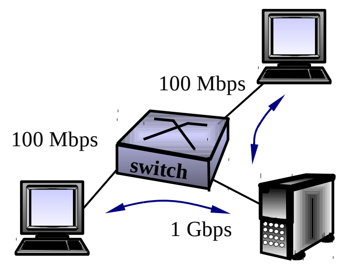
- It is equivalent to a “multiport bridge”.
- When a frame is received with a source address not in the table, it is added.
- If a frame is received with a destination address: (i) not in the table, (ii) broadcast or multicast: copy the frame in all transmission buffer of the other ports (flooding).
- 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).

Unit 5. Local Area Networks, LANs

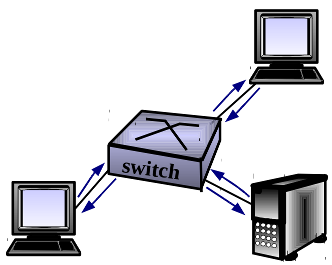
Ethernet Switches - Switch Capabilities



Simultaneous Transmissions



Ports with Different bitrates



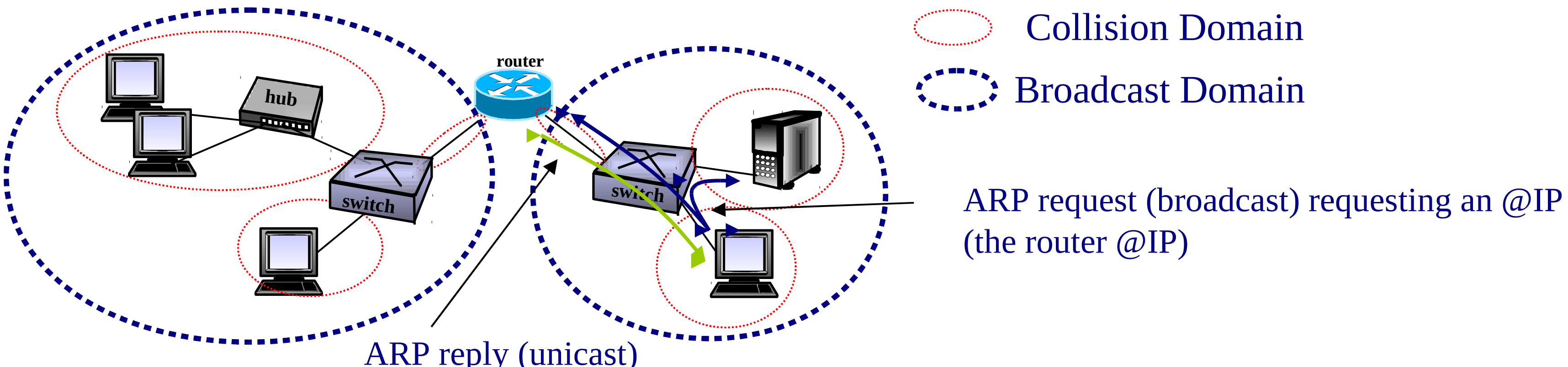
Full Duplex Ports

- 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 (usable if only one host is connected).
- There can be ports simultaneouly in half or full duplex mode.
- Security: Stations can only capture the traffic of their collision domain.
- ...

Unit 5. Local Area Networks, LANs

Ethernet Switches - Broadcast and Collision Domains

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

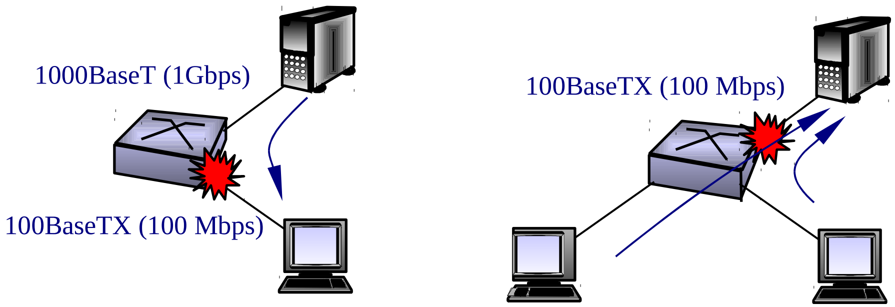


ARP cannot solve an @IP out of the broadcast domain. To leave the broadcast domain a router is required.

Unit 5. Local Area Networks, LANs

Ethernet Switches – Flox Control

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



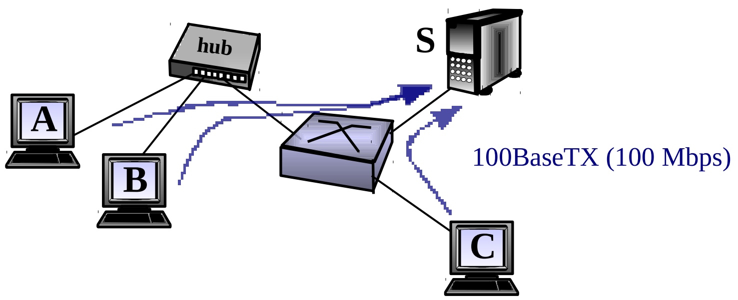
If no flox control is used, frames could be lost by buffer overflow.

- Flux 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.

Unit 5. Local Area Networks, LANs

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:



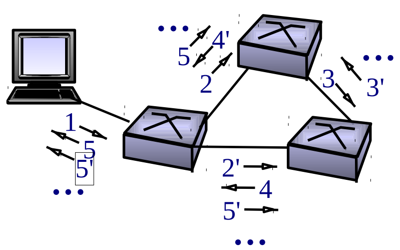
- If A, B and C simultaneously transmit to S:
  throughput C ≈ 100 Mbps / 2 = 50 Mbps
  throughput A = throughput B ≈ (100 Mbps / 2) / 2 = 25 Mbps

Unit 5. Local Area Networks, LANs

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

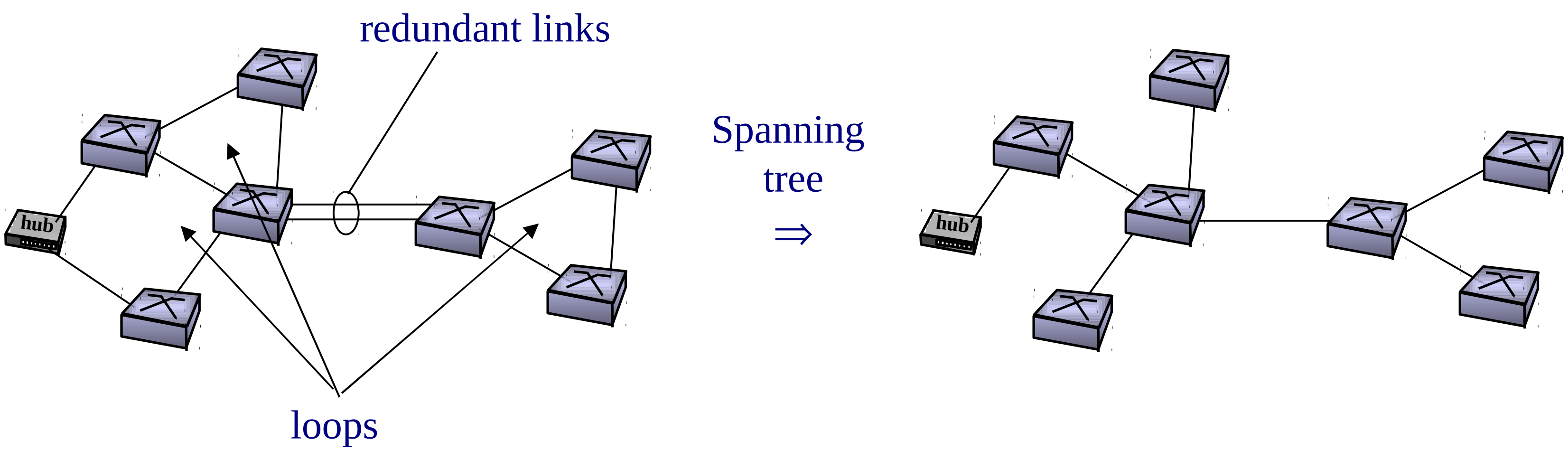
⇓

Solution: IEEE 802.1D Spanning Tree Protocol (STP)

Unit 5. Local Area Networks, LANs

Ethernet Switches – Spanning Tree Protocol (STP)

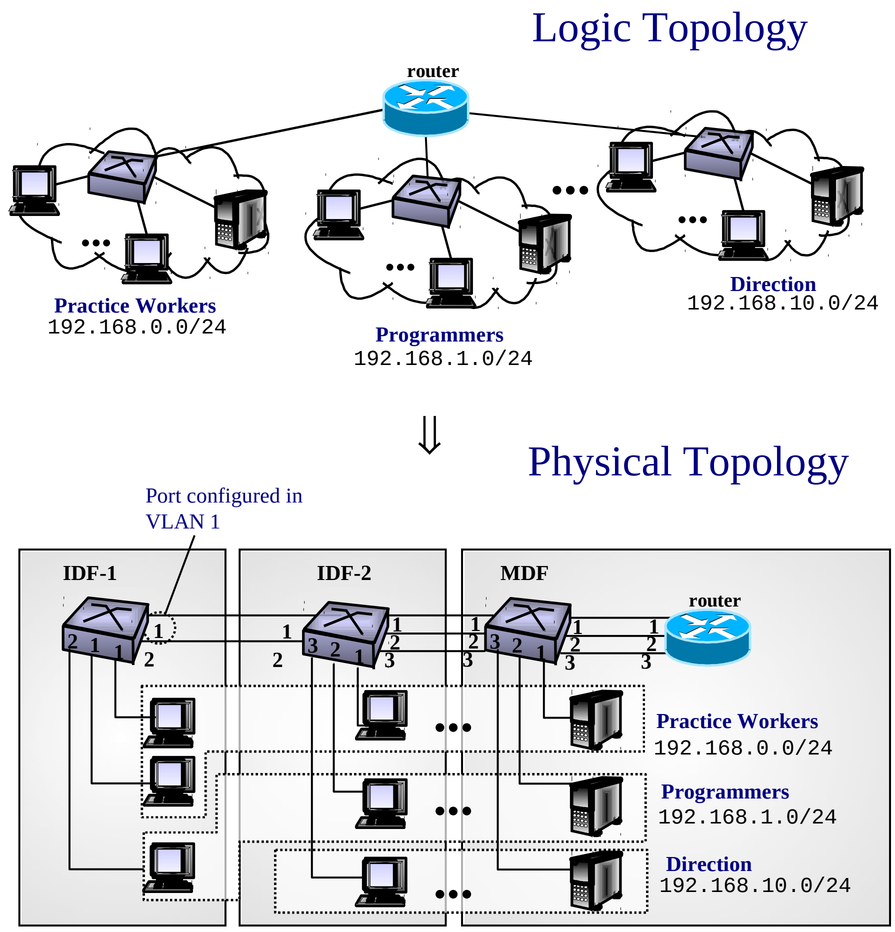
- STP goal: Build a loop free topology (STP-tree) with optimal paths. The ports that do not belong to the STP tree are blocked.
- The switches send 802.1D messages to their neighbors to build up the STP-tree. If the topology changes (e.g. due to a link failure), a new STP-tree is setup.



Unit 5. Local Area Networks, LANs

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 on 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.



Unit 5. Local Area Networks, LANs

Ethernet Switches – Virtual LANs, VLANs

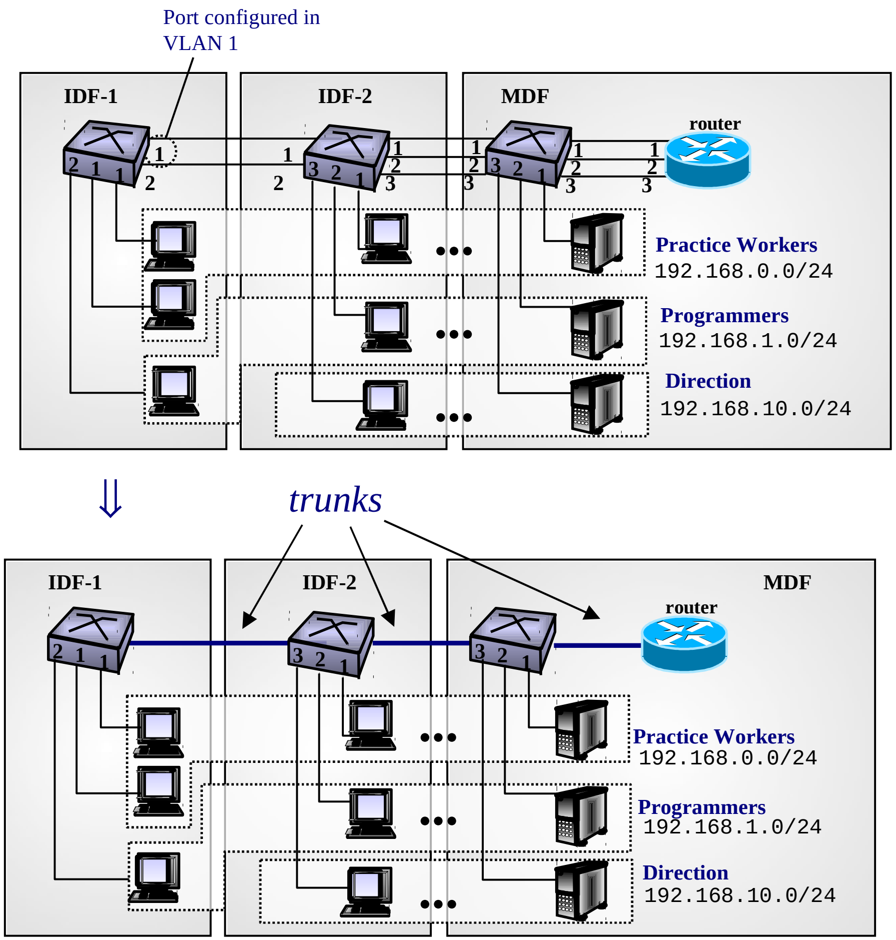
- Advantages:
- Flexibility of the physical placement of the devices.
- Facilitates the network grow.
- Facilitates the network management: Changing the topology, adding new subnetworks, moving ports from one network to another.

- 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.

Unit 5. Local Area Networks, LANs

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.



Unit 5. Local Area Networks, LANs

Ethernet Switches – VLAN Trunking

- Trunking Protocols:
- Inter-Switch Link (ISL). CISCO propietary protocol.
- 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 hex. value 8100 for an Ethernet frame.
- *Tag Control Information* (TCI): Contains several fields. The most important is the VLAN ID (12 bits), which identify the VLAN.

Unit 4. Local Area Networks, LANs

Outline

- Introduction
- IEEE LAN Architecture
- Random MAC Protocols
- Ethernet
- Ethernet Switches
- **Wireless LANs**

Unit 4. Local Area Networks, 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 …

802.11 APs

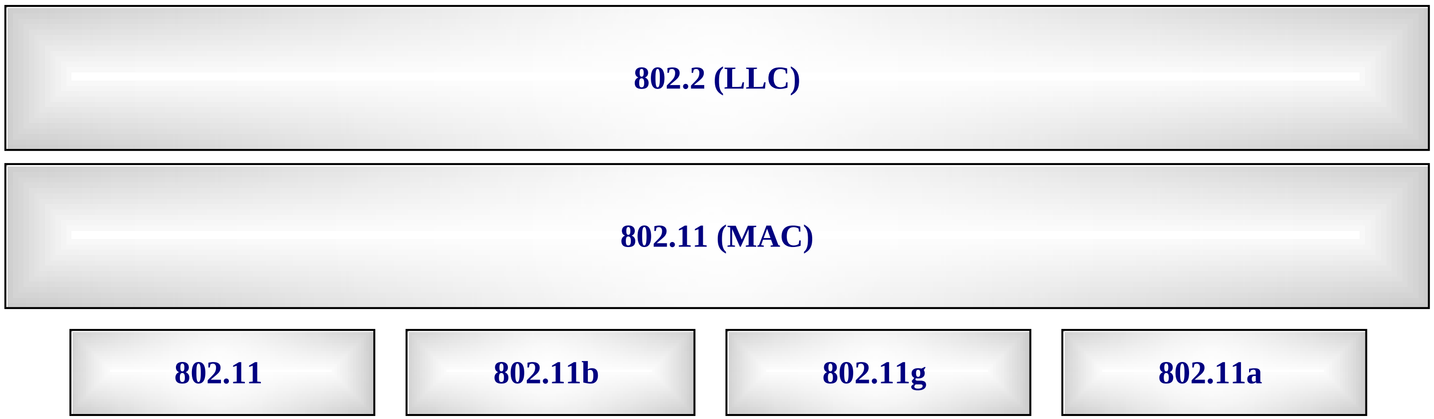
802.11 NICs

Home made antenna

802.11 Antennas

Unit 4. Local Area Networks, LANs

Wireless LANs (WLANs) – 802.11



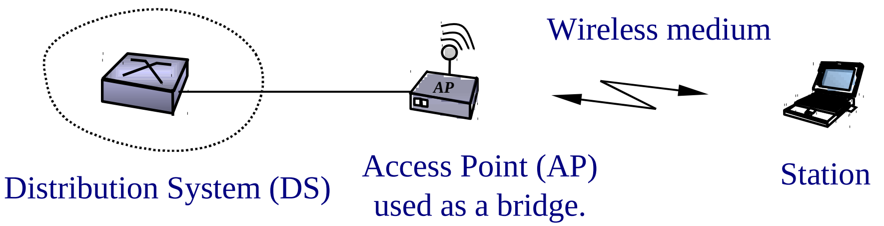
Standard	*Bitrate*	*ISM band*
802.11	1, 2 Mbps	2.4 GHz
802.11b	up to 11 Mbps	2.4 GHz
802.11a	up to 54 Mbps	5 GHz
802.11g	up to 54 Mbps	2.4 GHz

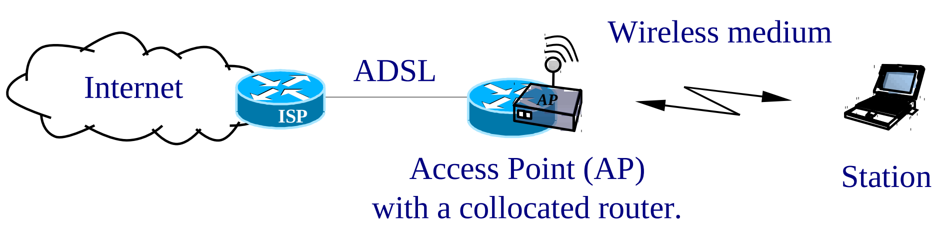
- ISM: Industrial Scientific and Medical. Free band for non commercial usage.

Unit 4. Local Area Networks, LANs

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.





Unit 4. Local Area Networks, LANs

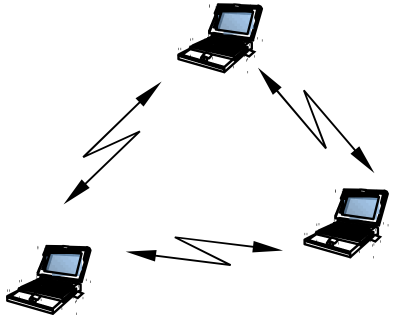
Wireless LANs (WLANs) – 802.11 Components

- 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).

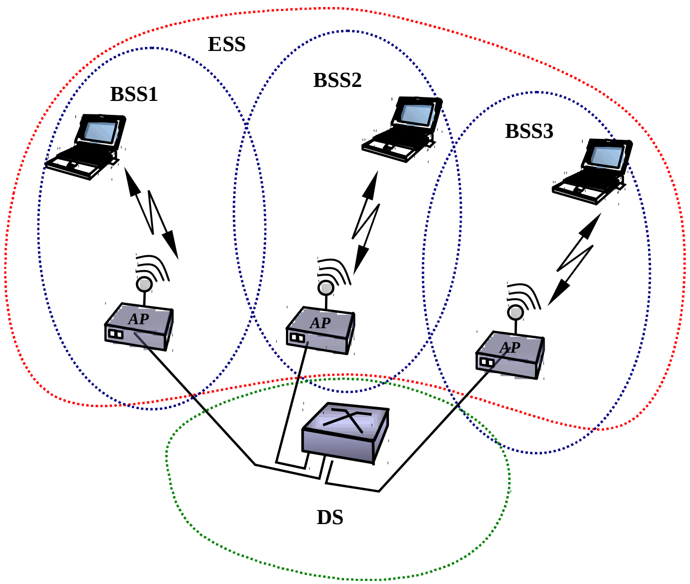
Unit 4. Local Area Networks, LANs

Wireless LANs (WLANs) – 802.11 Components

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

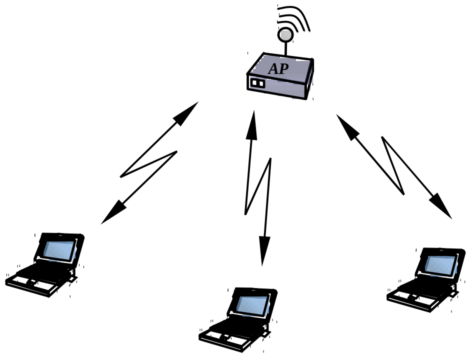


Extended Service Set (ESS)



Infrastructure BSS (*infrastructure mode*)

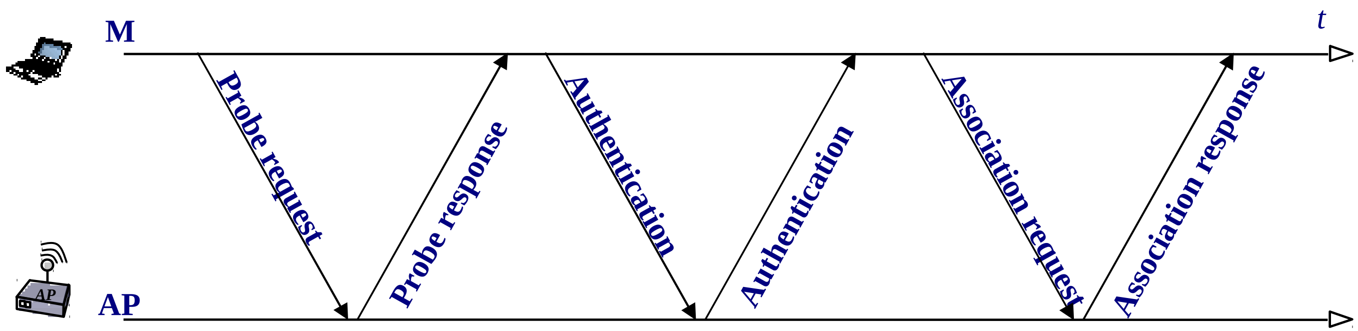
- An station must associate with an AP.
- All transmissions go through the APs.



Unit 4. Local Area Networks, LANs

802.11: Protocol description- Components

- Beacons
  - Special frames carrying information related to the BSS (e.g. the BSSID).
  - In infrastructure BSS are sent by the APs, in IBSS there is a contention algorithm for electing the station generating beacons.
  - BSSID are: (i) the MAC@ of the AP in infrastructure BSS, and (ii) the MAC@ of the station generating beacons in IBSS.
- AP Association:
  - Probe
  - Authentication
  - Association



Unit 4. Local Area Networks, LANs

802.11: Protocol description- Features

- Fragmentation
  - Optional mechanism to reduce the effect of Tx errors. If the frame size is larger than the threshold, it is fragmented into multiple frames.
- Power-saving mechanism
  - Optional mechanism to save battery: The AP sends periodically a TIM (Traffic Information MAP), informing which stations have buffered traffic. The stations wake up at the TIM Tx periods, and request the frames, if any.
- WEP (Wired Equivalent Privacy):
  - Frame payload is encrypted using a 64/128 key.

Unit 4. Local Area Networks, LANs

802.11: Protocol description- Frames

- Data frames
- Control frames: handle reliable transmission of data frames
  - ACK, RTS, CTS and polling
  - Typical time scales: Frame transmission time (<1ms)
- Management frames: communication between stations and APs
  - Beacons, association, Probe and authentication.
  - Typical time scales: 100 ms, minutes, hours,…

Unit 4. Local Area Networks, LANs

Wireless LANs (WLANs) – 802.11 Addresses

- Designed to be compatible with ethernet.
- 48 bits (6 bytes).
- Use ranges non overlapping with ethernet.
- Broadcast: FF:FF:FF:FF:FF:FF
- 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.
- When a station is searching for the BSS it uses the broadcast BSSID: FF:FF:FF:FF:FF:FF

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

Unit 4. Local Area Networks, LANs

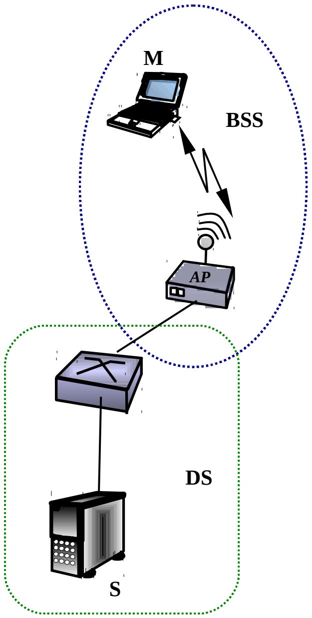
Wireless LANs (WLANs) – 802.11 Addresses

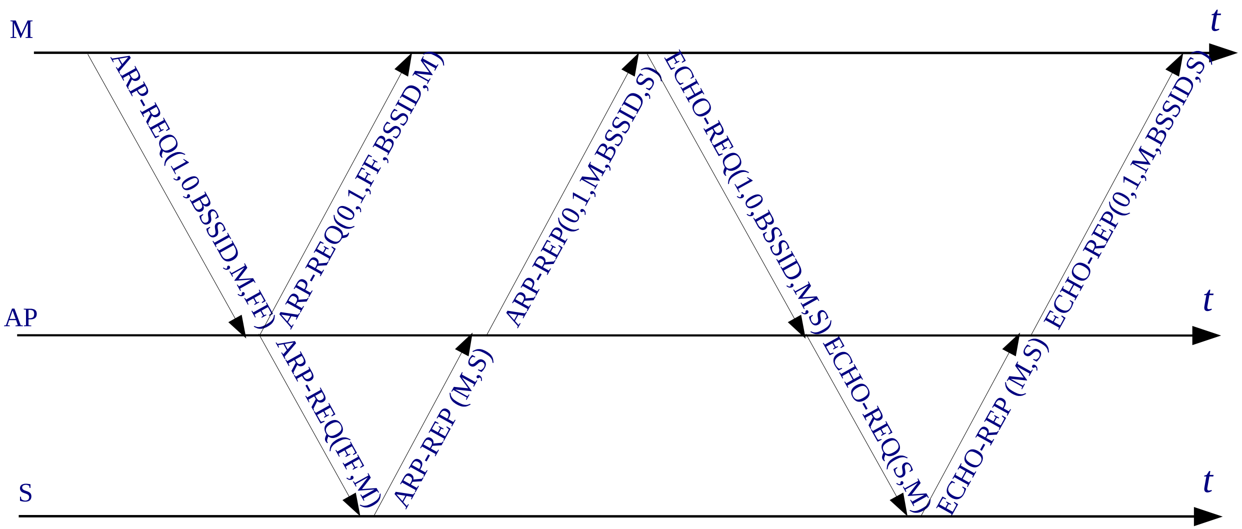
Scenario	Usage	to-DS	from-DS	Address1	Address2	Address3	Address4
STA→STA	Ad-hoc	0	0	DA	SA	BSSID	-
STA→AP	Infrastructure	1	0	BSSID	SA	DA	-
AP→STA	Infrastructure	0	1	DA	BSSID	SA	-
AP→AP	WDS	1	1	RA	TA	DA	SA

Legend: Destination Address (DA), Source Address (sA), Receiver Address (RA), Transmitter Address (TA)

Example:

`M# ping S`





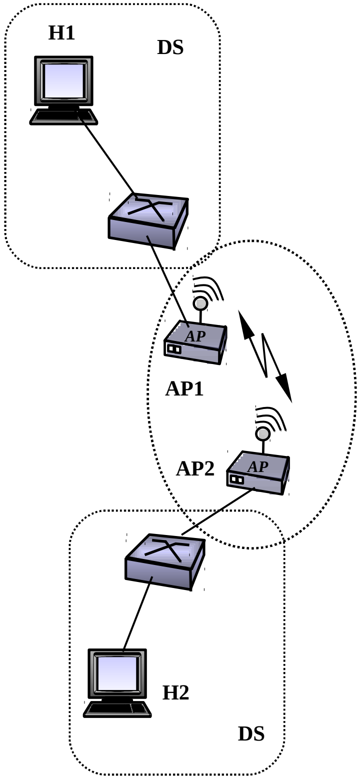
Legend, 802.11 frames:
MESSAGE-TYPE(to-DS, from-DS, Address1, Address2, Address3)
Legend, ethernet frames:
MESSAGE-TYPE(destination address, source address)
FF is the broadcast address

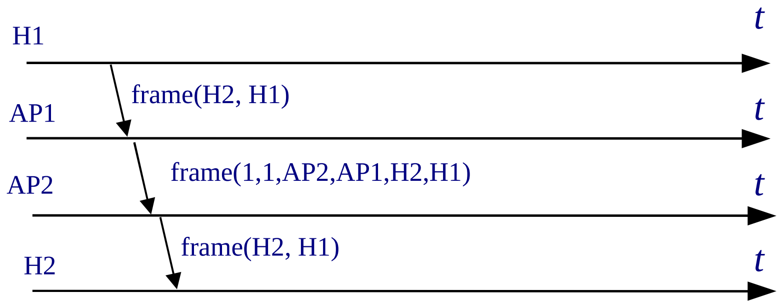
Unit 4. Local Area Networks, LANs

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)





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

Unit 4. Local Area Networks, LANs

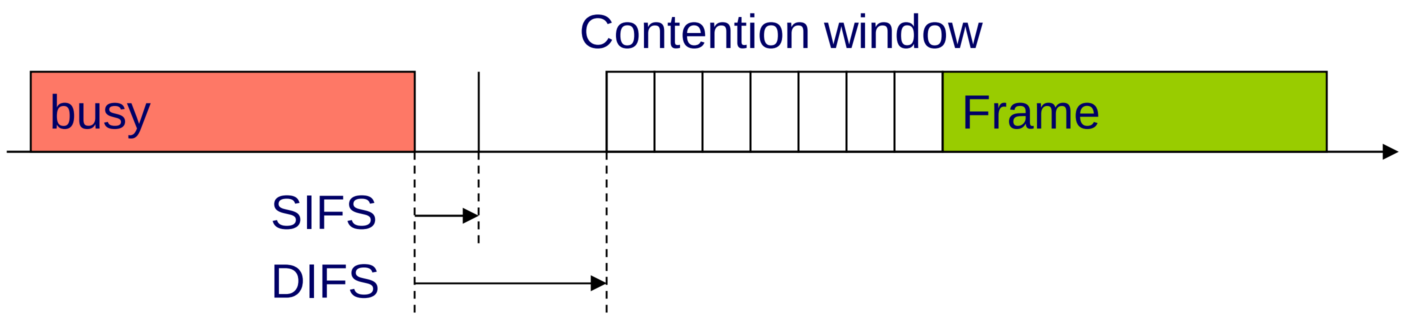
Wireless LANs (WLANs) – 802.11 MAC

Two Coordination Functions (CF) are defined:

- Distributed CF (DCF):
  - Contention MAC.
  - Best effort service
  - Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)
- Optional Point CF (PCF):
  - Contention free MAC built on top of DCF.
  - Centralized polling scheme. The AP poll each PCF station for Tx.
  - A contention free period (CFP) using PCF and a contention period (CP) using DCF follow each beacon.

Unit 4. Local Area Networks, LANs

Wireless LANs (WLANs) – Interframe Spaces



- *Short InterFrame Space (SIFS)*: Minimum time for highest priority transmissions: CTS, ACKs, and fragments.
- *DCF InterFrame Space (DIFS)*: e.g: Data frames, RTS, etc.

Unit 4. Local Area Networks, LANs

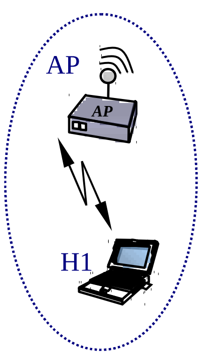
Wireless LANs (WLANs) – 802.11 DCF (CSMA/CA)

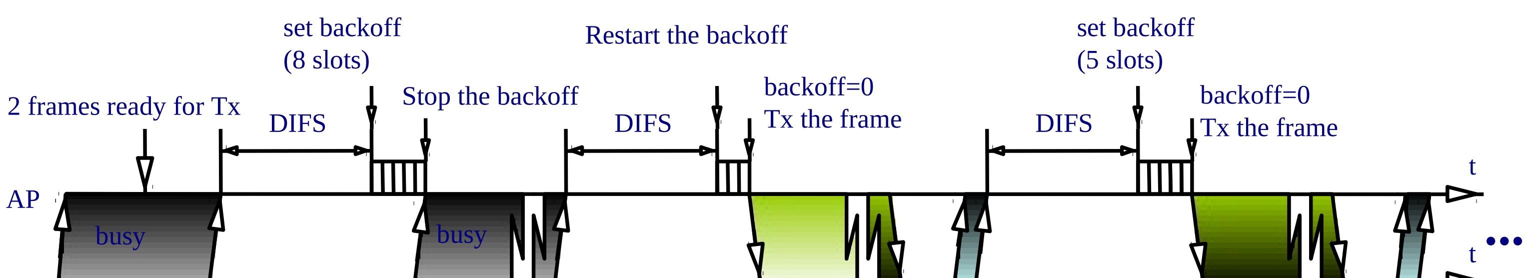
1 When a frame is ready for Tx, sense media. If not busy during a DIFS Tx, otherwise go to 2.

2 Set a backoff timer uniformly in [0..*CW*]. The backoff timer is decremented each slot time after sensing the channel idle during a DIFS. *CW* is called the Contention Window and is: $CW = \min(2^n - 1, CWmax)$.

3 Upon receiving a correct frame, send an ACK after a SIFS.

4 Upon receiving an ACK, if there are more frames, go to 2. If the ACK is not received, increase *n* and go to 2. If a maximum number of attempts is reached, the frame is discarded..





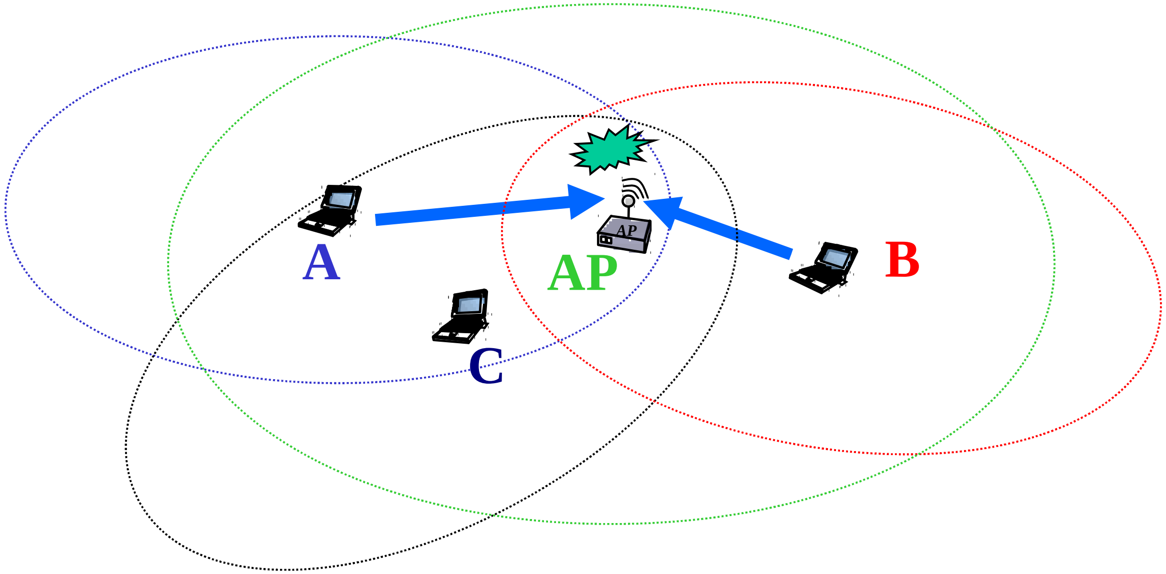
Legend:

- SIFS: Short InterFrame Space.
- DIFS: DCF InterFrame Space.

Unit 4. Local Area Networks, LANs

Wireless LANs (WLANs) – Hidden Node Problem

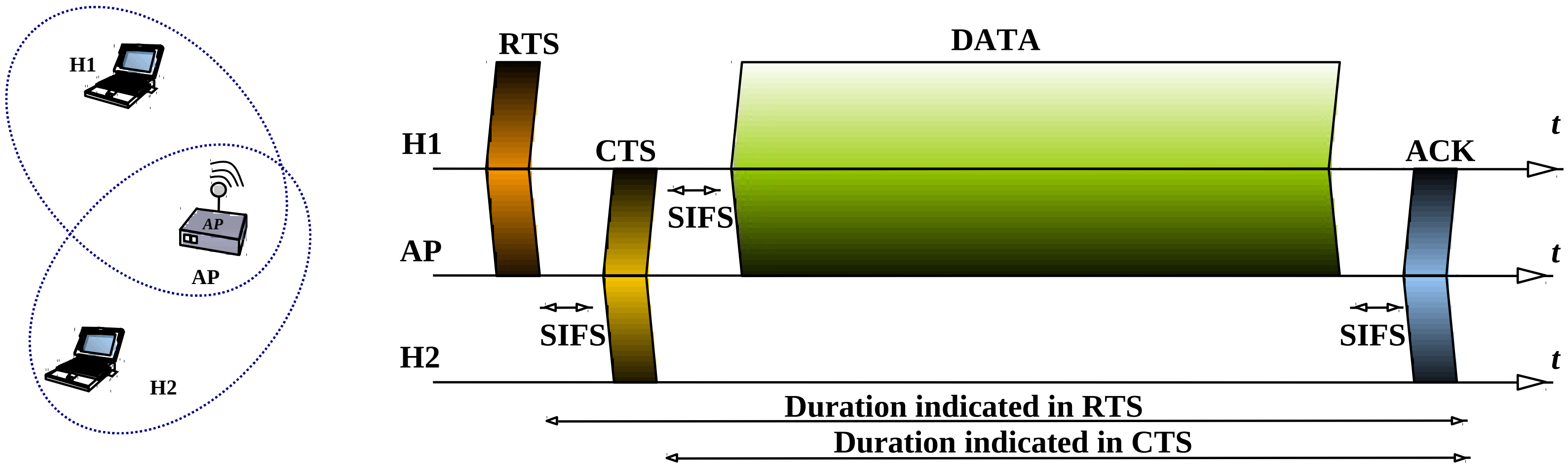
- Node A is in coverage with AP and C
- A and B cannot hear each other
- When A transmits to AP, B cannot detect the transmission using the carrier sense mechanism
- If B transmits, a collision will occur at AP



Unit 4. Local Area Networks, LANs

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.