Computer Networks

Grado en Ingeniería Informática

Departamento de
Tecnología Electrónica

Computer Networks
Lesson 5

The Data Link Layer

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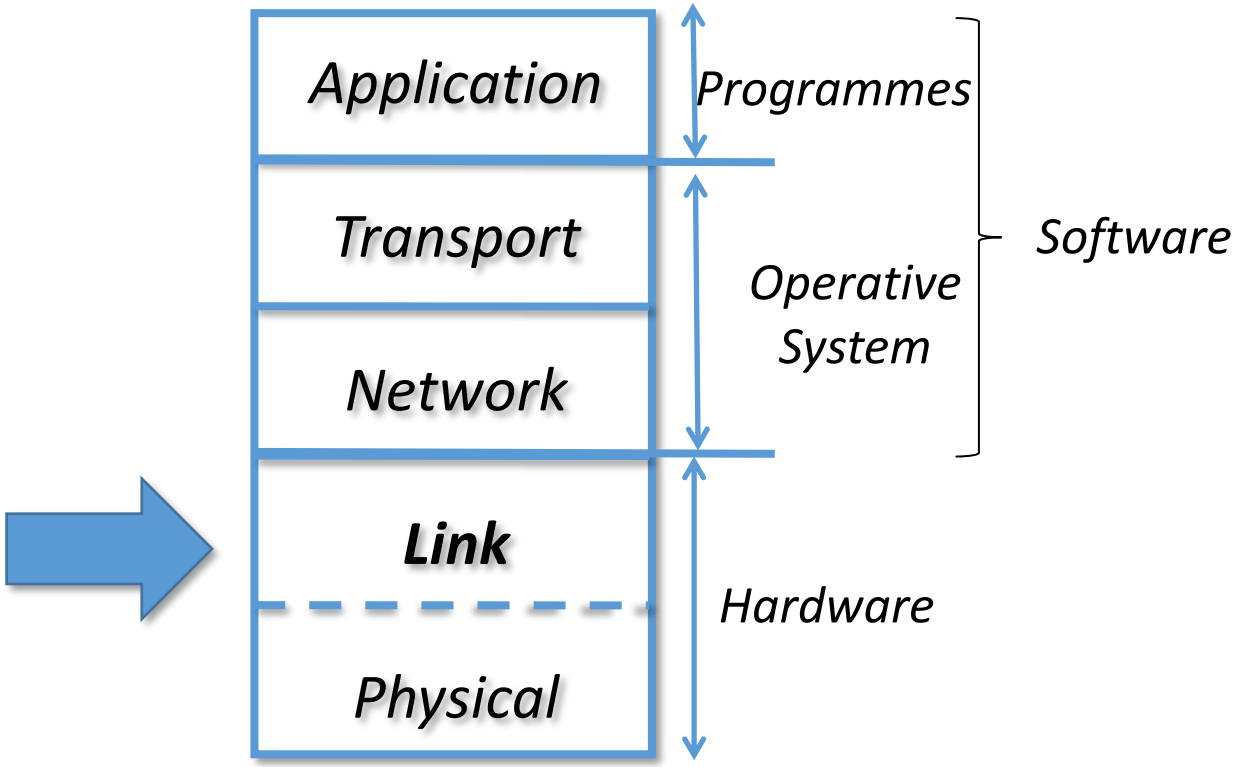
Tecnología Electrónica


Application
Transport
Network
Link
Physical
Programmes
Operative System
Software
Hardware

Tema 5: La Capa de Enlace de Datos

Objectives

- Understand the main services of the data link layer.
- Study an example of its implementation in local area networks (LAN): Ethernet.
-

Content

1. Introduction and services
2. Functions of the Data Link layer
3. Local Area Networks (LANs)
4. MAC Addresses
   - Ethernet (802.3)
   - Conmutadores (Switches)
5. ARP Protocol
6. Example

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Introduction and Services
Terminology

- Node: device that has a link layer (hosts, routers, switches,...).
- Communication channels that connect adjacent nodes through physical media are links.
  - Wired links
  - Wireless links.
- Links can be:
  - Point to Point: Two nodes connected by a single physical medium.
  - Multipoint: Multiple nodes connected by a single physical medium (shared media).
- The level 2 PDU (L_PDU) is the frame, which encapsulates L_UD (usually N_PDU, datagram).
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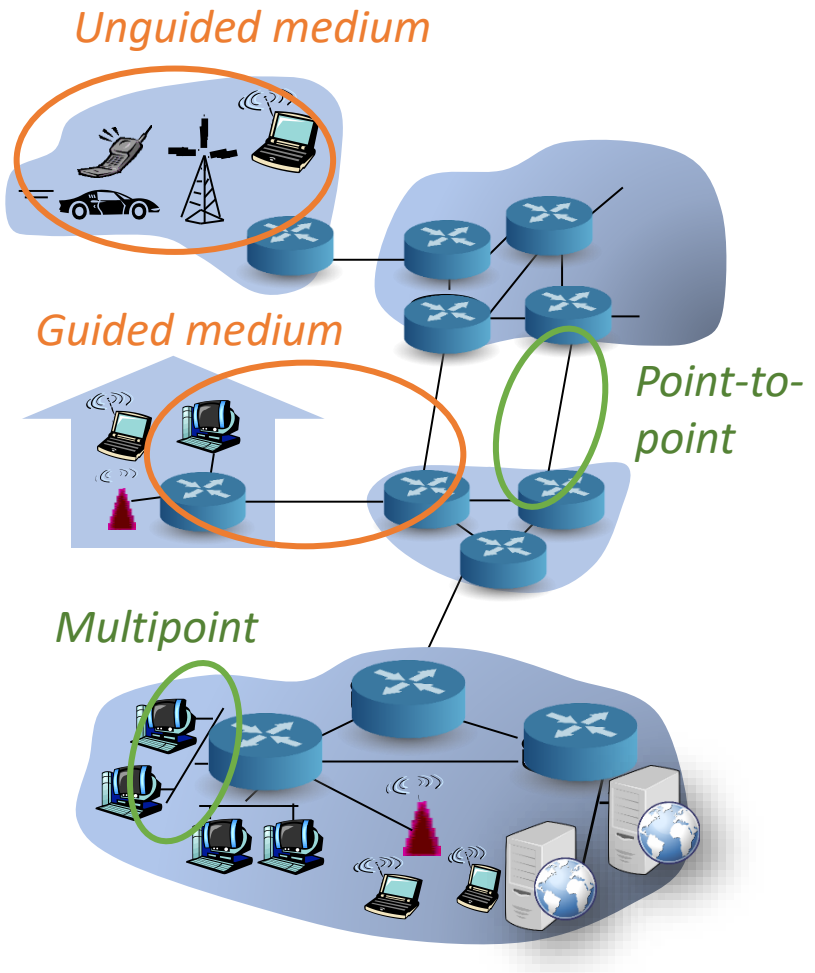
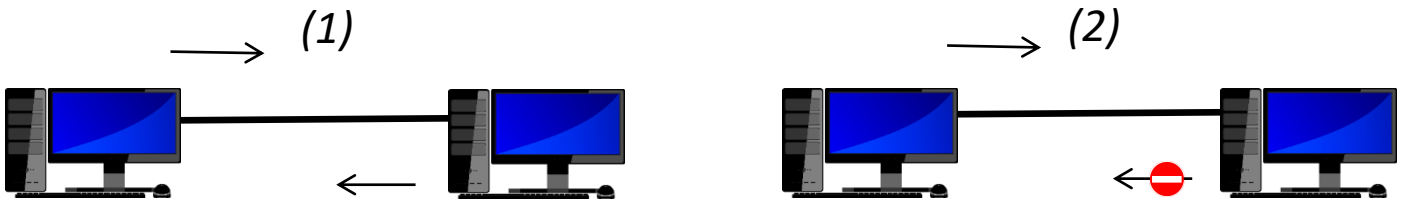


Data Link Layer Has the responsibility to transfer L_PDUs from one node to an adjacent node via a link

Introduction and Services
Link Layer: context

- The frames are transferred by different links using in each of them its own data link protocol:
  - Ex. A first Ethernet link, in between one Fast Ethernet and one final WI-FI.
- Each link layer provides different services.
  - Ex. May or may not provide reliable transfer of data over a link.
- The physical layer offers the data link layer an unreliable bit or byte send/receive service.
  - Sometimes it also reports the state of the physical medium: free medium (there are no transmitting nodes), occupied medium (there are transmitting nodes).
  - Depending on the physical level protocol and the physical medium used, it is possible that the data link level may be able to:
  - Send and receive bits or bytes simultaneously, known as full-duplex (1).
    - Only possible in point-to-point links.
    - Send and receive bits or bytes but not simultaneously, known as half-duplex (2).



Introduction and Services
Link Layer Services

- As the transport layer the data link layer can offer two types of services to its higher level:
  - reliable data delivery between adjacent nodes.
    - Works similarly to TCP with the mechanisms seen in lesson 3.
  - unreliable data delivery between adjacent nodes.
    - Works similarly to UDP
- Each link layer protocol offers one of these two types of service.
- Typically, it offers an unreliable data delivery service.
  - Most links have low error rate.
    - For example, fiber links or some types of twisted pair.
- In the case of high link error rate, the link level needs to implement the reliable data delivery service.
  - For example in wireless links.

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Data Link Layer Functions (I)

- Frame construction:
  - It encapsulates the L_UD in the L_PDU, adds L_PCI both in front, known as the header, and behind, known as the tail, of the L_UD.
- Frame syncronism:
  - Serves to distinguish where each L_PDU begins and ends within the stream of bits or bytes received at the data link level.
    - Each protocol defines the content of the L_PCI field that is used for this purpose.
      - For example: ASCII Code **STX** (**S**tart of **T**e**X**t) can be used to delimit the start and **ETX** (**E**nd of **T**e**X**t) for the end.
- Node identification (addressing):
  - Each node in the data binding must have a unique identifier that distinguishes it from other nodes.
    - Identifies the source and destination node of the L_PDU.
  - Dependent on technology.
  - Known as physical address.
    - For example MAC addresses
      - It is different from logical (IP) addresses!!!

Data Link Layer Functions (II)

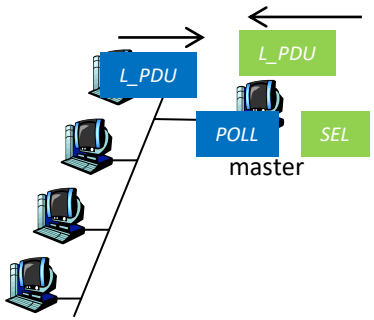
- Error detection:
  - Necessary due to errors caused by signal attenuation, noise... that cause L_PDUs to arrive damaged to the receiver.
  - It consists of adding additional bits of L_PCI to the L_PDU, known as redundant bits, in such a way that they allow to detect errors in some bits.
    - The transmitter calculates the value of these bits before sending the frame.
    - The receiver performs the same calculations to check if it matches the additional bits received.
  - No algorithm is 100% reliable.
    - Some errors will not be detected.
  - The most commonly used algorithm at the data link layer is the CRC (Cyclic Redundancy Check).
    - Technique based on the calculation of redundant bits by operations with binary polynomials.

Data Link Layer Functions (III)

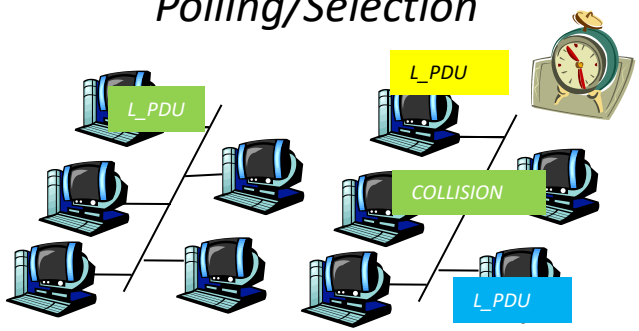
- Bug fixes:
  - Retransmission.
    - Mechanisms similar to those seen in lesson 3 are used.
  - The receiver locates and corrects the error(s) in the bit(s).
    - Typical uses: DTT, satellite video...
  - It is not always implemented.
- Flow control:
  - Regulates the rate of sending and receiving L_PDUs between adjacent nodes.
  - Not always implemented.

Data Link Layer Functions (IV)

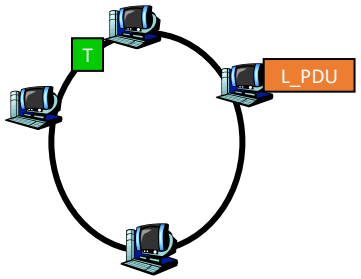
- Medium control access:
  - In the case of shared medium it is necessary to manage which node makes use of the link at all times.
  - It can be done:
    - **Centralized**: A node of the link, known as master is responsible for managing access to the environment of the rest of the nodes, known as slaves.
      - The Polling/Selection technique is used.
        - Poll sending L_PDU from slave to master.
        - Select sending L_PDU from master to slave.
    - **Distributed**: All the nodes of the link are coordinated to know at all times who has to transmit (make use of the link).
      - By content: A node makes use of the link if the physical level informs it that it is free. In case two or more nodes transmit a L_PDU almost at the same time a collision occurs. Each node tries again to transmit the L_PDU that has collided after a time that they choose randomly.
      - By circular rotation: Each node accesses the medium when it is its turn.



Polling/Selection



Content



Lesson 5: Data link layer

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LAN (Local Area Network) (I)

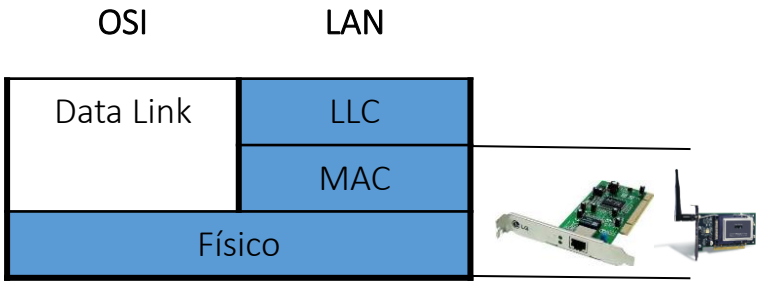
- Local area networks are the most widely used network technology.
- Allow to connect the final systems and routers within the broadcast domain.
- They implement, through the network interface, the two lower levels of the OSI model, the link and physical layer.

Note

The link level is subdivided into two sublevels:

- ***LLC** (Link Layer Control) . Performs flow control and error correction.*
- ***MAC** (Medium Access Control). It performs the functions of frame sync, error detection, media access control, and addressing.*

Up to the MAC sublevel is implemented in the network interface (network card, NIC).



LAN (Local Area Network) (II)

- IEEE (The Institute of Electrical and Electronics Engineers) it is responsible for standardizing LANs.
  - This allows different manufacturers to sell network interfaces, physical media, connectors,..., for the same LAN technology.
- The most commonly used LAN standards are:
  - The 802.3 family, known as Ethernet.
  - Guided physical medium.
    - Optical fiber or twisted pair.
  - The 802.11 family, known as WI-FI (WLAN, Wireless LAN).
    - Unguided physical medium.
      - 2.4 GHz and 5 GHz frequency band.

Local Area Networks (LAN)
MAC Addresses (I)

- They have a size of 48 bits.
  - Different notations are used to represent them, but they all group the 48 bits into bytes and each of those bytes are represented in hexadecimal:

    1B:03:F2:45:78:25

    F0.34.AB.23.45.12

    02DE0A.2343AC
- There are three types of MAC addresses:
  - **Unicast**: Used to send L_PDUs to a single destination.
    - All network interfaces have assigned one.
  - **Broadcast**: As a destination, it is used to send L_PDUs to all nodes in the broadcast domain (FF:FF:FF:FF:FF:FF).
  - **Multicast**: As a destination, it is used to send L_PDUs to a group of nodes in the broadcast domain.
    - Configurable. Have a 1 in the least significant bit of the first byte of the MAC address.

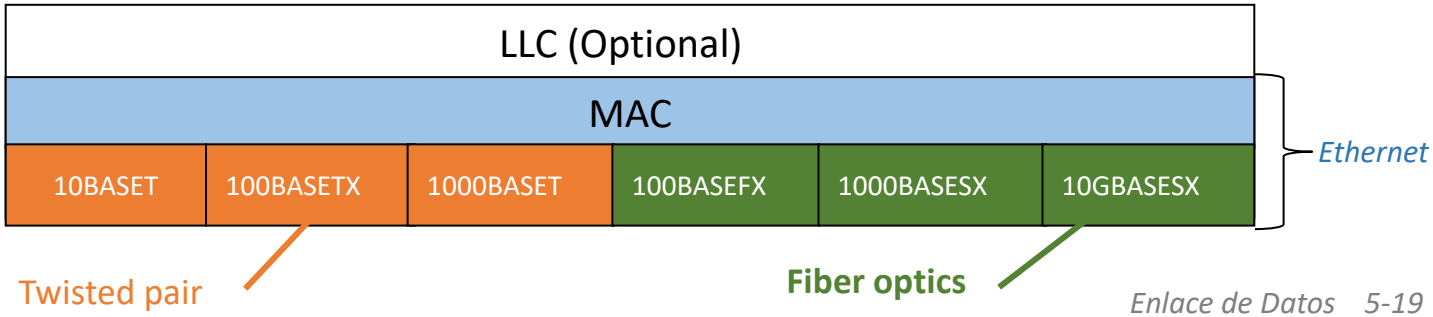
Local Area Networks (LANs)
MAC Addresses (II)

- IEEE manages the assignment of unicast MAC addresses that come from the factory.
  - Each manufacturer has assigned a portion of MAC addresses (to secure unique addresses).
  - it is possible to change the MAC address that comes from the factory.
- Analogy:
  - MAC address: ID of each person.
  - IP Address: Postal address.
- MAC: flat addressing → portability
  - We can move a network card from one LAN to another.
- IP: hierarchical addressing → NOT portable
- It depends on the IP network to which the node is connected.
- Example: the laptop that is used in class has a WI-FI interface that has a unique MAC, regardless of whether we connect to the IP network at home or the ETSII.

Local Area Networks (LANs)
Ethernet (802.3)

- It is the most successful LAN technology.
  - Easy to install.
  - Cheaper.
- Many different Ethernet standards.
  - In common the MAC sublevel.
    - Media Access Protocol.
      - Mechanism of contention.
    - Format of the MAC_PDU (frame).
  - Allows multipoint or point-to-point links.
  - Different physical level protocols:
    - Physical media: fiber, coaxial and twisted pair.
    - Different speeds (R): 2 Mbps, 10 Mbps, 100 Mbps, 1 Gbps, 10 Gbps.

Internet

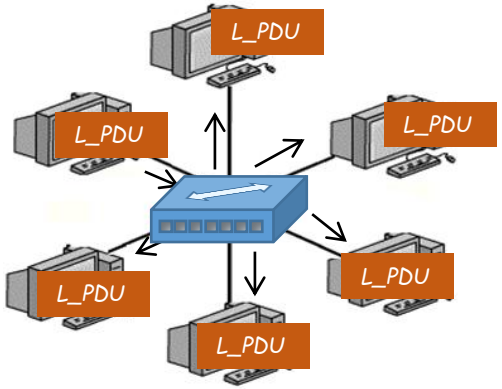


Local Area Networks (LANs)

Ethernet 802.3 - How do the nodes connect?

- Up to 100 Mbps you can have point-to-point (half-duplex or full-duplex) or multipoint links.
- Multipoint links use a physical-level device, known as a hub or hub.

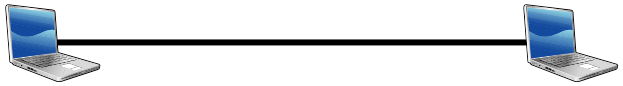
  - A hub allows everything that is sent by a network interface (node) to be received by the rest of the network interfaces.



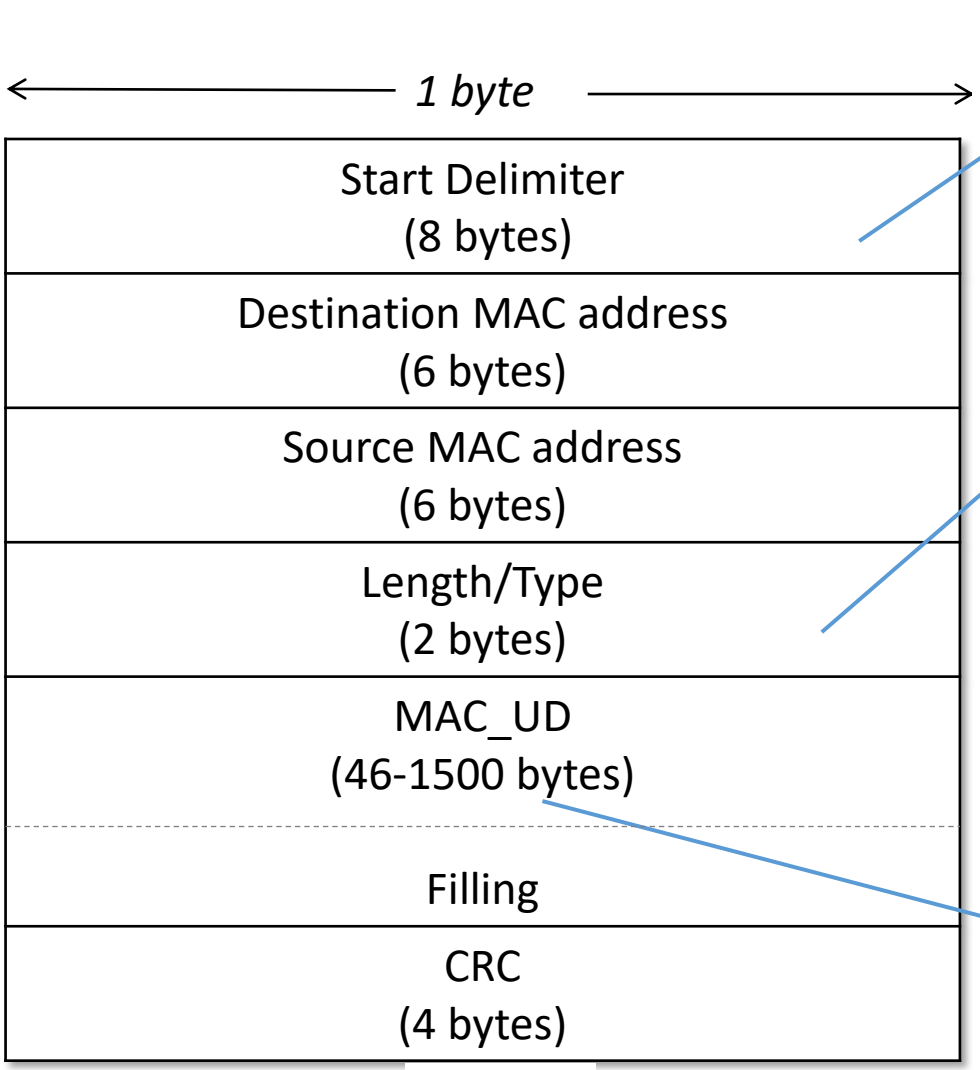
Note

If two or more nodes transmit almost simultaneously, a collision occurs

- From 1Gbps the links are point to point (half-duplex or full-duplex).
  - Only two network interfaces (nodes) in the link.
  - For example:



Local Area Networks (LAN)
Ethernet 802.3 – MAC_PDU (frame)



7 bytes 10101010.
1 byte (the last) 10101011.

- *Value less than or equal to 1500 meaning length:*
  - *- Indicates number of bytes of MAC_UD*
  - *- There is sublevel LLC.*
- *Value greater than or equal to 1536 type meaning:*
  - *Multiplexing and demultiplexing*

Top level data, usually IP, ARP or LLC.
If the number of bytes in MAC_UD is less than 46, it is filled with bytes of 0.

Nota

La MTU de Ethernet es **1500 bytes**

Local Area Networks (LAN)
Ethernet 802.3 – Basic operation

- Transmission: A node once it has a MAC_PDU to be sent, if the physical level is...
  - …half-duplex, check that the link is free, if yes it sends bit by bit all the bits of the MAC_PDU, if not, it waits for it to be free.
  - If collisions occur, try to transmit it after a random time.
    - …full-duplex, sends bit by bit all the bits of the MAC_PDU.
  - Reception: A node once it receives a MAC_PDU check if it is the destination of the same, if yes, it will process the MAC_PDU, deencapsuling it, in another case, it will discard it.
  - If it receives an erroneous MAC_PDU discards it and does not notify the transmitter.
  - Ethernet offers an unreliable delivery service, so it does not require connection establishment (operation similar to IP and UDP).

Local Area Networks (LAN)
Switches

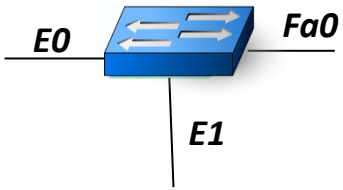
- A LAN switch, also known as LAN bridge allows LANs that use the same or different MAC sublevel to be transparently interconnected (the physical level does not have to match either).
- For example: Connect a WLAN (WIFI) with Ethernet. This type of switch is known as an access point.
- The operation of these devices is described in the IEEE 802.1d standard, "Media Access Control Bridges", MAC Bridges.

Switch

Bridge

Local Area Networks (LAN)
Switches – Features

- A switch consists of a set of network interfaces, each of the same or different LAN technology.
- The interfaces of a switch are identified similarly to routers.



Note

E = Ethernet, R:10 Mbps
Fa = Fast Ethernet, R:100 Mbps.
Gi = Gigabit Ethernet, R:1Gbps.

- Each interface of a switch is a distinct link that can be point-to-point or multipoint, known as a collision or bandwidth domain..
- In case of multipoint or point-to-point half-duplex link, access to the medium will be controlled by the MAC protocol of the LAN technology used in that interface.

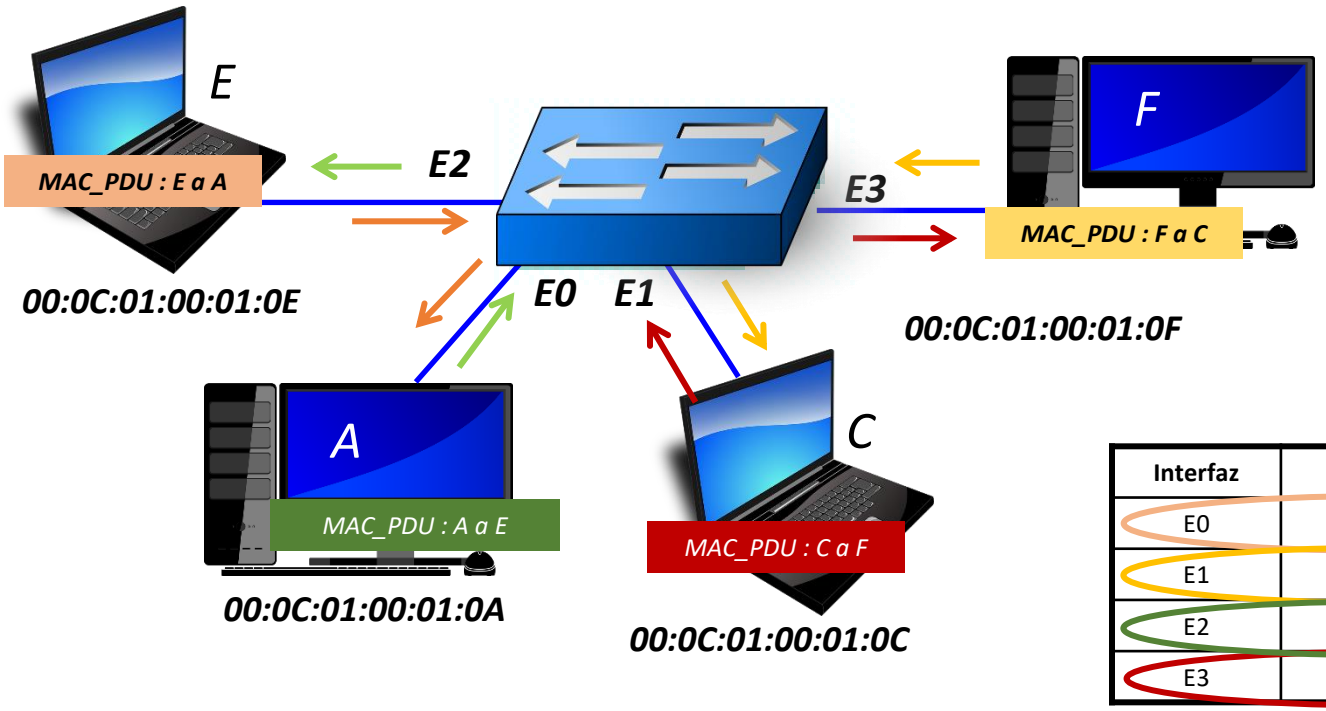
Local Area Networks (LAN)
Switches – Operation (I)

- A switch will process all the MAC_PDU it receives through one of its interfaces to:
  - Learn the location of the source node of the MAC_PDU.
  - Forward the MAC_PDU, if applicable, through an interface other than that of the source.
    - **It doesn't work like a HUB.**
  - Known as a storage and forwarding device
- A switch maintains a table known as a MAC address table or switching table where it records the location of the different nodes that are in the broadcast domain and queries it to see whether or not it should forward a MAC_PDU received by an interface.

Local Area Networks (LANs)
Switches – Operation (II)

- Each entry in the switching table contains:
  - Interface.
  - MAC address.
  - Time stamp.
- How do I populate the switching table?
  - Manually.
    - It's not usual.
  - Dynamically.
  - Learning from the MAC_PDUs that the switch receives for each of its interfaces.
  - **It doesn't work like a router.**
  - **Entries** are kept for a while.

Local Area Networks (LANs)
Switches – Operation (III)



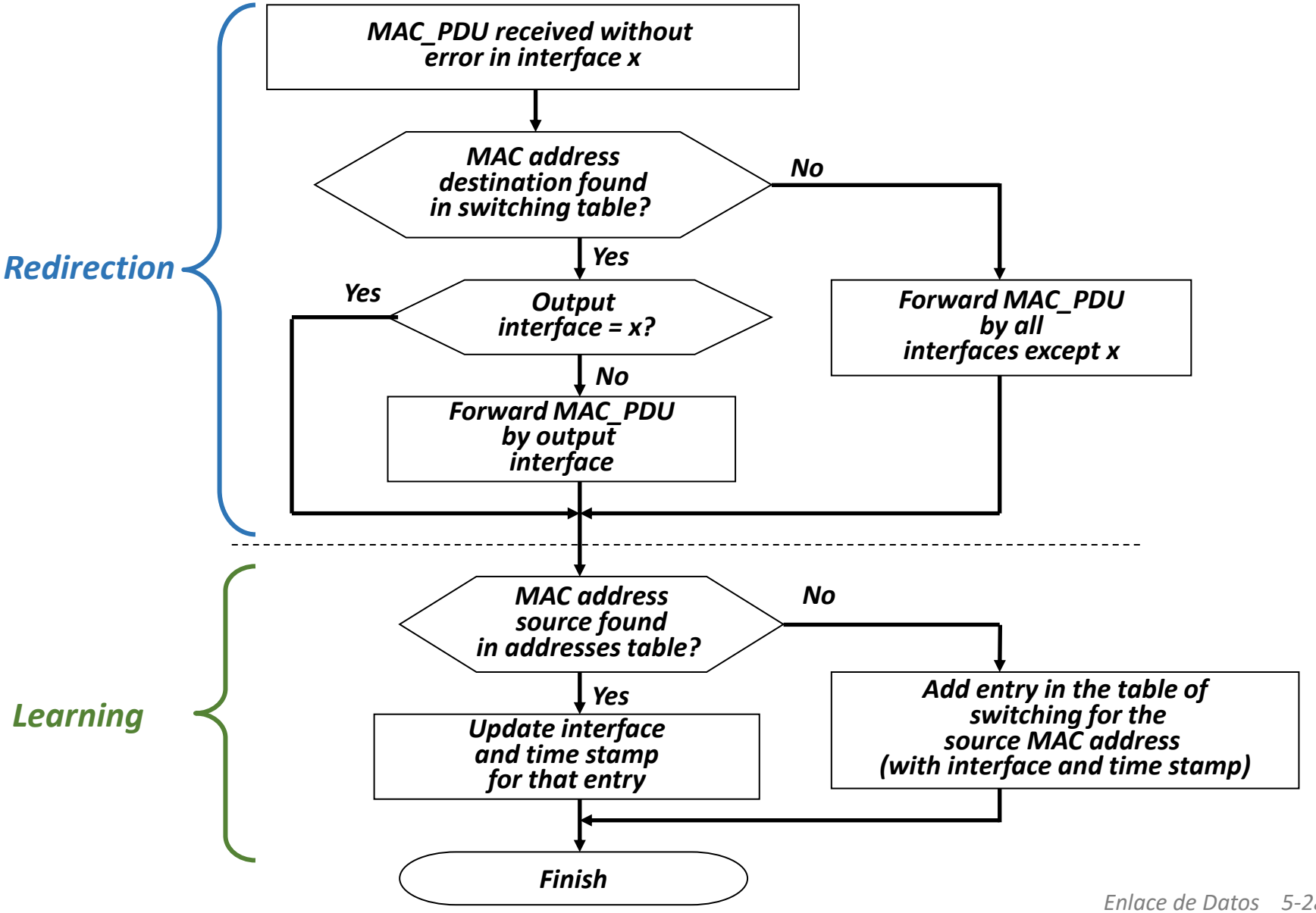
Interfaz	MAC
E0	00:0C:01:00:01:0A
E1	00:0C:01:00:01:0C
E2	00:0C:01:00:01:0E
E3	00:0C:01:00:01:0F

Nota

A switch, just like a router, ...
... it requires buffers to store both the MAC_PDU that arrive through an interface before processing them, and the MAC_PDUs before being sent by an interface.
... introduces delays.

Local Area Networks (LANs)

Switches – Operation (IV)



Local Area Networks (LAN)
Switches – Example (I)

a) How many bandwidth domains are there?

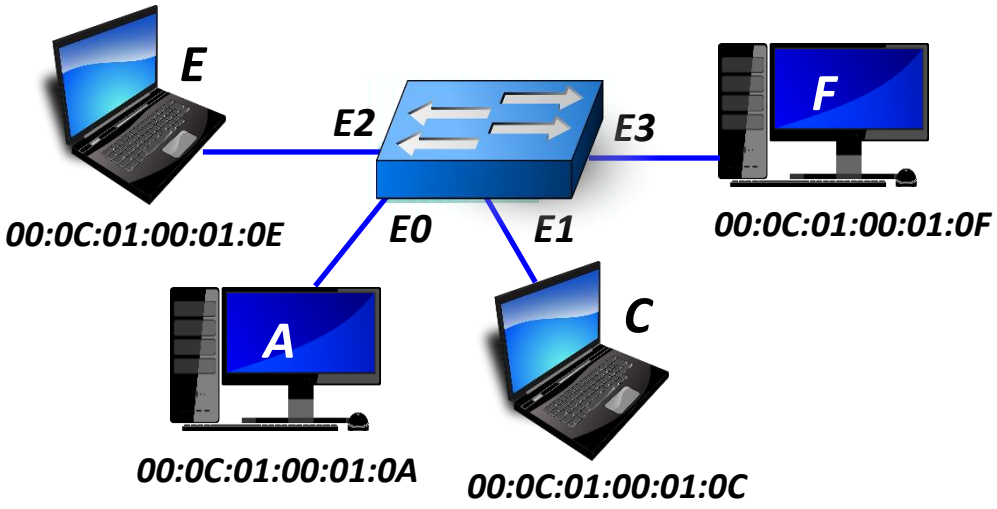
b) F sends a MAC_PDU to A. Who receives and processes it?

c) A minute later C sends MAC_PDU to F. Who receives and processes it?

d) Two minutes later F sends a MAC_PDU to the MAC broadcast. Who receives and processes it?

e) How many broadcast domains are there?

Interface	MAC	Time



Local Area Networks (LAN)

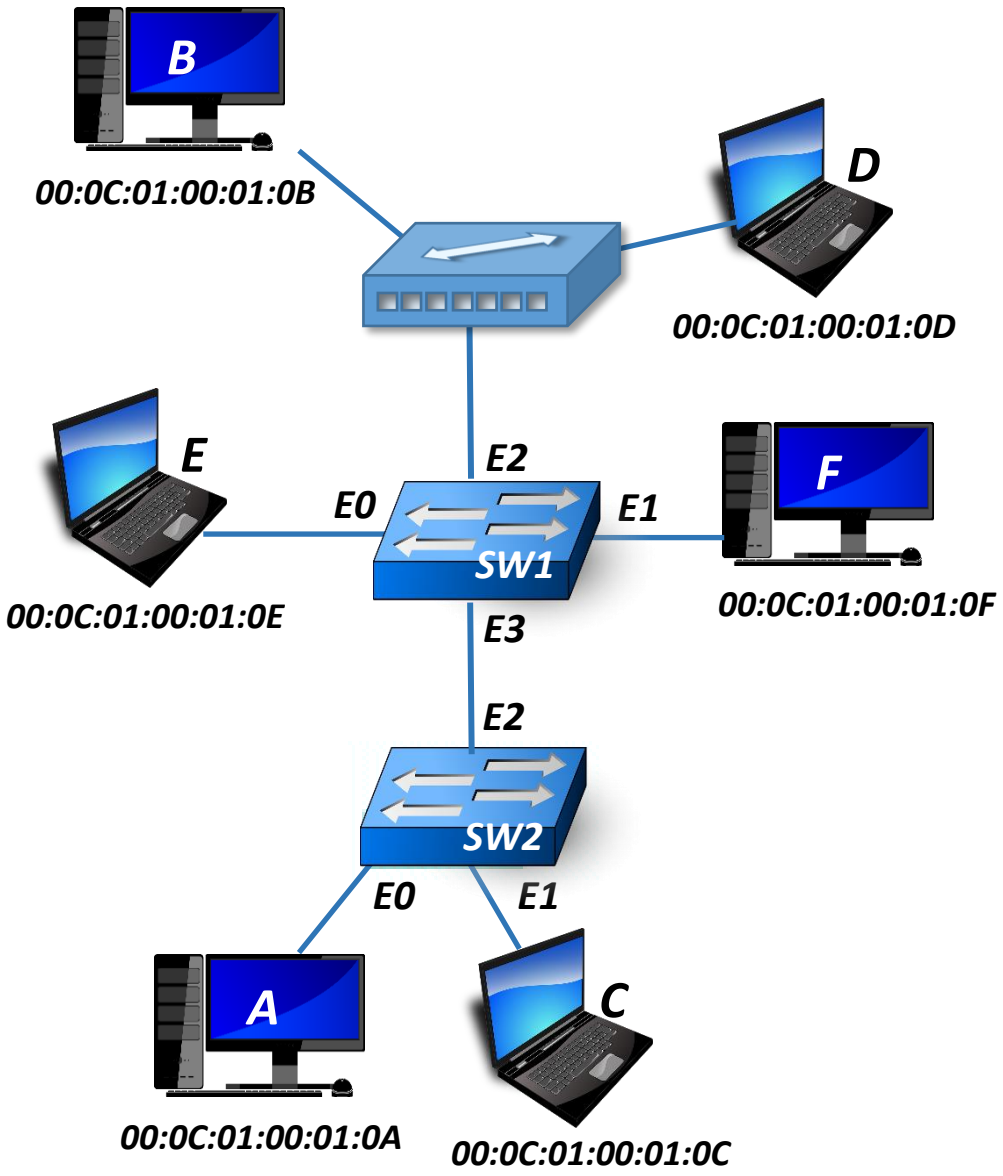
Switches – Example (II)

a) How many bandwidth domains are there?
b) Who sent the last MAC_PDU? to whom?
c) F sends a MAC_PDU to B. Who receives and processes it?

Switch 1		
Interface	**MAC**	**TIME**
E2	**00:0C:01:00:01:0B**	4

d) A minute later D sends MAC_PDU to C. Who receives and processes it?
e) Three minutes later E sends a MAC_PDU to the MAC broadcast. Who receives and processes it?
f) How many broadcast domains are there?

Switch 2		
Interface	**MAC**	**TIME**
E1	**00:0C:01:00:01:0C**	5
E0	**00:0C:01:00:01:0A**	1



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6. Example

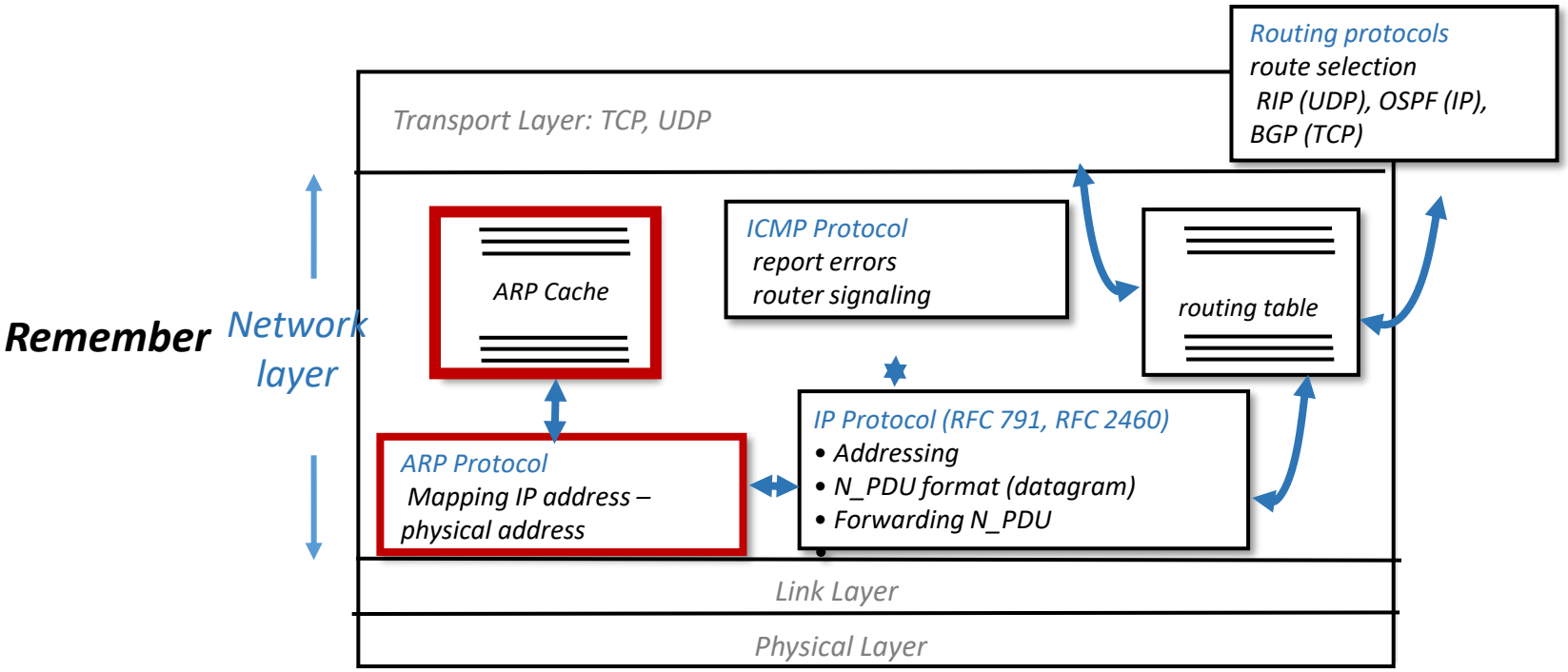
ARP Protocol
Introduction

- The data link layer in order to create and deliver the L_PDU to its destination requires the network layer to indicate the destination node of the network, that is, the value that the physical destination address field of the L_PCI.
  - For LANs the destination MAC address.
- The network layer is indicated by using a field in the L_ICI of the L_IDU that delivers to the link layer.
- IP only knows the IP address of the destination or the IP of the next hop.

Protocolo ARP

How does IP discover the physical address?

- Using the services of an Internet network layer protocol: The ARP (Address Resolution Protocol). RFC 826.



- ARP also uses link-level services.

ARP Protocol
ARP Cache (I)

- Each Internet network layer device maintains a table, known as arp cache, that maps the physical layer address (for example, the MAC address) of the device that has a specific IP address configured.
- ARP can both query and modify the contents of this table.
- The ARP cache table contains three entries:
  - IP address.
  - Physical address.
  - Time stamp. (We will ignore it)

Example arp cache	
IP address	**MAC Address**
193.1.1.25	00:0C:01:00:01:0A
193.1.1.12	00:0C:01:00:01:0C

ARP Protocol
ARP Cache (II)

How the ARP cache is populated?

Manually.

- Static inputs.
- Unusual.

Dynamically:

- Using the ARP protocol.
  - ARP when it learns the physical address associated with an IP address.
- Entries are deleted from the cache after a while.
- Each query in a cache entry updates its times stamp to the maximum value.

ARP Protocol

Basic ARP operation (I)

When the IP protocol on an internet-layered device prompts ARP for the physical address associated with an IP the SRP protocol queries the arp cache:

- In the event that there is entry for that IP address, it communicate IP the associated physical address.
  - Updates the time stamp of that entry to the maximum value.
- In case it does not exist, then,
  - sets in motion a mechanism, known as a question/answer, to discover the physical address associated with the IP address consulted by the IP protocol.
    - Both the device whose ip was not known, destination, and the source modify its arp cache.
      - the destination updates or includes a new entry in the arp cache for the source device.
      - the source includes a new entry in the arp cache.

ARP Protocol

Basic operation ARP (II)

Question:

- Sends a ARP_PDU, known as ARP Request, to inquire about the IP address requested by IP and report its own IP address and physical address to the respondent.
    - Must be received by all Internet-tier devices in the broadcast domain.
        - ARP when requesting services at the link level to send this ARP_PDU indicated in the L_ICI of the L_IDU that the destination physical address is broadcast.

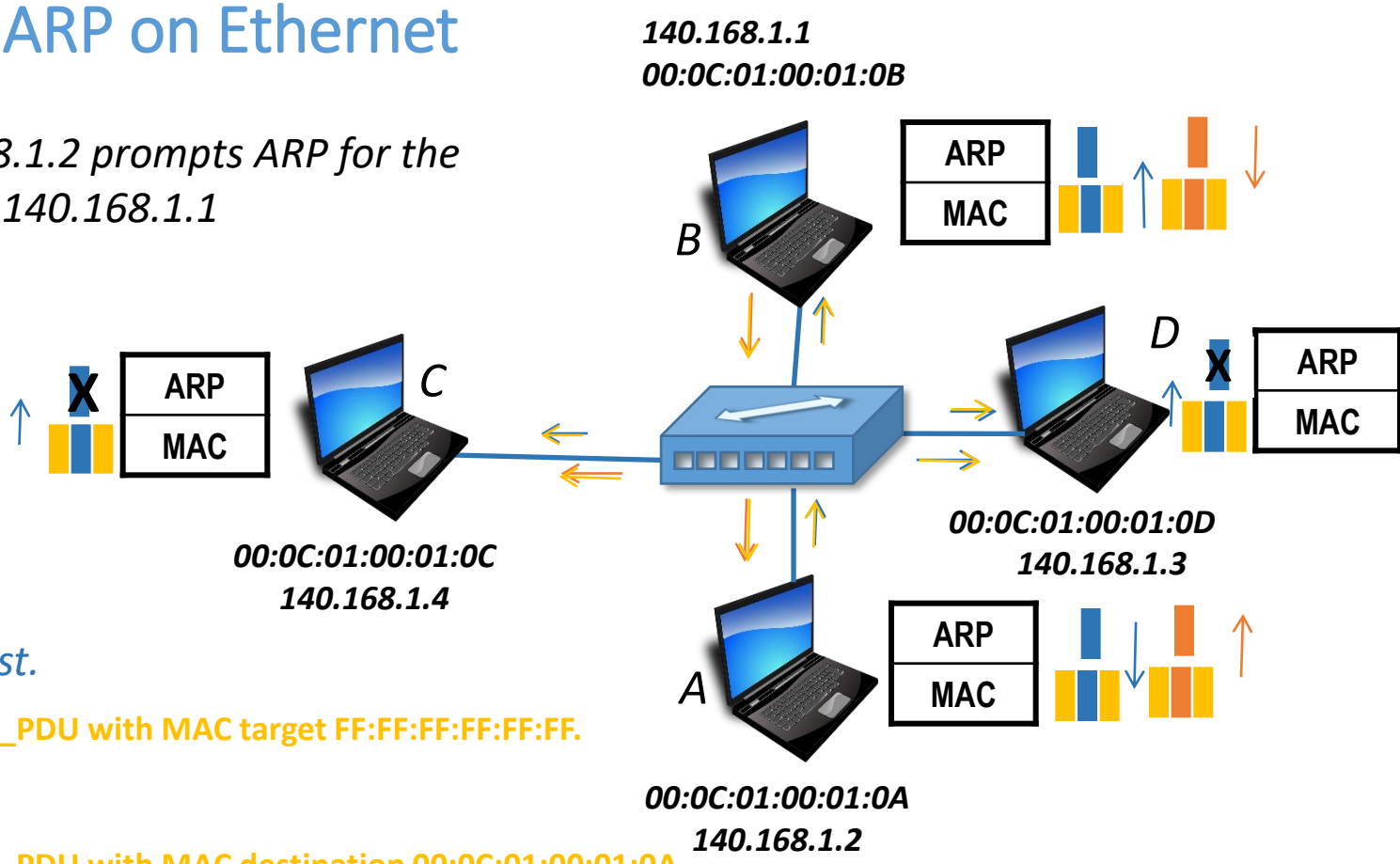
Answer:

- The device in the broadcast domain whose IP address matches the requested one responds with a ARP_PDU, known as ARP Reply to report its IP and physical address.
    - It should be received only by the device that sent the ARP Request.
        - arp when requesting services at the link level to send this ARP_PDU indicate in the L_ICI of the L_IDU that the destination physical address is the one you just added to your arp cache .

Protocolo ARP

Example, ARP on Ethernet

IP on PC 140.168.1.2 prompts ARP for the MAC address of 140.168.1.1



1.- ARP_PDU request.

Encapsulated in MAC_PDU with MAC target FF:FF:FF:FF:FF:FF.

2.- ARP_PDU reply.

Encapsulated in MAC_PDU with MAC destination 00:0C:01:00:01:0A.

arp cache A	
IP address	MAC Address
140.168.1.1	*00:0C:01:00:01:0B*

arp cache B	
IP address	MAC Address
140.168.1.2	*00:0C:01:00:01:0A*