Local Area Networks (LAN)

-

Introduction to Switching, IPv4 and Routing

Fundamentos de Redes

Mestrado Integrado em
Engenharia de Computadores e Telemática
DETI-UA

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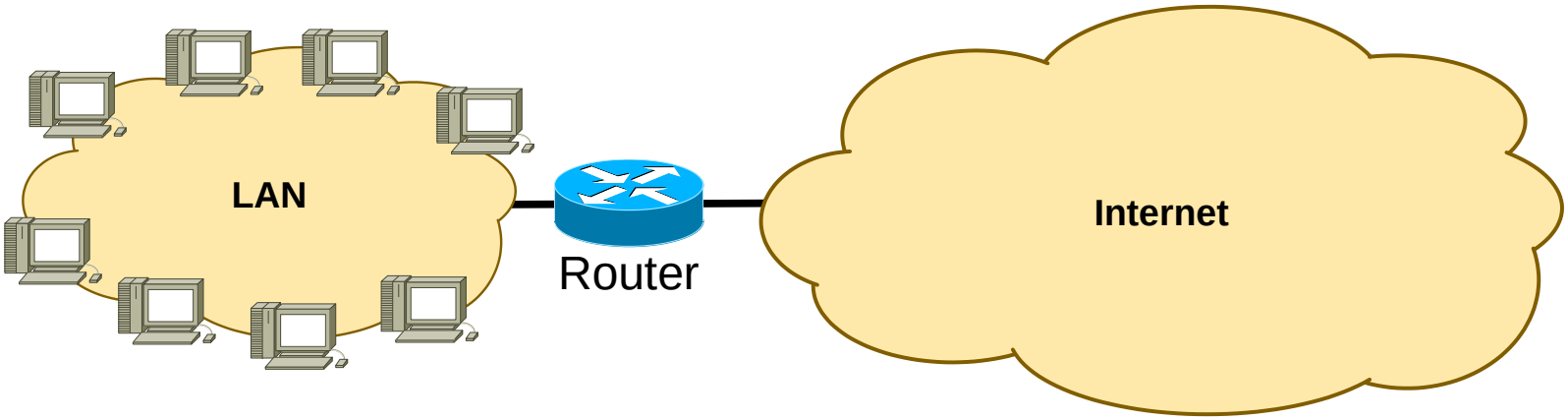
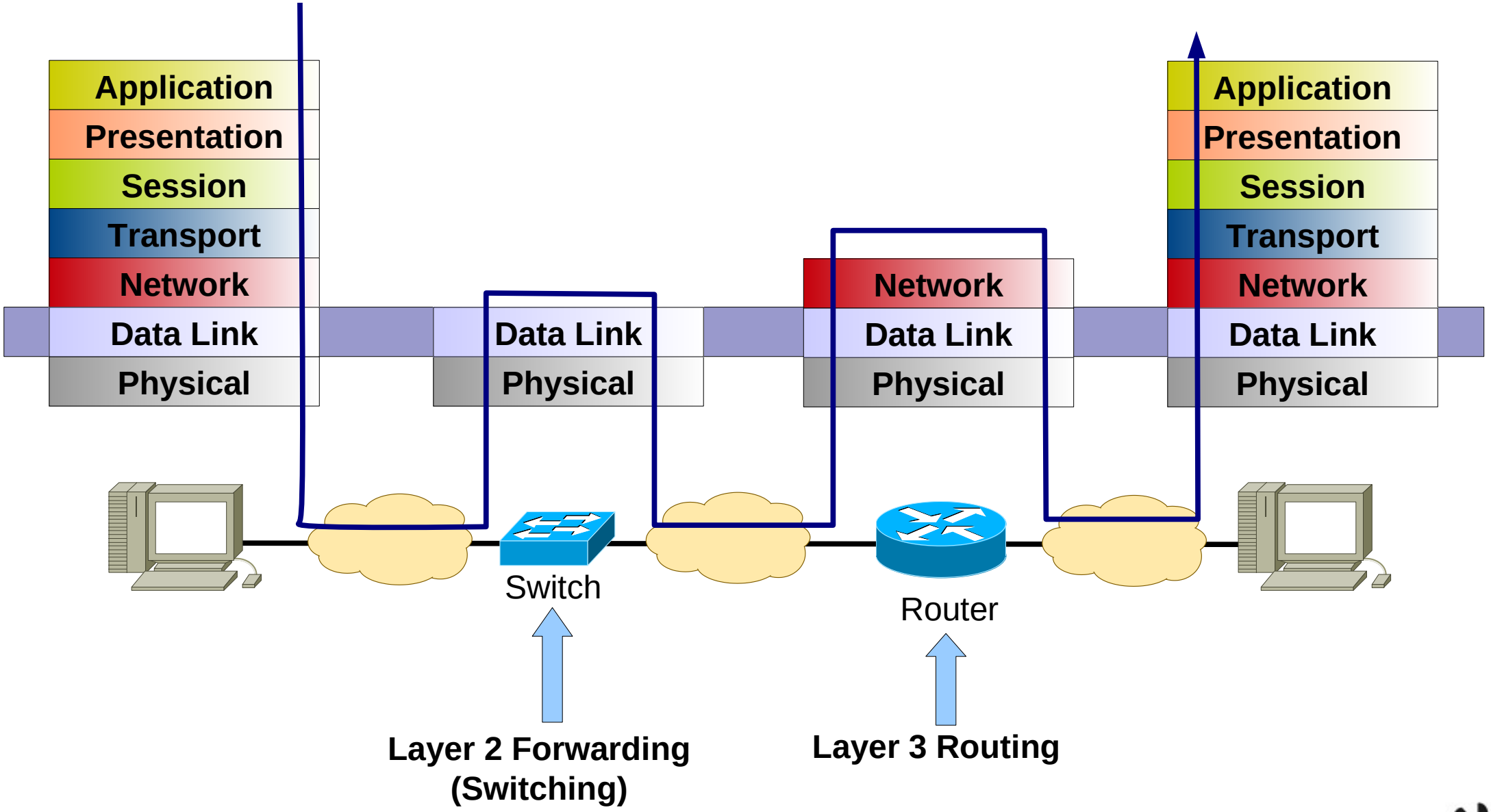
Local Area Network (LAN)

- Is a computer network within a small geographical area.
  - Home, school, room, office building or group of buildings.
- Is composed of inter-connected hosts capable of accessing and sharing data, network resources and Internet access.
  - Host refers generically to a PC, server, or any other terminal.
- Technologies
  - Current: Ethernet, 802.11 (Wi-Fi)

    Legacy: Token Ring, FDDI, …

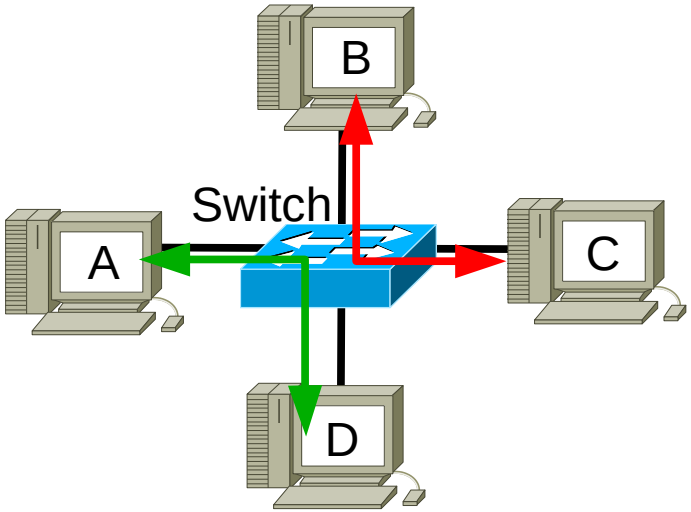


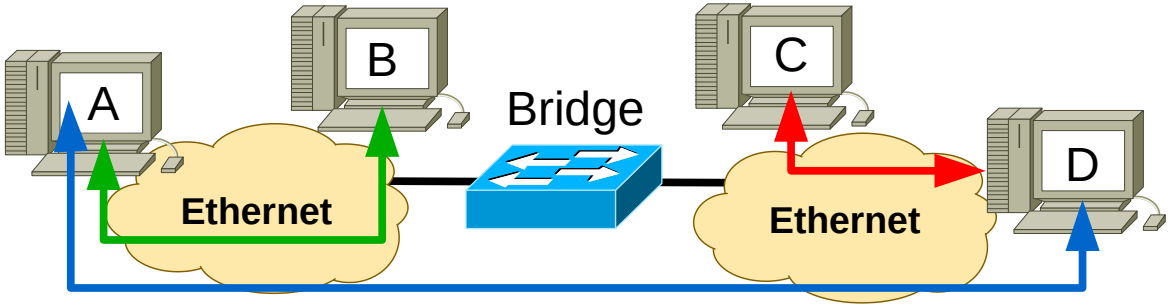
Local Area Network (LAN)



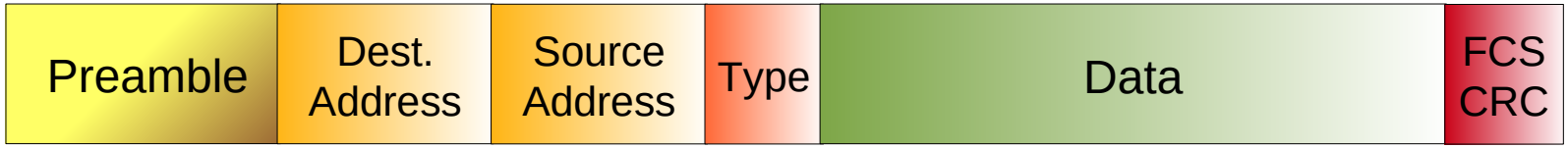
Switching

- With Switches/Bridges
  - Interconnection done at OSI Layer 2.
  - Hosts can transmit simultaneously.
  - A network of Switches is a **Broadcast Domain**
    - An Ethernet frame with destination FF:FF:FF:FF:FF:FF (Broadcast) will reach all connected switches and hosts.





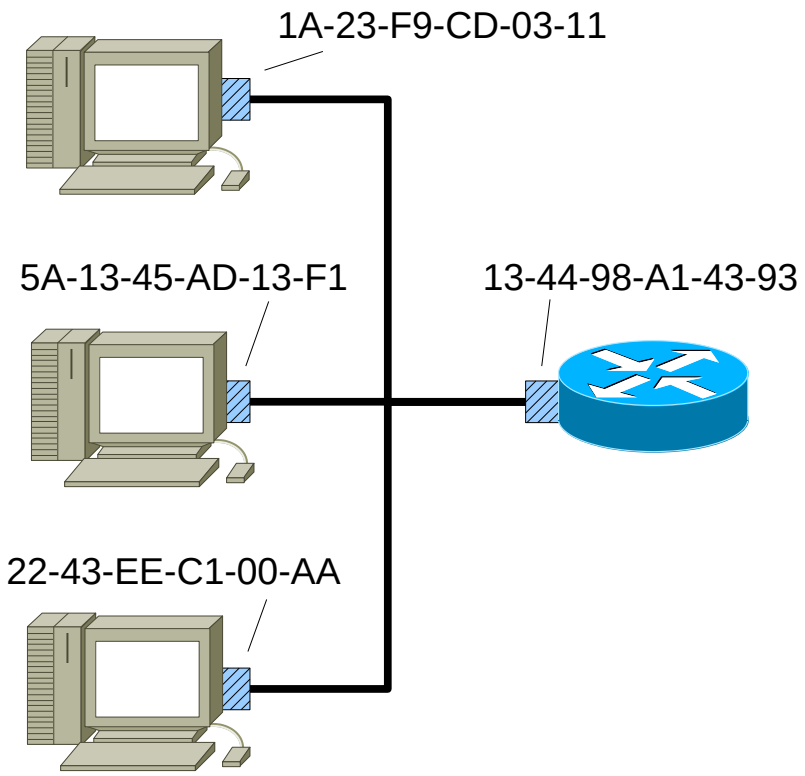
Ethernet Frame



- The sender's network card encapsulates an IP datagrama (or any other network protocol) in an Ethernet frame.
- Preamble:
  - 7 bytes with pattern 10101010 followed by one byte with pattern10101011.
  - Used to sincronize the sending and receiving clocks.
- Destination and Source addresses: 6 bytes Physical (MAC) address
  - If the network card receives a frame with destination equal to its own address or its the broadcast address, it will pass data to the network level process.
  - If not, drops the frame.
- Type defines which protocol is encapsulated in the frame (usually IPv4 or IPV6).
- The frame check sequence (FCS) is a four-octet cyclic redundancy check (CRC) that allows detection of corrupted data within the entire frame as received on the receiver side.

MAC Addresses

- MAC (Physical, Ethernet or LAN) Address:
  - Function: Allow the exchange of data between network interfaces connected using a Layer 2 network.
  - Have 6 bytes/48 bits.
  - Are unique.
  - Each network card has its own address.
  - Defined by manufacturer
    - Some hardware allows change.
    - First 24-, 28-, or 36-bits assign to manufacturer.
  - Hexadecimal notation
    - Broadcast: FF-FF-FF-FF-FF-FF



Ethernet Frame Minimum Size

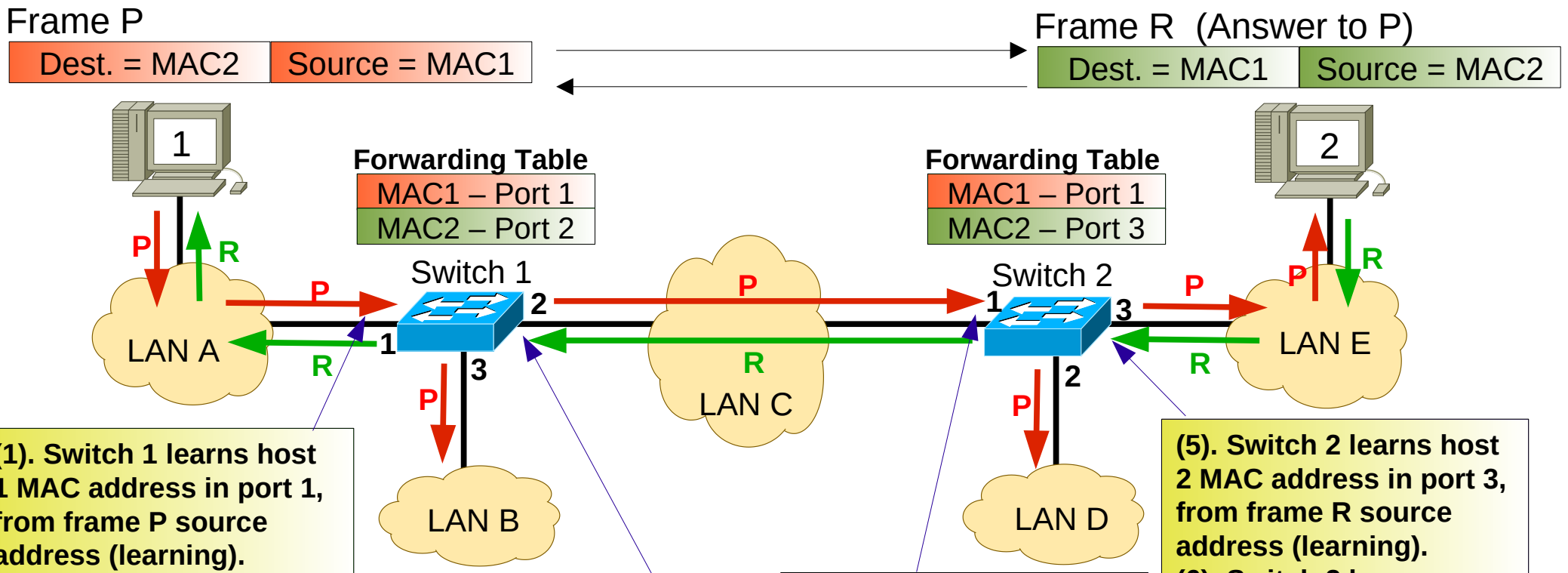
- Historically there were Ethernet technologies that allowed collisions and a collision detection mechanism had to be present (CSMA/CD).
- Depending on the technology and maximum cable size, the Ethernet frame had to be big enough to allow the collision detection mechanism to detect a frame being transmitted before the last frame byte leaving the source host.
- By legacy (it is possible to merge different Ethernet technologies) the **minimum frame size is 64 bytes**.
- If the frame's header plus data do not reach 64 bytes, a set of zeros must be added to the end of the frame to reach 64 bytes.
  - This is called **padding**.

Switches Basic Operations

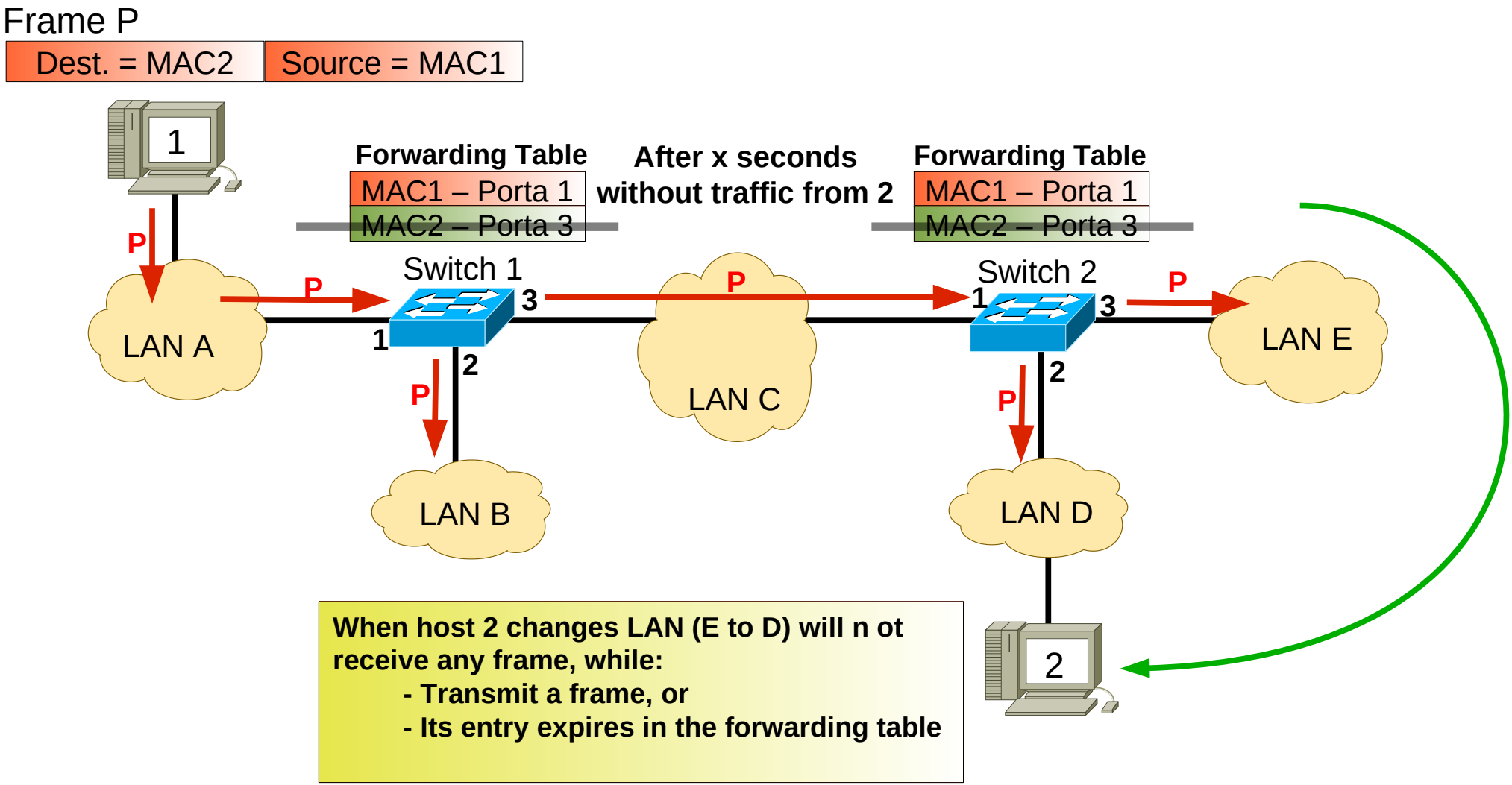
MAC	Porta
00:11:11:11:11:11	1
00:22:22:22:22:22	1
A1:33:33:33:33:33	2
44:44:44:44:44:44	3
55:55:55:00:00:55	3

- Switches have a **Forwarding Table**.
- When a switch receives an Ethernet frame:
  - Registers an entry at the Forwarding Table the frame's source MAC address and the port where the frame was received.
    - If no frames are received from that MAC address after some time (**aging time**) the entry is removed.
  - Searches the Forwarding Table for the frame's destination MAC address and forwards the packet according:
    - **Forwarding** mechanism:
      - If the frame's destination MAC address exists in the table, the switches forwards the frame through the port associated with that MAC address.
    - **Flooding** mechanism:
      - If the frame's destination MAC address DOES NOT exist in the table, the switches forwards the frame through all active ports (except the one where it was received).
        - » Note: Just within the same VLAN (more details later).

Learning, Flooding and Forwarding

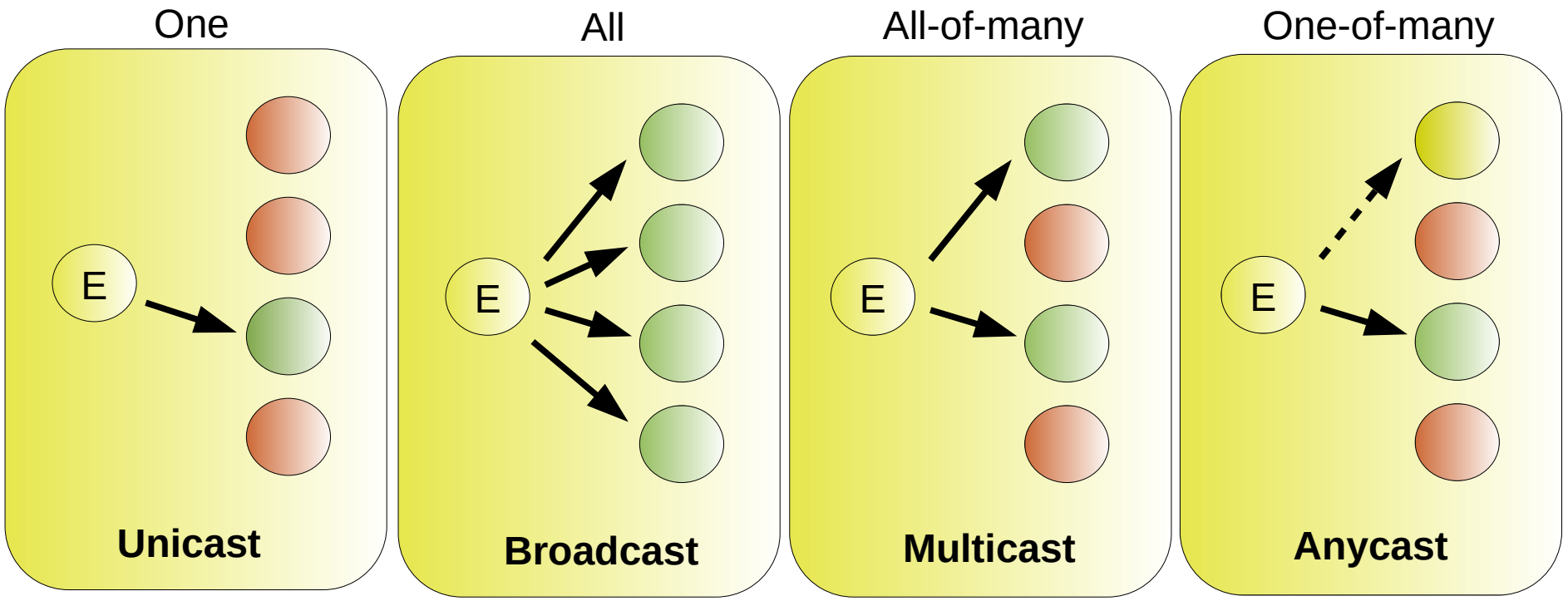


Forwarding Table Aging Time



Types of Addresses

- Unicast – Identify a single sender/receiver.
- Broadcast – All are receivers.
- Multicast – Identify all elements of a group as receivers (all-of-many)
- Anycast – Identifies any element of group as receiver (one-of-many)



IPv4 Addressing

- An IPv4 address is a unique address for a network interface
- Exceptions:
  - Dynamically assigned IPv4 addresses (DHCP)
  - IP addresses in private networks (NAT)

- An IPv4 address:
  - is a **32 bit long** identifier
  - encodes a network number (**network prefix**)
    and a **host identifier**

Network Prefix and Host Identifier

- The network prefix identifies a network and the host identifier identifies a specific host (actually, interface on the network).

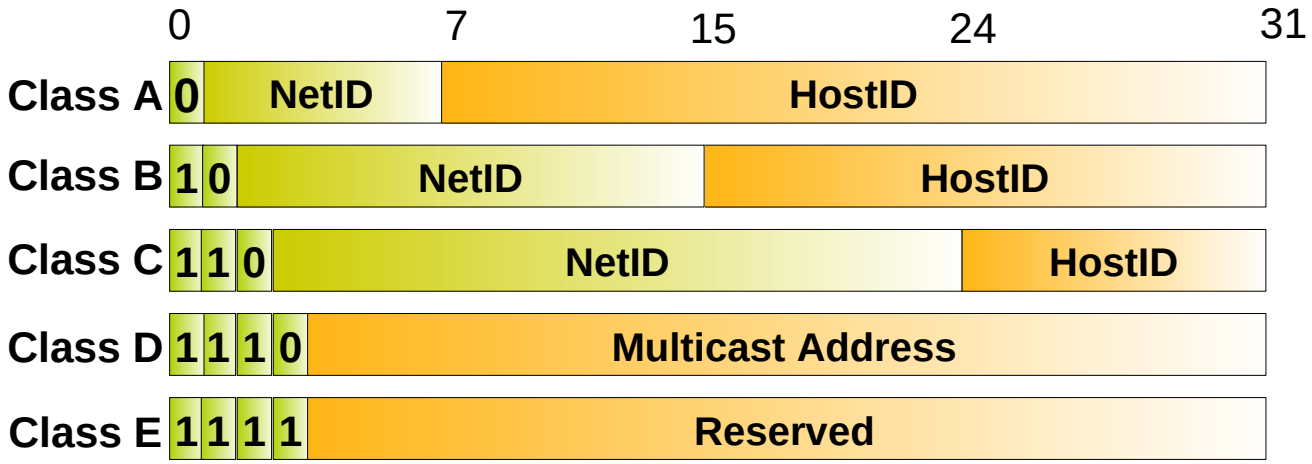
- How do we know how long the network prefix is?
  - **Before 1993:** The boundary between network prefix and host identifier is implicitly defined (**class-based/classful addressing**)

  or

  - **After 1993:** The boundary between network prefix and host identifier is indicated by a **netmask.**

IPv4 Classful Addressing

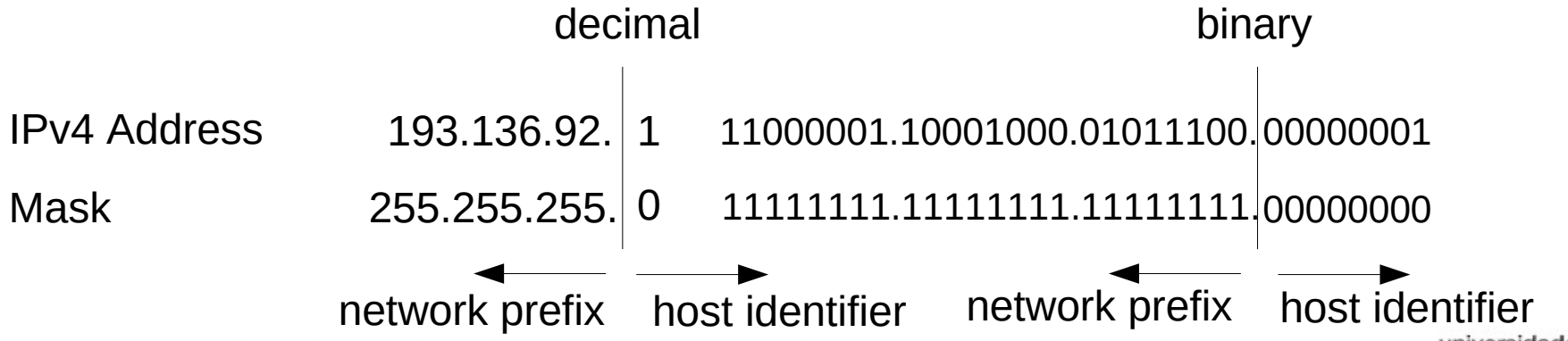
- Initially (until 1993) the boundary between the network prefix and host identifier was predefined by the value of the first byte (class).
- Resulted in a huge waste of addresses:
  - Classes A and B were to big,
  - Not enough class C networks.
- Routing Tables were becoming very long
  - It was not possible to merge (aggregate) networks to simplify routing tables.



Class	First Address	Last Address
A	1.0.0.0	126.0.0.0
B	128.0.0.0	191.255.0.0
C	192.0.0.0	223.255.255.0
D	224.0.0.0	239.255.255.255
E	240.0.0.0	255.255.255.254

Classless Inter-Domain Routing (CIDR)

- New interpretation of the IP addressing to increase efficiency and flexibility.
  - Network Masks were created to define the boundary between the IP network prefix and host identifier.
  - A bit of the mask equal to one indicate that that bit (in that position) of the address belongs to the network prefix.
    - A bit of the mask equal to zero indicate that that bit (in that position) of the address belongs to the host identifier.
  - Called VLSM (Variable Length Subnet Mask).
  - Must be provided with the IP address.
- Allowed the partition of a network in smaller networks or sub-networks (subnets).
- Allowed to merge several network under a single prefix (aggregation or summary process).



Mask Notations

- There are two notations for IPv4 masks:
  - Decimal: 4 bytes separated by dots.
  - CIDR: A slash (/) a a number with the number of bits of the network prefix.
- Both notations still exist today.
  - CIDR starts to become prevalent.
  - IPv6 only supports CIDR.

CIDR	Decimal
/21	255.255.248.0
/20	255.255.240.0
/19	255.255.224.0
/18	255.255.192.0
/17	255.255.128.0
/16	255.255.0.0
/15	255.248.0.0
/14	255.240.0.0
/13	255.224.0.0

CIDR	Decimal
/30	255.255.255.252
/29	255.255.255.248
/28	255.255.255.240
/27	255.255.255.224
/26	255.255.255.192
/25	255.255.255.128
/24	255.255.255.0
/23	255.255.254.0
/22	255.255.252.0

IPv4 Packet Format (1)

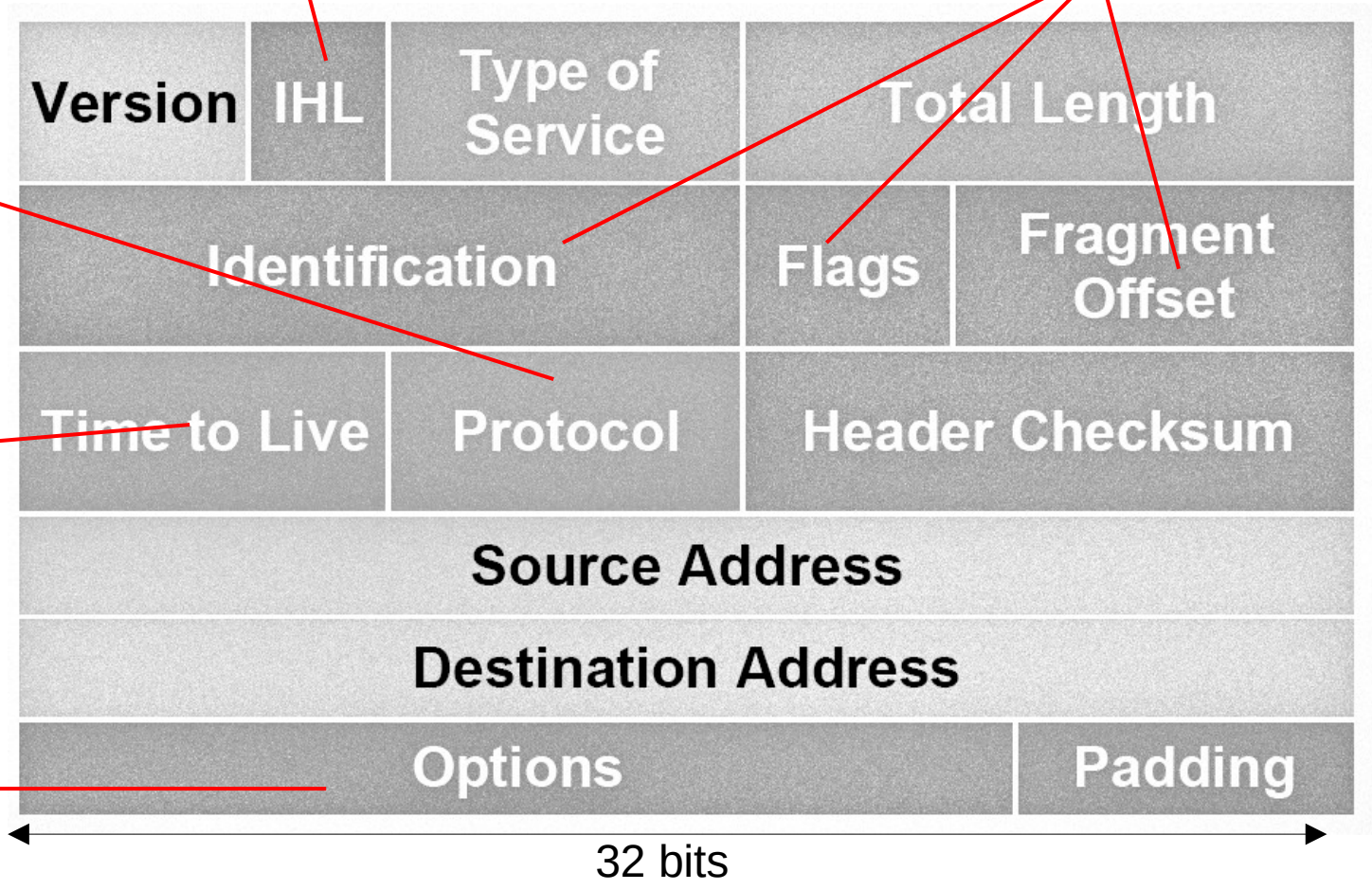
IP Header Length (bytes)

For use in fragmentation and reconstruction

Specifies the underlying protocol (ICMP (1), TCP (6), UDP (17), ...)

Maximum number of hops until the destination (decremented by one in each router on the path)

E.g.,Timestamps, Path record, Routing defined at the source (size must be a multiple of 32, zero padding may be needed)



IPv4 Packet Format (2)

- Version (4 bits) – Protocol version
- Header Length (4 bits) – Header size (number of blocks of of 4 bytes)
  - Without options, the header uses 5 blocks of 4 bytes (20 bytes) and the first byte of the header is 0x45 (version 4, 5 blocks of 4 bytes).
- Type od Service (1 byte) – To implement QoS
  - By default is 0x00.
- Total Length (2 bytes) – packet size in bytes including the header.
  - Maximum IPv4 packet size is 65 535 bytes.
  - Usually this value is limited by the local network Maximum Transport Unit (MTU).

IPv4 Packet Format (3)

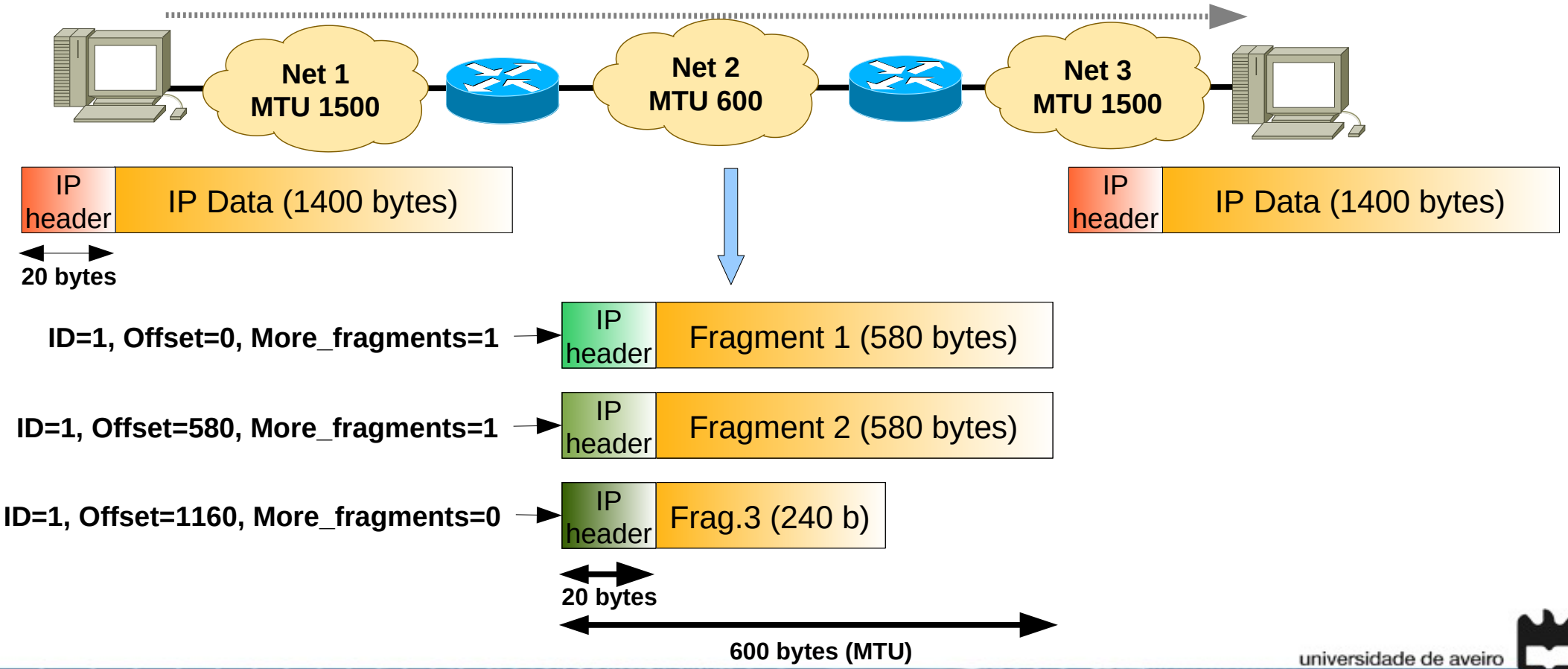
- Time to Live (1 byte) – maximum hops until destination
  - Each router on path reduces TTL by 1.
  - If TTL reaches 0 the packet is discarded and router may notify sender.
- Protocol (1 byte) – specifies the encapsulated protocol
- Header Checksum (2 bytes) – for header error detection
  - Each router on path must recalculate checksum.
    - Changes at least TTL.

IPv4 Packet Format (4)

- Identification (2 bytes) – identifies fragments of the same original IPv4 packet.
- Flags (3 bits)
  - First bit for future use (always 0).
  - Second bit is 0 if packet can be fragment, and 1 otherwise (do not fragment).
  - The third bit is 0 for the last fragment, and 1 otherwise (more fragments flag).
- Fragment Offset (13 bits) – position (in multiples of 8 bytes) of a fragment in the original IPv4 packet (for first fragment is 0x00).

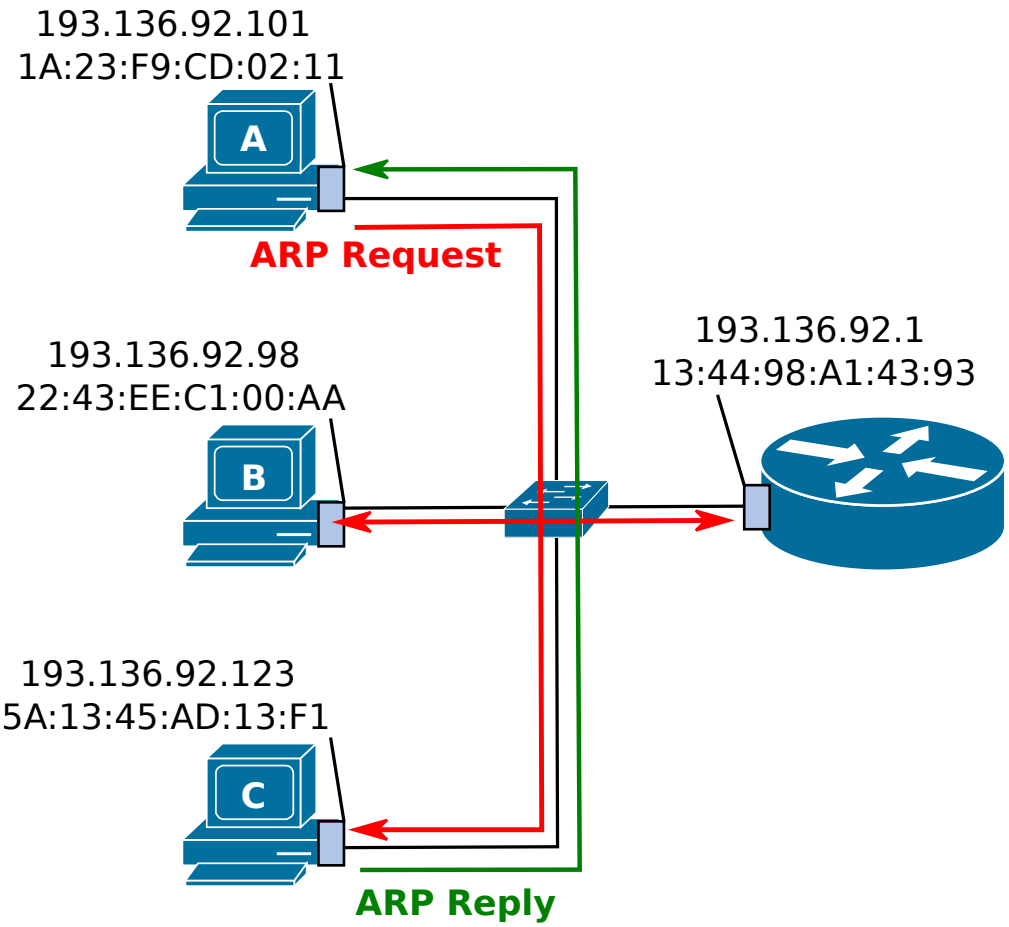
IPv4 Fragmentation and Reconstruction

- Each network defines the maximum packet that can be sent.
  - MTU - Maximum Transfer Unit
- For larger packets, the packet must be fragmented at entry and reconstructed after.
- Header fields used on the process:
  - Identification, fragment offset, flags: do not fragment e more fragments

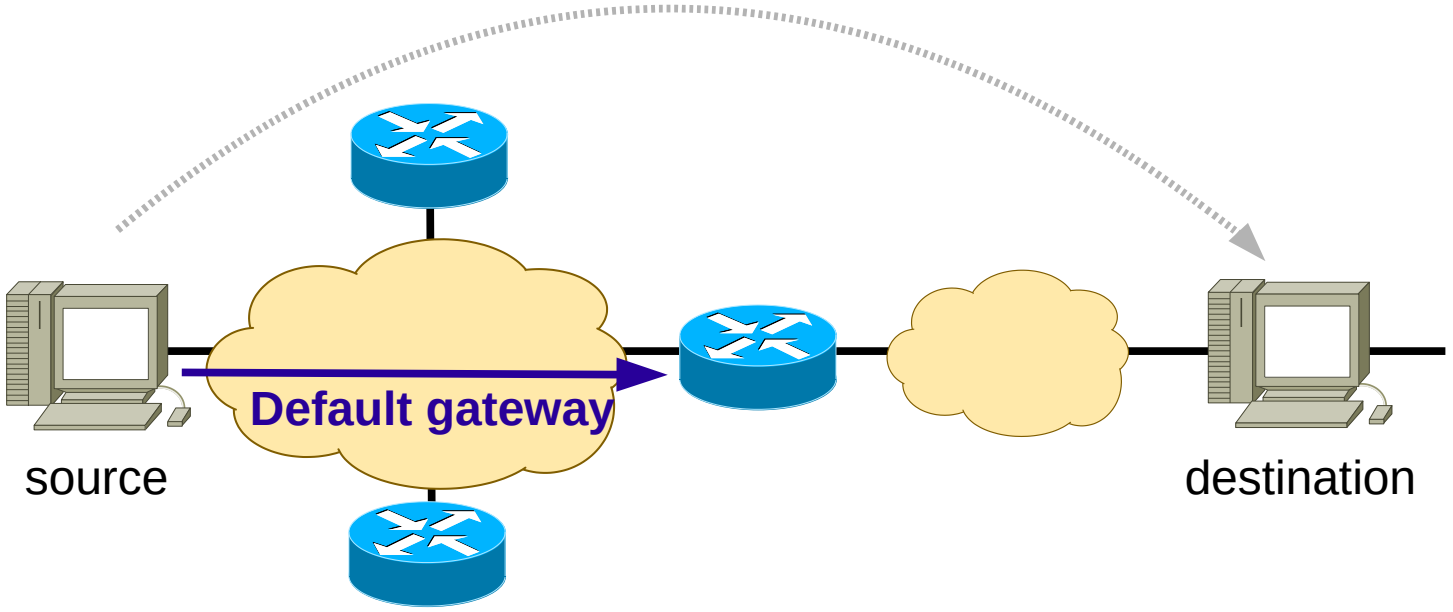


Address Resolution Protocol (ARP)

- IPv4: Address Resolution Protocol (ARP)
- Example:
  - When “A” wants to contact “C” by IPv4:
    - “A” requires “C” MAC address.
    - Only knows IPv4 address.
    - If “C” IPv4 address is not present in the ARP table, then:
      - “A” send an “ARP Request” in broadcast to the local network (destination MAC: FF:FF:FF:FF:FF:FF) with the IPv4 address of “C”,
      - All machines receive this packet,
      - “C” verifies that is IPv4 addess is on the the “ARP request”, responds directly to “A” with a “ARP reply” (destination MAC==MAC of “A”) with it’s on MAC address.
- MAC address resolution only happens in a the local network.
  - ARP packets to not pass through routers.



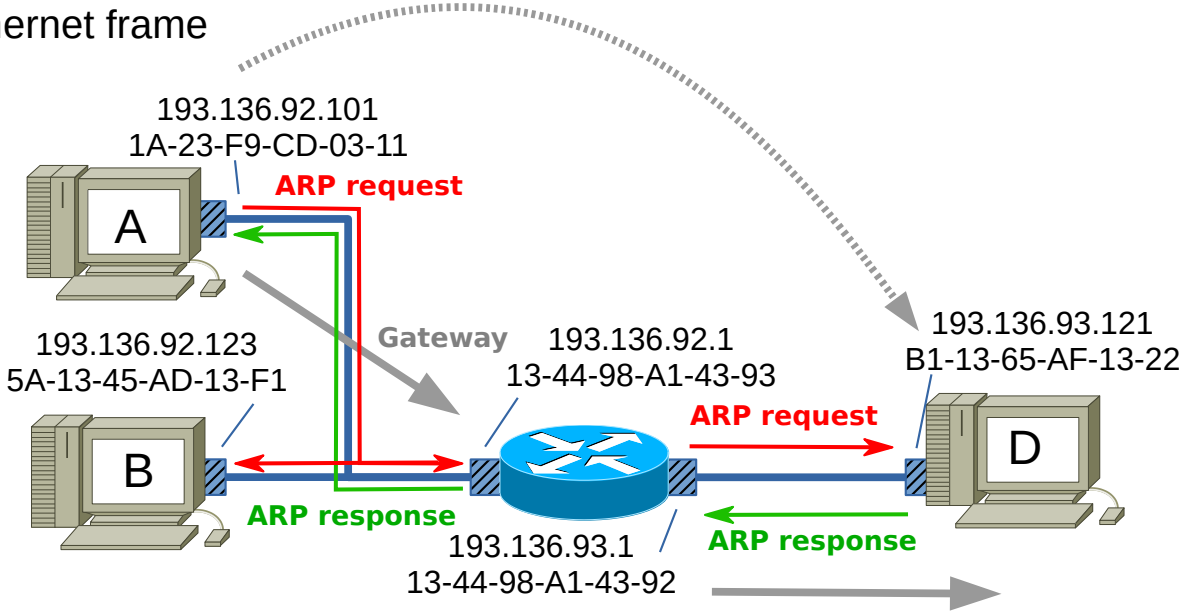
Routing to Another IP Network (1)



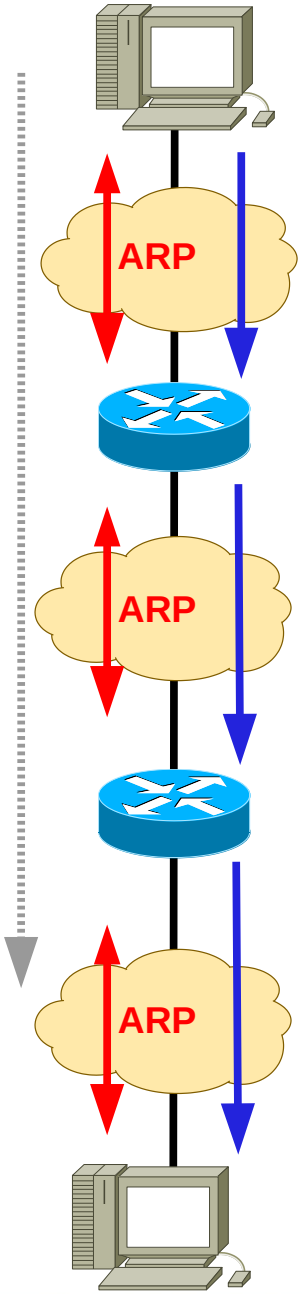
- When a host must send an IP packet to another IP, the packet must be sent to the **default gateway.**
- The **default gateway** must be provided at the same time than the IP address.
  - Manually or by self configuration.

Routing to Another IP Network (2)

- Sending an IP packet from host “A” to host “D”
  - “A” constructs the IP packet with the IPv4 address of “A” as source, and the IPv4 address of “D” as destination
  - “A” verifies that the address of “D” belongs to a different IPv4 network, “A” will send the packet to the configured gateway (router)
  - “A” determines the MAC address of the gateway (ARP)
  - “A” constructs Ethernet frame with the MAC address of “A” as source and the MAC address of the gateway as destination
  - “A” encapsulates the IP packet within the Ethernet frame
  - “A” send the Ethernet Frame
  - The router (GW) receives the Ethernet frame
  - The router removes the IP packet from the Ethernet frame, and verifies that the destination is “D”
  - The router determines the MAC address of “D” (ARP)
  - The router constructs a new Ethernet frame with the MAC address of the output interface as source and the MAC address of “D”as destination
  - The router encapsulates the received IP packet (changing just the TTL) within the Ethernet frame
  - The router sends the Ethernet Frame



Routing over Multiple IP networks



Datagrama IP

Ethernet header | Datagrama IP

MAC destino = MAC gateway

Datagrama IP

Ethernet header | Datagrama IP

MAC destino = MAC next hop

Datagrama IP

Ethernet header | Datagrama IP

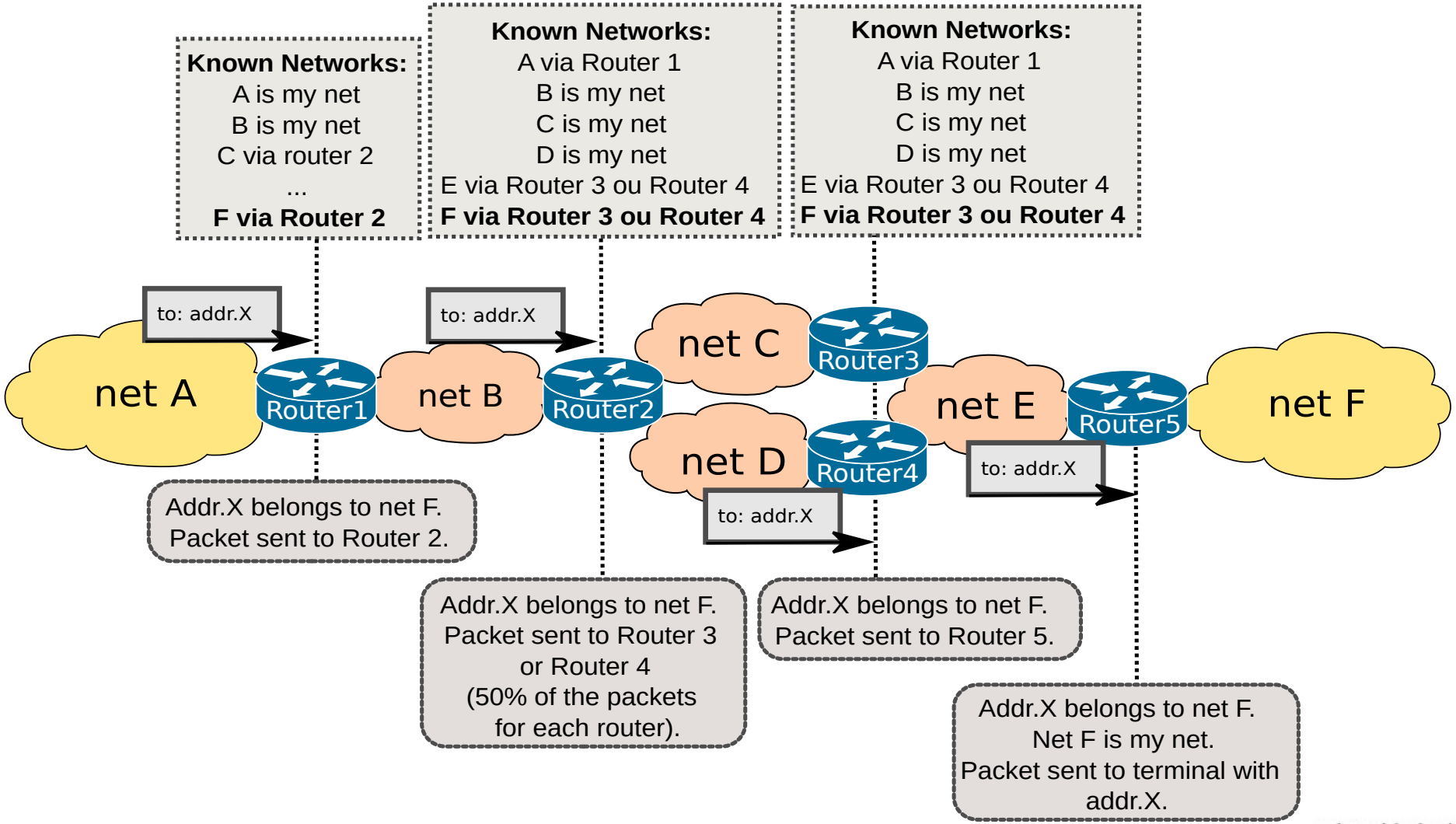
MAC destino = MAC PC destino

IP Routing Overview (1)

- Routers forward packets toward destination networks.
- Routers must be aware of destination networks to be able to forward packets to them.
- A router knows about the networks directly attached to its interfaces
- For networks not directly connected to one of its interfaces, however, the router must rely on outside information.
- A router can be made aware of remote networks by:
  - **Static routing**: An administrator manually configure the information.
  - **Dynamic routing**: Learns from other routers.
  - **Routing policies**: Manually routing rules that outweigh static/dynamic routing.

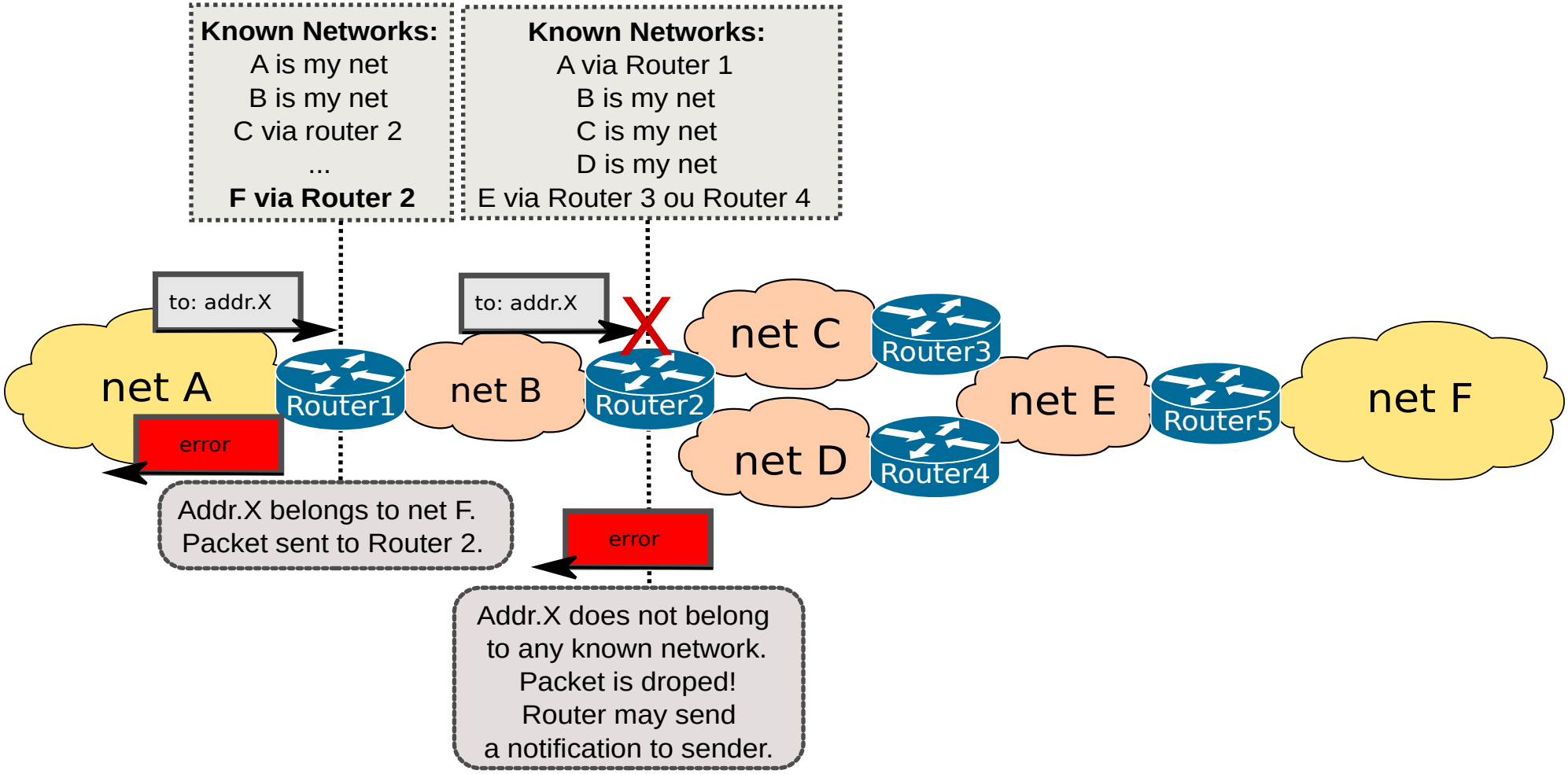
IP Routing Overview (2)

- Hop-by-hop decision:
  - Based on the packets' **IP Destination Address**.
  - Rules listed on the **IP Routing Table.**



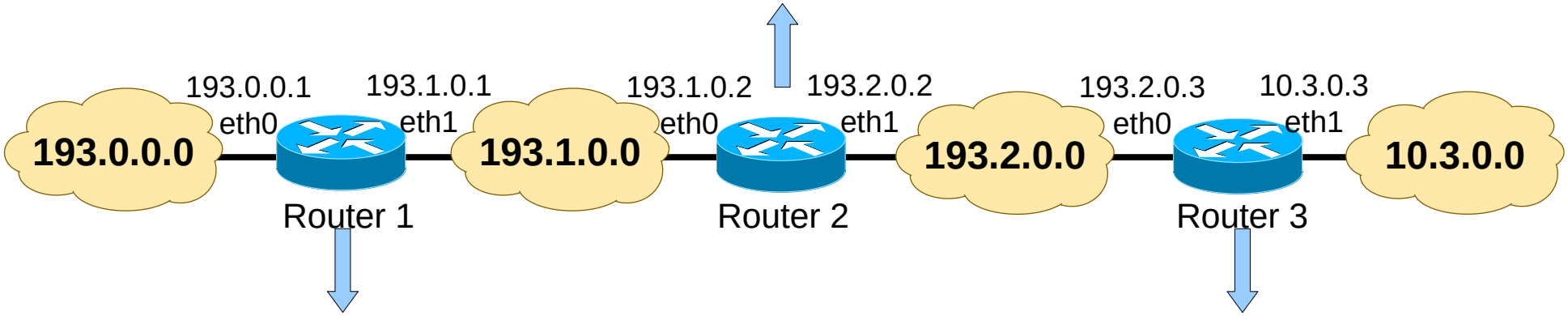
IP Routing Overview (3)

- Hop-by-hop decision:
  - If a packet for an unknown network reaches the router this will drop the packet, and MAY notify the sender about the routing error.



IP Routing Tables (1)

Dest.	Mask	Next hop	Interface	Metric
193.0.0.0	/24	193.1.01	eth0	1
193.1.0.0	/24	direct	eth0	-
193.2.0.0	/24	direct	eth1	-
10.3.0.0	/8	193.2.0.3	eth1	1



Dest.	Mask	Next hop	Interface	Metric
193.0.0.0	/24	direct	eth0	-
193.1.0.0	/24	direct	eth1	-
193.2.0.0	/24	193.1.0.2	eth1	1
10.3.0.0	/8	193.1.0.2	eth1	2

Dest.	Mask	Next hop	Interface	Metric
193.0.0.0	/24	193.2.0.2	eth0	2
193.1.0.0	/24	193.2.0.2	eth0	1
193.2.0.0	/24	direct	eth0	-
10.3.0.0	/8	direct	eth1	-

IP Routing Tables (2)

- Define how a remote network is reachable:
  - Next-hop (identified by its address), and
  - Local interface that provides connection.
- A network may be reachable using more than one path: (next-hop,local interface) pair.
- Mandatory elements
  - **Destination prefix**
  - **Destination mask**
  - **Metric**
    - Could be defined by key tags.
      - e.g., Directly Connected
  - One or both
    - **Next-hop address**
    - **Output interface**
- Optional elements
  - **Administrative distance**
  - **Protocol**
  - **Entry age (last time information received)**
  - **Scope**
  - **Flags**
  - **Source-specific**

Cisco IOS

```
R     200.1.1.0/24 [120/1] via 200.19.14.10, 00:00:16, FastEthernet0/1
      200.19.14.0/24 is variably subnetted, 2 subnets, 2 masks
C        200.19.14.0/24 is directly connected, FastEthernet0/1
L        200.19.14.4/32 is directly connected, FastEthernet0/1
R     200.38.0.0/24 [120/1] via 200.43.0.8, 00:00:03, FastEthernet1/1
      200.43.0.0/24 is variably subnetted, 2 subnets, 2 masks
C        200.43.0.0/24 is directly connected, FastEthernet1/1
L        200.43.0.1/32 is directly connected, FastEthernet1/1
```

Linux: route -n

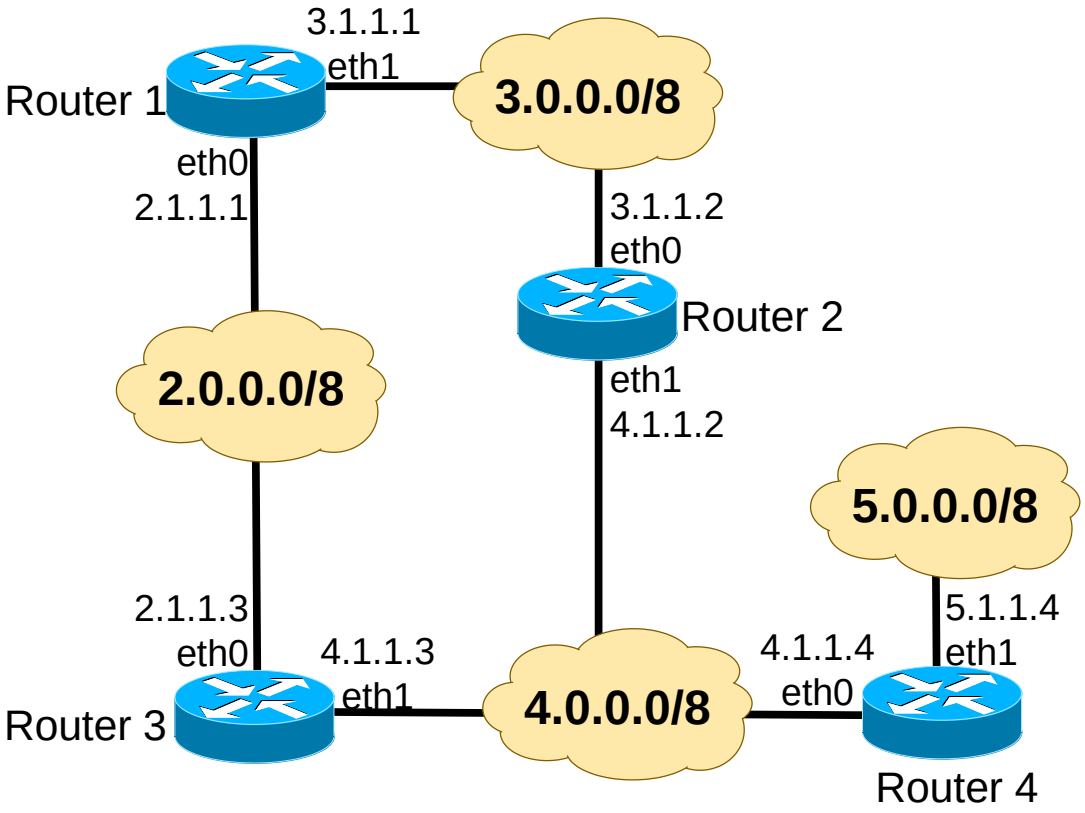
```
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
0.0.0.0         193.136.92.1    0.0.0.0         UG    100    0        0 enp5s0f1
169.254.0.0     0.0.0.0         255.255.0.0     U     1000   0        0 enp5s0f1
193.136.92.0    0.0.0.0         255.255.254.0   U     100    0        0 enp5s0f1
```

Linux: ip route

```
default via 193.136.92.1 dev enp5s0f1  proto static  metric 100
169.254.0.0/16 dev enp5s0f1  scope link  metric 1000
193.136.92.0/23 dev enp5s0f1  proto kernel  scope link  src 193.136.93.104  metric 100
```

- The next path hop (next hop address) may be found using more than one table entry (recursive resolution).
  - e.g., Network A is reachable through address from network B, Network B is reachable through address from network C, …
- The next-hop address may be obtained from external information (configurations or other mechanisms).
  - e.g., Tunnels, Point-to-point connections, etc…
- When an entry uses a next-hop address from an unknown network, that entry is removed.
- All entries obtain by dynamic methods may have an entry age (time since last update/confirmation).
  - After a timeout value without an update/confirmation the entry is removed.

IP Routing Example



C	2.0.0.0/8 is directly connected, Ethernet0
C	3.0.0.0/8 is directly connected, Ethernet1
R	4.0.0.0/8 [120/1] via 3.1.1.2, 00:00:16, Ethernet1
	[120/1] via 2.1.1.3, 00:00:12, Ethernet0
R	5.0.0.0/8 [120/2] via 3.1.1.2, 00:00:13, Ethernet1
	[120/2] via 2.1.1.3, 00:00:02, Ethernet0

Router 1

R	2.0.0.0/8 [120/1] via 4.1.1.3, 00:00:26, Ethernet1
	[120/1] via 3.1.1.1, 00:00:02, Ethernet0
C	3.0.0.0/8 is directly connected, Ethernet0
C	4.0.0.0/8 is directly connected, Ethernet1
R	5.0.0.0/8 [120/1] via 4.1.1.4, 00:00:23, Ethernet1

Router 2

C	2.0.0.0/8 is directly connected, Ethernet0
R	3.0.0.0/8 [120/1] via 4.1.1.2, 00:00:06, Ethernet1
	[120/1] via 2.1.1.1, 00:00:05, Ethernet0
C	4.0.0.0/8 is directly connected, Ethernet1
R	5.0.0.0/8 [120/1] via 4.1.1.4, 00:00:20, Ethernet1

Router 3

R	2.0.0.0/8 [120/1] via 4.1.1.3, 00:00:13, Ethernet0
R	3.0.0.0/8 [120/1] via 4.1.1.2, 00:00:08, Ethernet0
C	4.0.0.0/8 is directly connected, Ethernet0
C	5.0.0.0/8 is directly connected, Ethernet1

Router 4