Workshop on Scientific Applications for the Internet of Things (IoT)

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IP Networks: From IPv4 to IPv6

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Contents

Objectives

- Give an overview of IP data networks to understand where we are nowadays
- “Equalize” students knowledge (in order to)
- Be prepared for the IPv6 concepts we will see during the workshop

Digital Data Transmission (I)

- Objective is to send some information from one place/device to another
- Different type of info, through different transport networks
- You have to codify the info -> digitally

  A B C

  - Three diff. characters: using 1 transmitted unit of information you could represent 3 different *codes* (A,B or C)(3^1)
  - If you transmit 2 units of information: 9 *codes* (3^2)
- Binary codification -> uses two characters: 0 / 1
- Bit (0 or 1) minimal unit of information
- Byte = 8 bits -> used for ASCII characters => 256 (2^8)

Digital Data Transmission (II)

- If you want to transmit “hi”:
  - h -> | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
  - i -> | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 |
  - This codification is defined by ASCII
  - There could be other ones
- You could codify hexadecimal (16 from 0 to F) numbers using 4 bits (2^4 = 16)
  - 0 = | 0 | 0 | 0 | 0 | -> Represented as 0x0
  - 1 = | 0 | 0 | 0 | 1 | -> Represented as 0x1
  - 2 = | 0 | 0 | 1 | 0 | -> Represented as 0x2
  - . . .
  - A = | 1 | 0 | 1 | 0 | -> Represented as 0xA

Switched Packet Networks (I)

- Two options to send information:

1. **Circuits**: fixed paths, reserved resources, communication starts only when circuit is established (example: telephone)
2. **Switching**: paths can vary, shared resources (best effort), communication can start at any moment (example: postal mail, Internet)

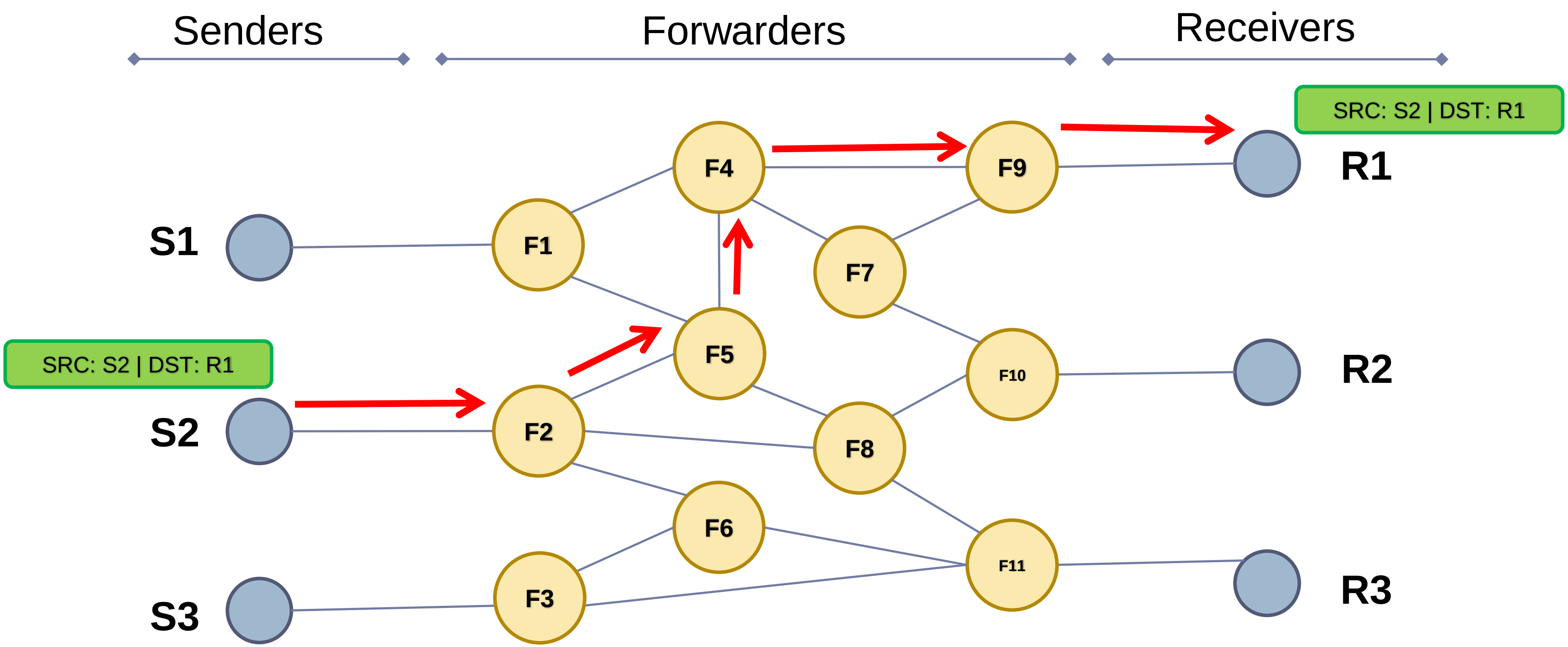
- **Packet switching is much more efficient and flexible**

Switched Packet Networks (II)

- Basic elements on a switched network:

1. **Sender**: Generates the info to be sent to a receiver. Should codify the message.
2. **Receiver**: Is the destination of the information sent by the sender. Should decode the message.
3. **Forwarder**: Nor the origin or the destination of the information. Just receive and forward the information in its path to the destination
4. **Identification**: Each element in the switched network should be uniquely identified

Switched Packet Networks (III)



Switched Packet Networks (VI)

- Role Play
- Three kinds of roles: senders, receivers, forwarders
  1. **Receivers**: get an IP destination card -> shows it
  2. **Senders**: take an origin IP card and envelopes -> choose one destination IP from receivers showing
  3. **Forwarders**: will receive packet envelopes and forward to the best neighbor
- Start:
  1. Senders: put the first part of the word in an envelope and write the origin and destination IP for it
  2. Senders: pass the packet to their "gateway" router
  3. Forwarders: get packets, look at the destination IP and pass it to the router they consider is in the shortest path to the destination IP
  4. Receiver: get packets and put together word parts, when it has the full word it should say it loud

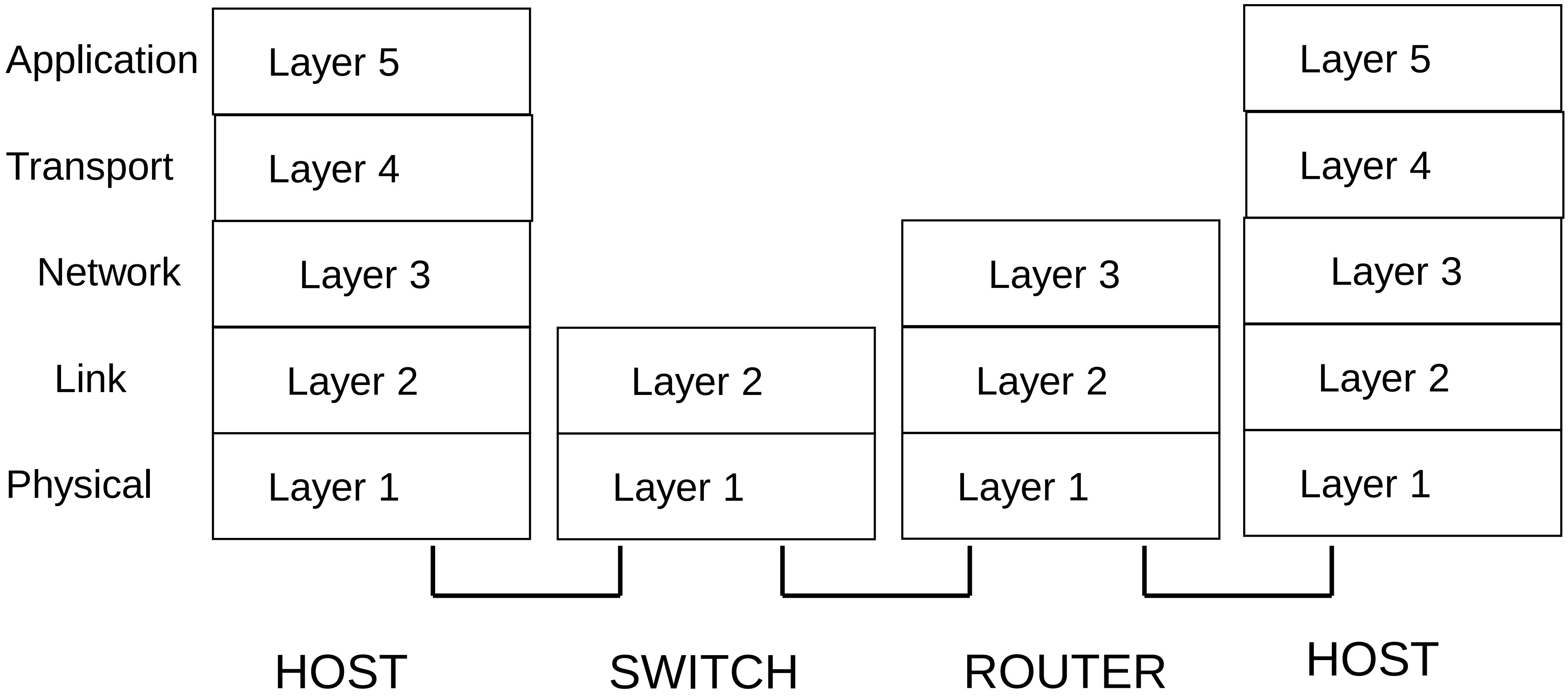
Layered Model (I)

- Let’s define things:

1. **Layered model**: physical, link, network, etc. each one is in charge of different things
2. **Network elements**: Node, host, router, server
3. **Addresses**: link layer, network layer
4. **Protocol**: definition of the format and order of messages exchanged between two or more communicating entities, as well as the actions taken on the transmission and/or reception of a message or other event

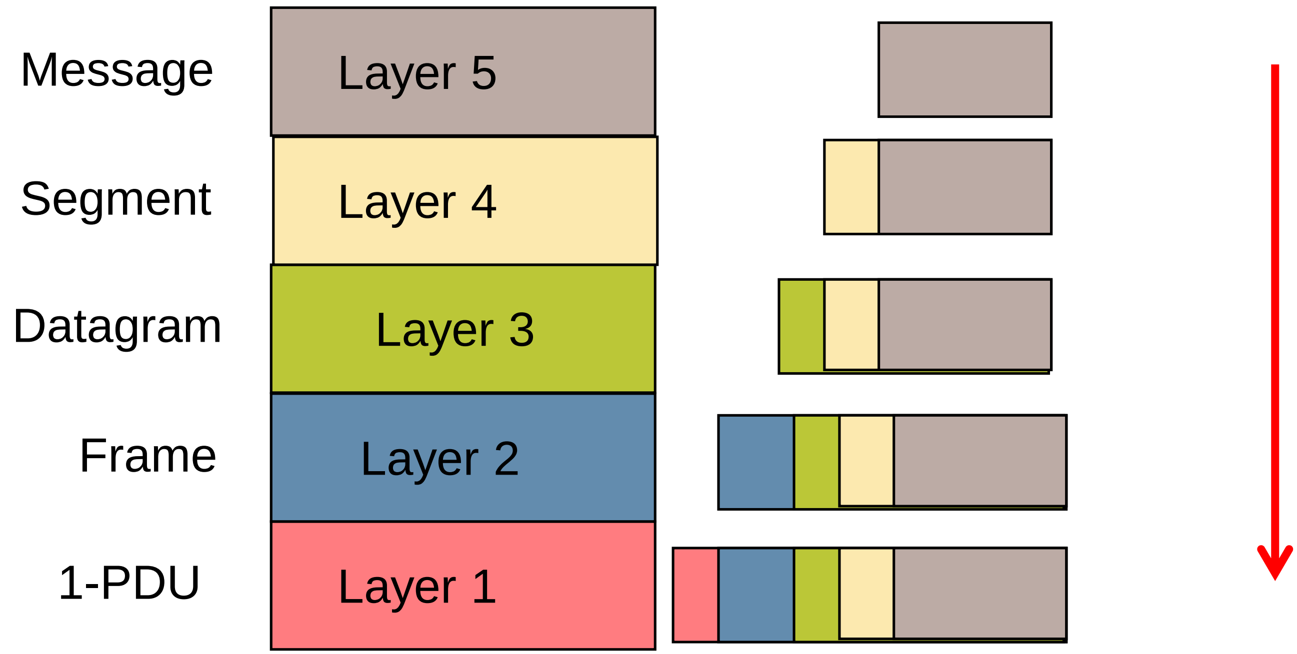
Layered Model (II)

- TCP/IP layered model -> Used in Internet



Layered Model (III)

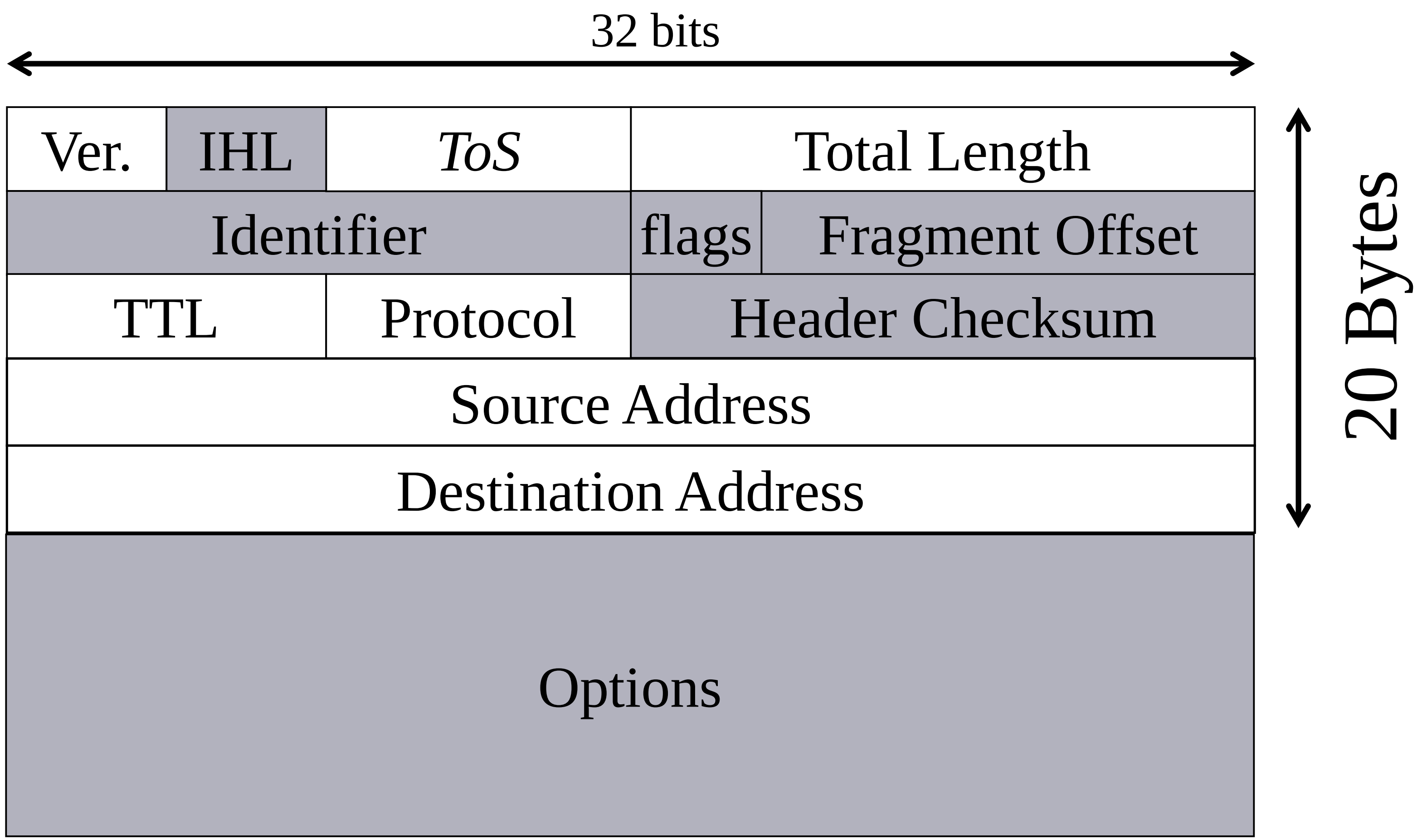
- PDU: Protocol Data Unit



- Layer 3 Header includes Source and destination Network Address (IP Address)
- Layer 3 is the only one common layer in Internet: IP

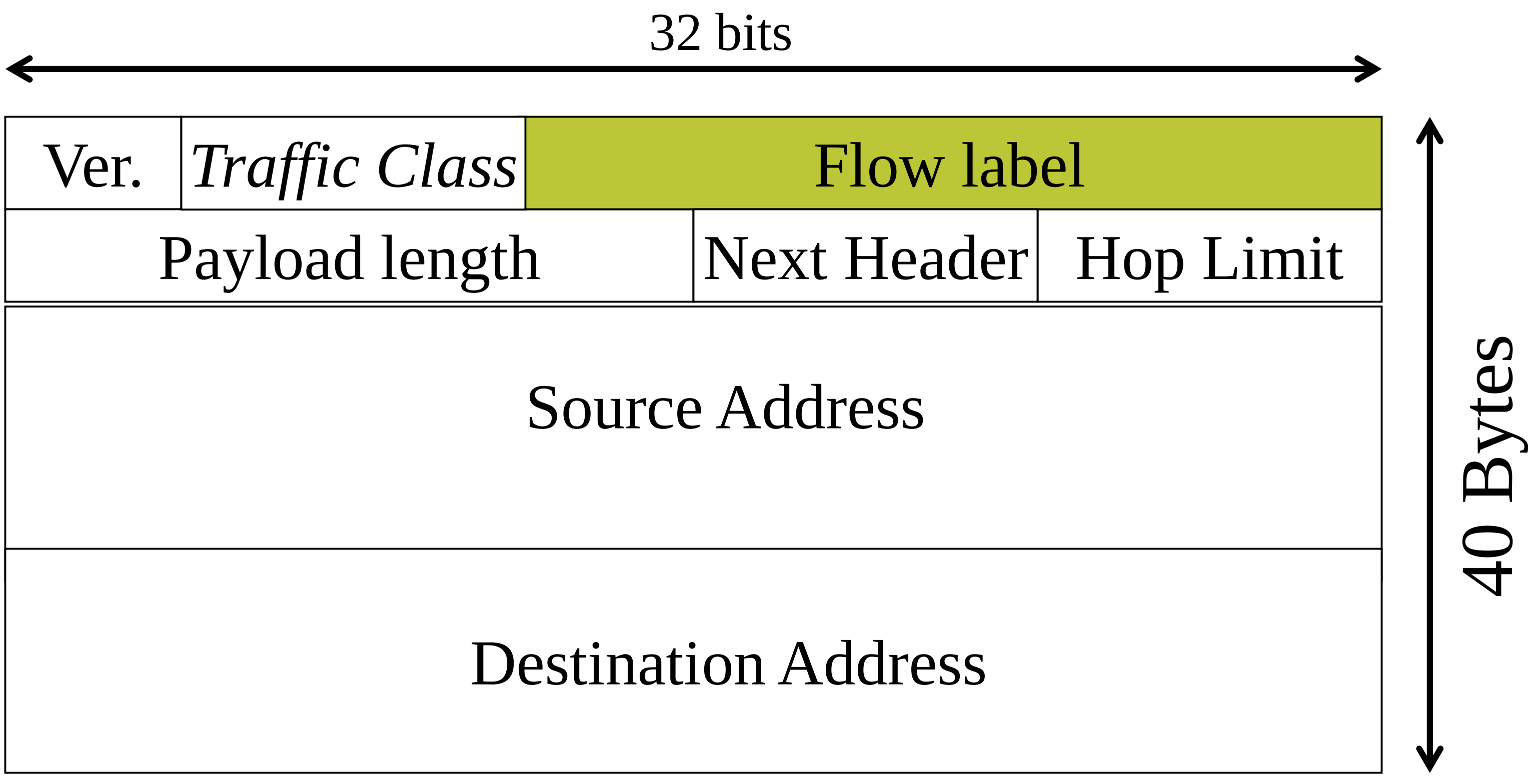
IPv4 and IPv6 basics (I)

- IPv6 is an evolution of IPv4



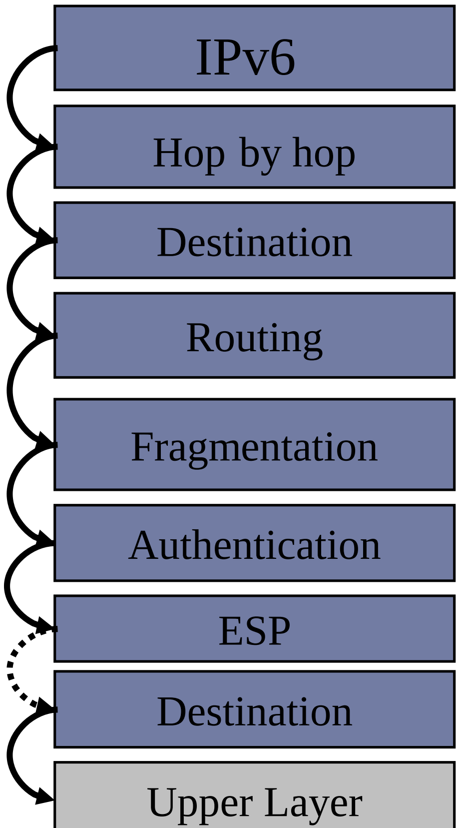
IPv4 and IPv6 basics (II)

- Simplified, fixed-length, 64 bits aligned -> complexity from core to border



IPv4 and IPv6 basics (III)

- Extension Headers: To cover IP layer needs -> flexible
- Limited and ordered



Processed by every router

Processed by routers listed in *Routing extension*

List of routers to cross

Processed by the destination

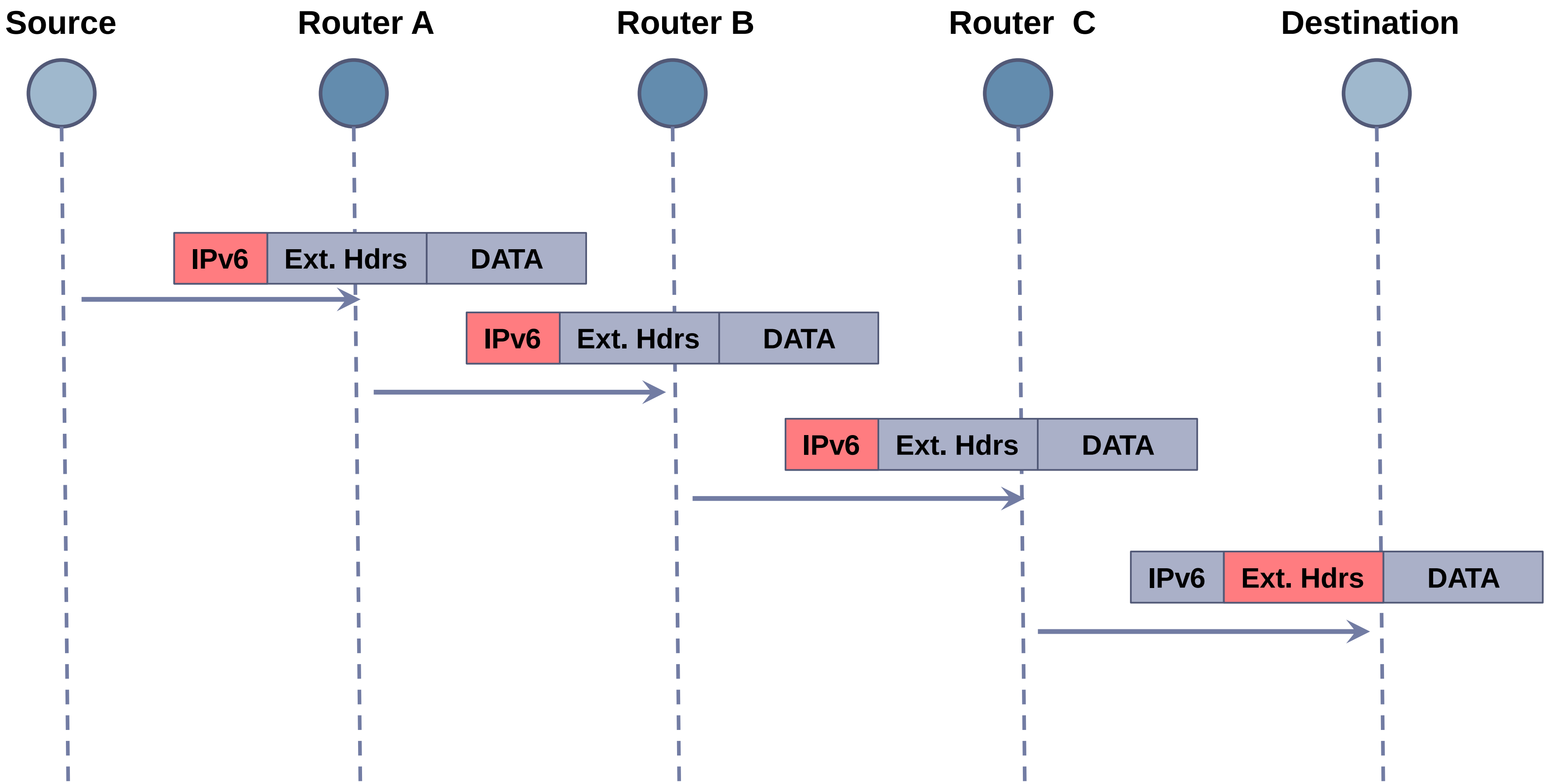
After reassembling the packet

Cipher the content of the remaining information

Processed **only** by the destination

IPv4 and IPv6 basics (IV)

- Basic IPv6 header is processed in all hops
- Extension headers are processed in destination



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IP addresses (v4/v6) (I)

- IPv4 addresses have 32 bits
- Represented using decimal notation of each byte (8 bits) separated by .
- Examples: 10.1.1.2, 192.168.11.1
- Each decimal number corresponds to 8 bits, for example: 10 -> 00001010
- Do you remember/know about binary to decimal conversions?

IP addresses (v4/v6)(II)

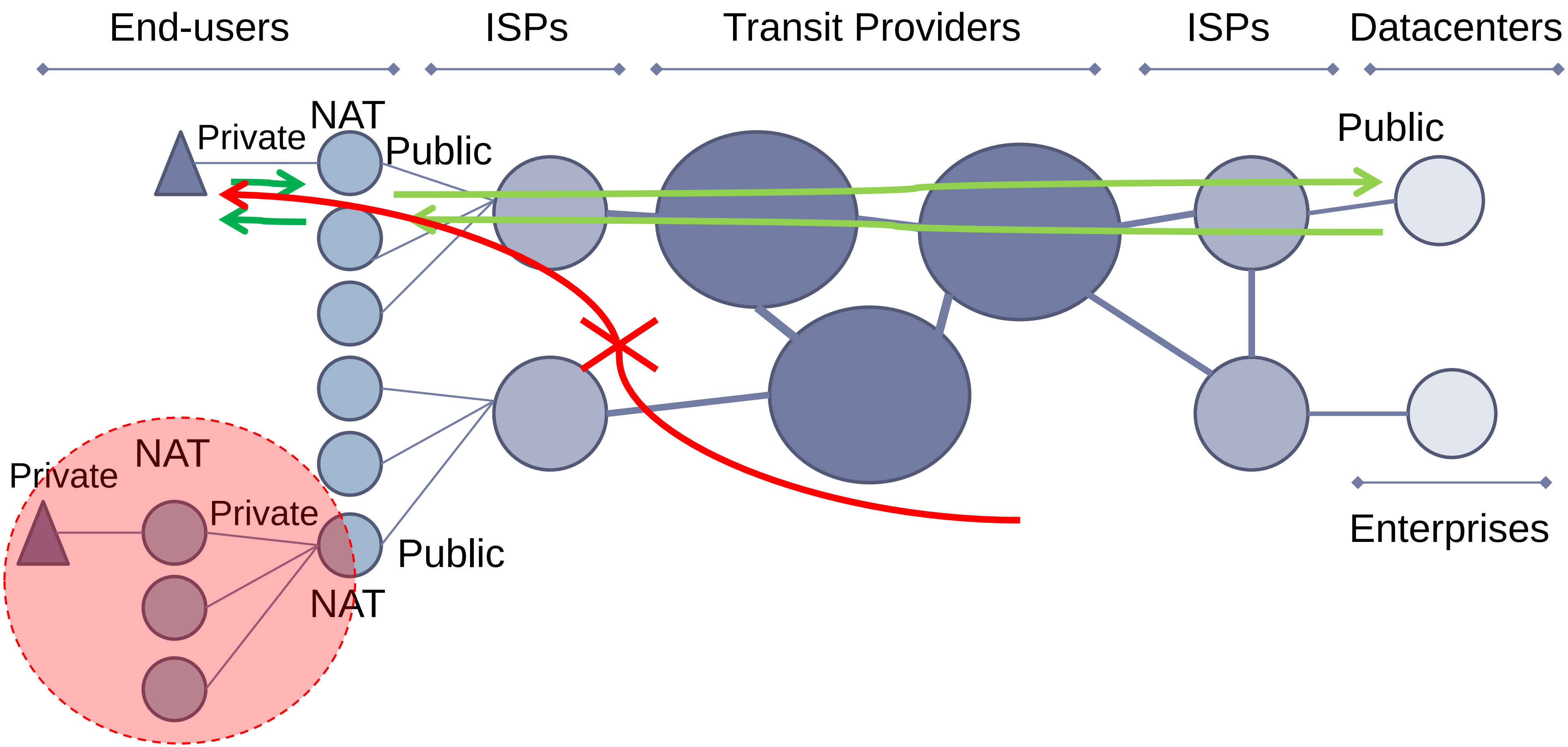
- At the beginning different “classes” were defined:
  - Class A: 8 bits mask (/8) -> first byte 0 to 127
  - Class B: (/16) -> first byte 128 to 191
  - Class C: (/24) -> first byte 192 to 223
- Later, classes were abandoned by CIDR (Classless Inter Domain Routing) Notation: prefix / length
- Example 10.1.2.0/24:
  - 24 bits network prefix
  - 8 bits for hosts
  - 254 possible host addresses (all 0s (network) and all 1s (broadcast) could not be used)

IP addresses (v4/v6)(III)

- Private addresses were defined:
  - 10.0.0.0/8 (1 x A): 10.0.0.0 to 10.255.255.255
  - 172.16.0.0/12 (16 x B): 172.16.0.0 to 172.31.255.255
  - 192.168.0.0/16 (256 x C): 192.168.0.0 to 192.168.255.255
- Private addresses are used behind a NAT device
  - Works “well” in a client-server model
  - Do not allow for P2P or similar applications
  - Do not allow innovation on the Internet
  - Makes software development more expensive
  - Management and security gets harder

IP addresses (v4/v6)(IV)

- NAT issues examples: private not reachable, several levels of NAT



IP addresses (v4/v6)(V)

- Unicast (one-to-one)
  - Link-local
  - Unique Local (ULA)
  - IPv4-mapped
  - Global (GUA)
  - Site-local (deprecated)
  - IPv4-compatible (deprecated)
- Multicast (one-to-many)
- Anycast (one-to-nearest) (taken from unicast space)
- Reserved (Trans. Mechs, documentation, loopback, etc.)
- There are no BROADCAST addresses -> well-known multicast

IP addresses (v4/v6)(VI)

- IPv6 address notation rules:
  - 8 Groups of 16 bits separated by ":"
  - Hexadecimal notation of each nibble (4 bits) ->
  - No case sensitive
- Compression rules:
  - Leftmost zeroes within each group could be eliminated
  - One or more groups of all zeroes could be changed by "::". Only once!
- Use "[]" to specify port: ->http://[2001:db8::10]:8080
- Examples:
  - 2001:0db8:0102:0DA0:0000:0000:0000:1000 -> 2001:db8:102:DA0::1000
  - 2001:db8:0000:0000:0020:0000:0000:0abc -> ?

Binary	-	Hex.
0000	->	0
0001	->	1
0010	->	2
…		
1110	->	E
1111	->	F

IP addresses (v4/v6)(VII)

- Network prefixes follow CIDR notation
- Compression rules could be applied
- Examples:
  - 2001:db8::**/32** -> **2001:0db8:**0000:0000:0000:0000:0000:0000
  - 2001:db8:1200::**/40** -> **2001:0db8:12**00:0000:0000:0000:0000:0000
  - 2001:db8:abcd::**/48** -> **2001:0db8:abcd:**0000:0000:0000:0000:0000
- Non-prefix bits (rightmost) used for subneting
  - Example: I'll take the first two /52 prefixes out of 2001:db8:abcd::/48
  - 2001:0db8:abcd:**0**000:0000:0000:0000:0000 -> **2001:db8:abcd:0**000::/52
  - 2001:0db8:abcd:**1**000:0000:0000:0000:0000 -> **2001:db8:abcd:1**000::/52

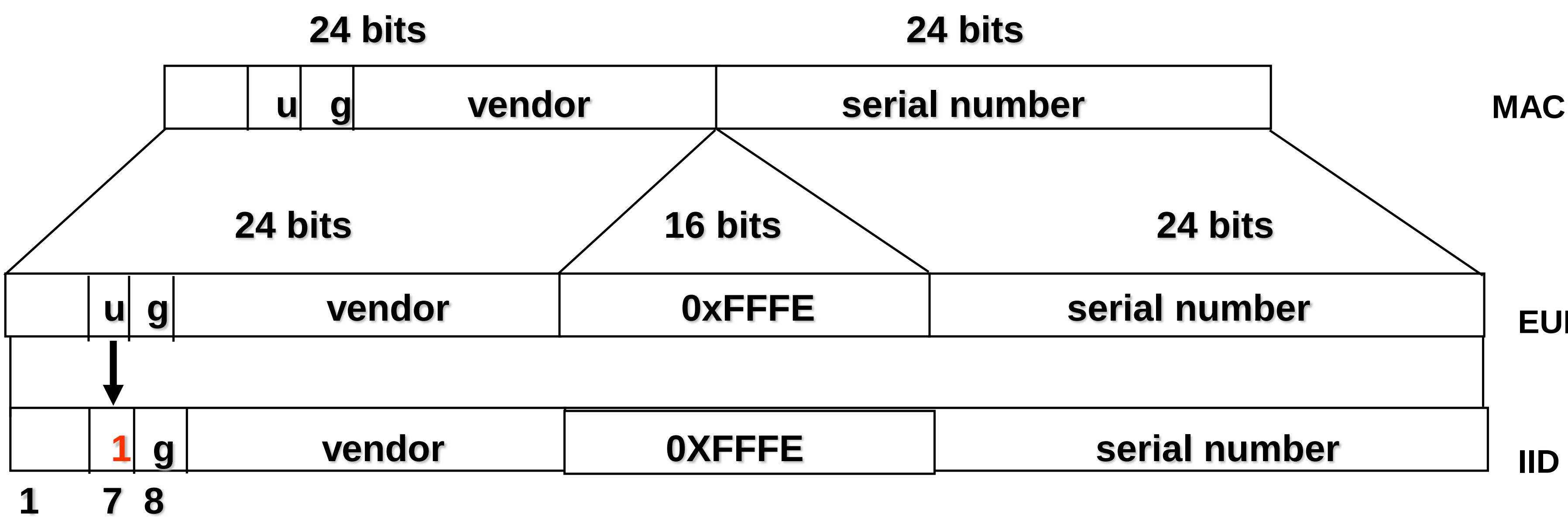
IP addresses (v4/v6)(VIII)

Network ID	Interface ID
64 bits	64 bits

- Network prefix in a LAN will be /64
- Interface ID: 64 bits available to identify hosts in the LAN
- They could be created in many different ways
  - From MAC addresses (EUI-64)
  - Automatically using some kind of algorithm
  - Manually
  - DHCPv6
- TWO IDEAS HERE:
  - /64 prefix for a LAN -> this is the minimum unit you will manage on your addressing plan
  - Interface identifier are generated locally on the host (except DHCP)

IP addresses (v4/v6)(IX)

- IEEE defines a mechanism to create an **EUI-64** from an IEEE 802 MAC address (Ethernet, FDDI)
- You get the IID modifying the EUI-64's u bit (Universal). Set to 1 to indicate universal scope and 0 to indicate local scope



IP addresses (v4/v6)(X)

fe80::	Interface ID
64 bits	64 bits

- Link-Local Addresses: Valid only in a link
- Always present in any IPv6-enabled interface
- In practice fe80::/64 is used
- Interface ID is generated locally on the host: based on MAC, randomly or anyhow

IP addresses (v4/v6)(XI)

Prefix	L	global ID	subnet ID	interface ID
7 bits	1	40 bits	16 bits	64 bits

- ULA Addresses: FC00::/7 Prefix
- L = 1 if the prefix is locally assigned
- L = 0 may be defined in the future (RFC4193) (in practice used for centrally assigned prefixes)
- global ID: pseudo-randomly generated
- You'll create a /48 prefix, usually starting with FD00::/8

IP addresses (v4/v6)(XII)

11111111	flags	scope	group ID
8	4	4	112 bits

- Multicast Addresses: Prefix FF00::/8
- Flags: used for multicast routing and services
- Scope: part of network where address is valid
  - 1 - Interface-Local
  - 2 - link-local
  - 4 - admin-local
  - 5 - site-local
  - 8 - organization-local
  - E - global
- Group ID: Identifies the multicast group
- Well-known: FF02::1 (all nodes), FF02::2 (all routers)

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Network Startup Resource Center

IP addresses (v4/v6)(XIII)

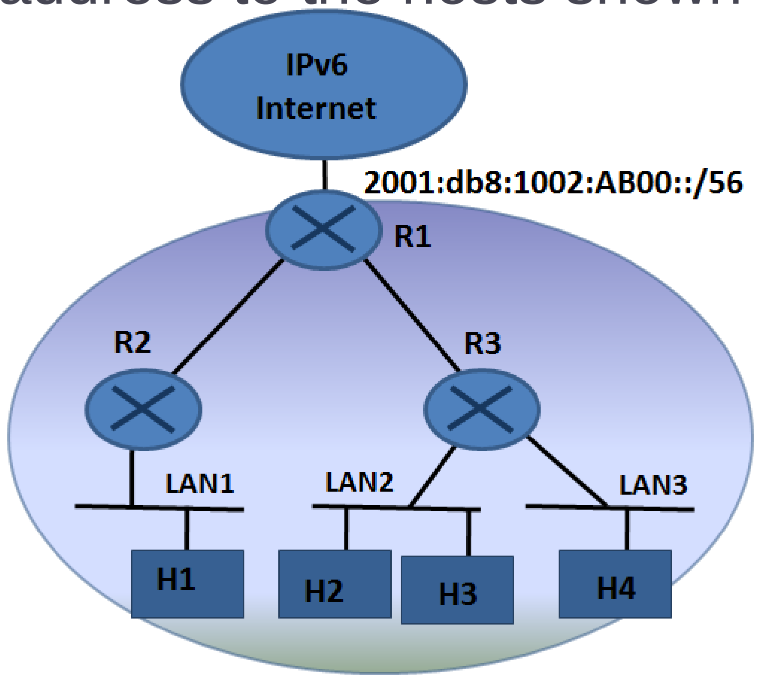
- Unicast (one-to-one)
  - Link-local (FE80::/10)
  - Unique Local (ULA) (FC00::/7)
  - IPv4-mapped (::FFFF:IPv4/128)
  - Global (GUA) (2000::/3) (binary: **001**0)
  - Site-local (deprecated) (FEC0::/10)
  - IPv4-compatible (deprecated)(::IPv4/128)
- Multicast (one-to-many) (FF00::/8)
- Anycast (one-to-nearest) (taken from unicast space)
- Reserved (Trans. Mechs, documentation (2001:db8::/32), loopback (::1/128), unspecified (::/128), etc.)
- There are no BROADCAST addresses -> well-known multicast (FF02::1, FF02::2)

IP addresses (v4/v6)(XIV)

- Which IPv6 addresses will you use?
- For sure:
  - Link-local
  - Multicast (link-local scope)
  - Loopback & Unspecified
- Probably (or you should)
  - GUA
- Maybe
  - ULA
  - Multicast (other scopes)
  - IPv4-mapped (transition mechs.)
  - Reserved (transition mechs., documentation for tests, etc.)

IP addresses (v4/v6)(XV)

- Short Exercise with IPv6 Addresses:
  - You have the IPv6 prefix 2001:0db8:1002:AB00::/56
  - Take three /64 prefixes from it to assign to three different LANs
  - Give a complete IPv6 address to the hosts shown in the figure



IP addresses (v4/v6)(XVI)

- Fill the table:

Description	Prefix/Address
LAN1	/64
LAN2	/64
LAN3	/64
H1	
H2	
H3	
H4	

IP addresses (v4/v6)(XVII)

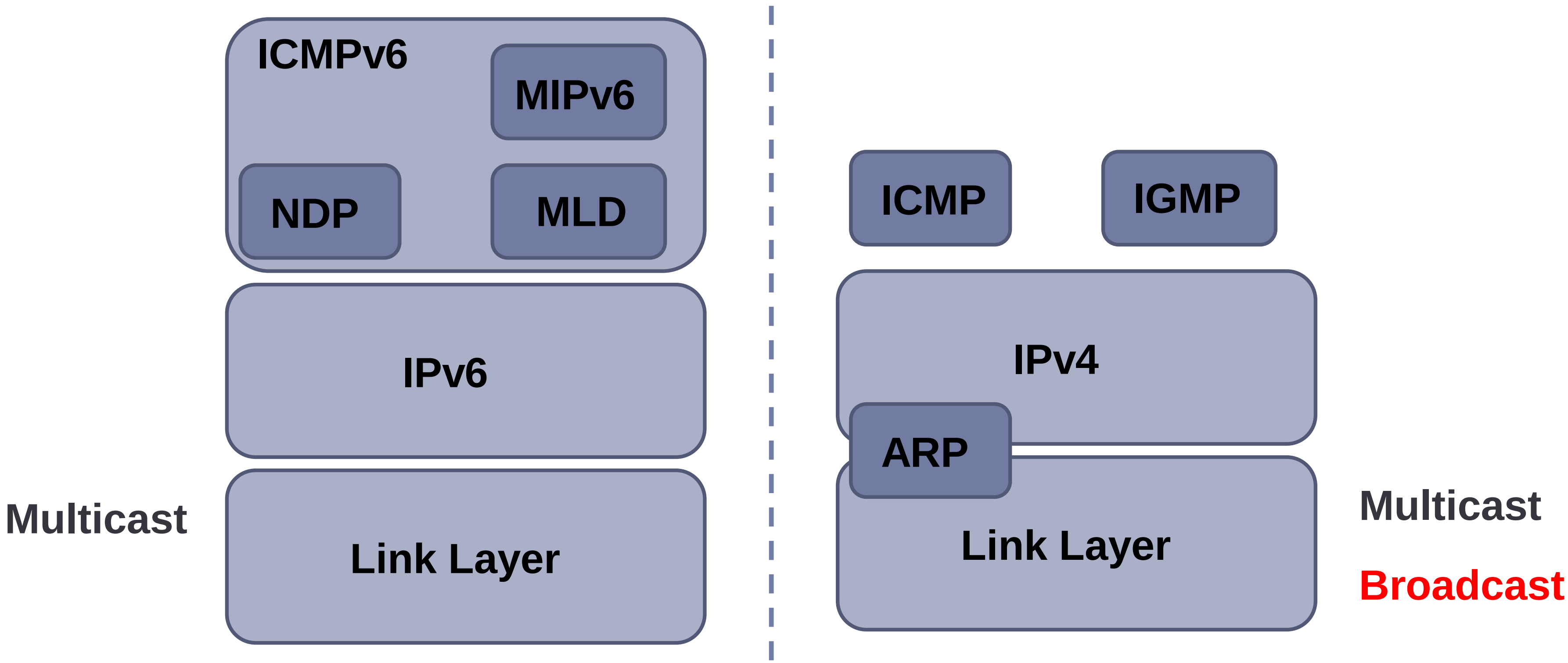
- Start with /56 prefix -> you have to divide into /64s
  - 2001:db8:1002:AB00::/56 ->
    2001:0db8:1002:AB00:0000:0000:0000:0000
  - : **1010 1011** 0000 0000 : (binary) :**AB**00:
  - : **1010 1011** 0000 0001 : (binary) :**AB**01:
  - : **1010 1011** 0000 0010 : (binary) :**AB**02:
  - . . . . . .
  - : **1010 1011** 0000 1111 : (binary) :**AB**0F:
  - . . . . . .
  - : **1010 1011** 1111 1111 : (binary) :**AB**FF:
- I've got 2^8 = 256 /64 prefixes: 2001:db8:1002:ab00::/64, 2001:db8:1002:ab01::/64, … 2001:db8:1002:abFF::/64

IPv6 Protocols and Autoconfiguration (I)

- ICMPv6 is a fundamental part of IPv6
- It’s used for several things, both:
  - Locally on the LAN: **NDP, MLD**
  - On the Internet: Fragmentation, detect other errors
- You should be careful when filtering
- Two type of messages:
  - Error: Destination unreachable, packet too big, time exceeded, parameter problem
  - Informative: echo request, echo reply

IPv6 Protocols and Autoconfiguration (II)

- ICMPv6 fundamental part of IPv6



IPv6 Protocols and Autoconfiguration (III)

- ICMPv6 Error Messages
- Destination Unreachable (type = 1, parameter = 0)
  - No route to destination (code = 0)
  - Communication with destination administratively prohibited (code = 1)
  - Beyond scope of source address (code = 2)
  - Address Unreachable (code = 3)
  - Port Unreachable (code = 4)
  - Source address failed ingress/egress policy (code = 5)
  - Reject route to destination (code = 6)
- Packet Too Big (type = 2, code = 0, parameter = next hop MTU)
- Time Exceeded (type = 3, parameter = 0)
  - Hop Limit Exceeded in Transit (code = 0)
  - Fragment Reassembly Time Exceeded (code = 1)
- Parameter Problem (type = 4, parameter = offset to error)
  - Erroneous Header Field (code = 0)
  - Unrecognized Next Header Type (code = 1)
  - Unrecognized IPv6 Option (code = 2)

IPv6 Protocols and Autoconfiguration (IV)

- NDP is used for hosts-hosts and routers-hosts communication
- It offers several services on a LAN:
  - Discovery of routers, network prefixes, network parameters
  - Autoconfiguration
  - Address Resolution
  - DAD (Duplicate Address Detection)
  - NUD (Neighbor Unreachability Detection)
- It only uses 5 type of ICMPv6 packets:
  - **RA**: Router Advertisement
  - **RS**: Router Solicitation
  - **NA**: Neighbor Advertisement
  - **NS**: Neighbor Solicitation
  - Redirect

IPv6 Protocols and Autoconfiguration (V)

- Autoconfiguration in general is about automatically configure network parameters, not manually
- In IPv4 we only have DHCP
- In IPv6 there are more options
- Two scenarios: router or non-router
- **Router**:
  - Sends RAs -> M and O Flags -> four combinations
  - Hosts should look at M and O flags and then start to autoconfigure
  - M is about IPv6 address, O is about other parameters (DNS, etc.)
  - We have two “tools” SLAAC (0) and DHCPv6 (1)

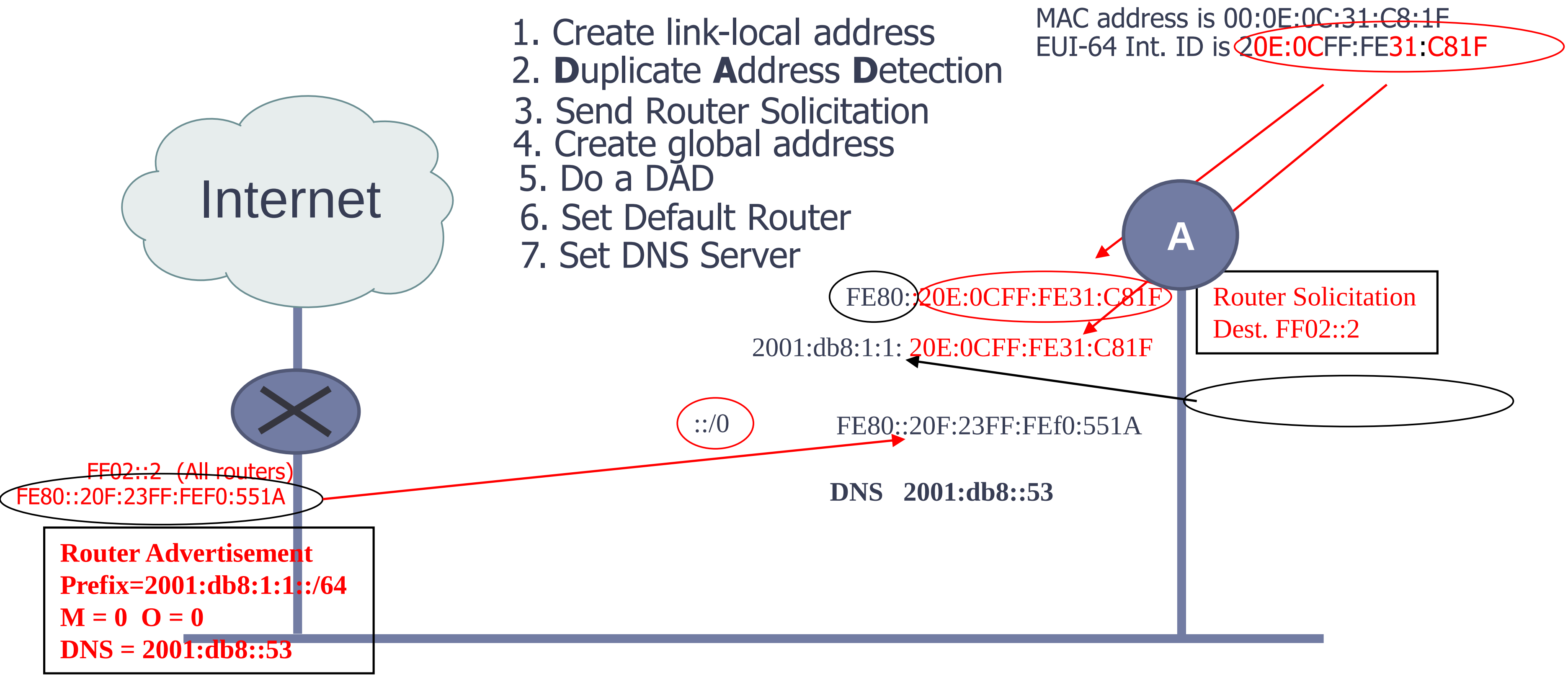
IPv6 Protocols and Autoconfiguration (VI)

- SLAAC vs. DHCPv6
- NOTE: Default gateway is learnt from the RA(s)

IP / Other	M	O	Comments
SLAAC / SLAAC	0	0	If dual-stack, could use IPv4 for DNS
SLAAC / DHCPv6	0	1	DHCPv6 Stateless
DHCPv6 / SLAAC	1	0	If dual-stack, could use IPv4 for DNS
DHCPv6 / DHCPv6	1	1	Gateway is learnt from RA

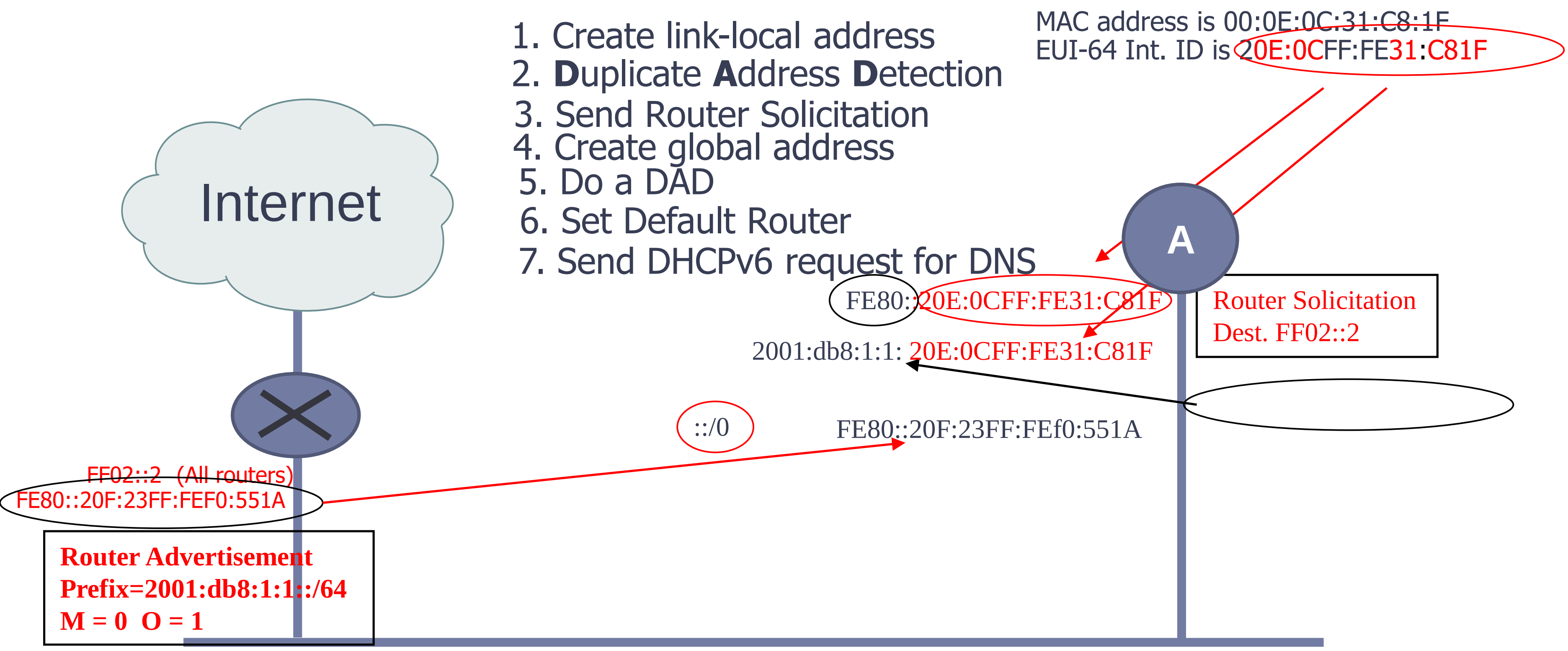
IPv6 Protocols and Autoconfiguration (VII)

- Host A attaches to a network with a Router



IPv6 Protocols and Autoconfiguration (VIII)

- In practice SLAAC for DNS is not yet available. Use IPv4 for DNS resolution (dual-stack) or DHCPv6 (O = 1)



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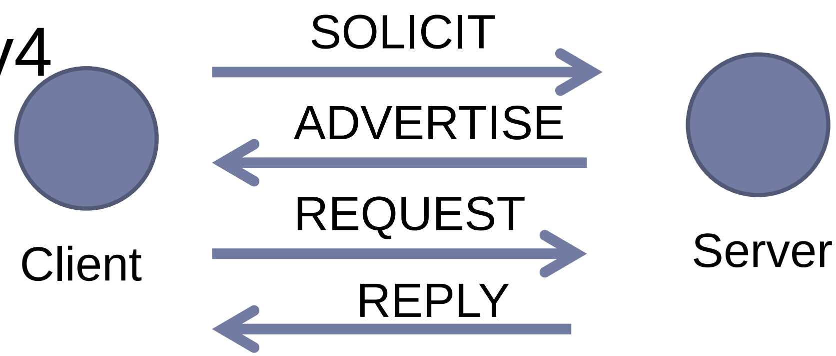
IPv6 Protocols and Autoconfiguration (IX)

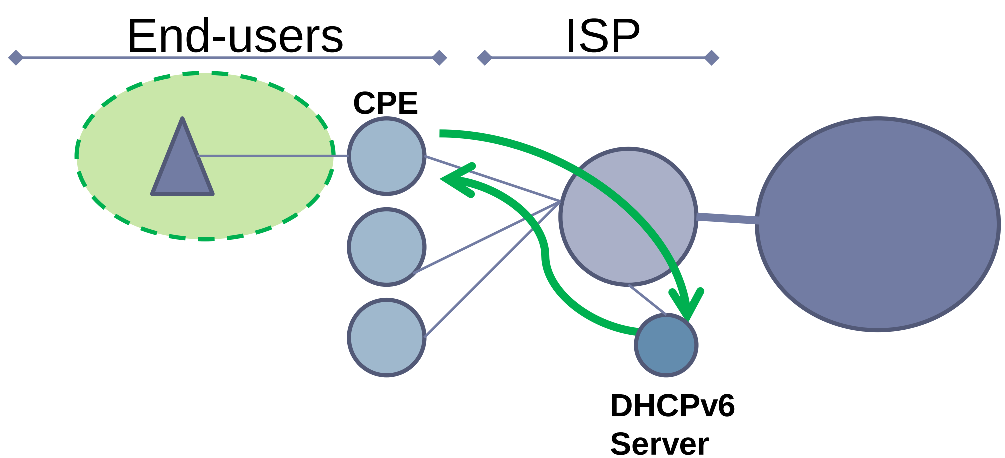
- DHCPv6 works as DHCPv4
  - Client-server
  - UDP
  - Use of proxy



- DIFFERENCE: Does not provide default gateway
- Messages names change: SOLICIT, ADVERTISE, REQUEST,REPLY
- Servers listen on well-known multicast addresses (FF02::1:2)
- DHCPv6 stateless: only provides “other” info, not IP

IPv6 Protocols and Autoconfiguration (X)

- DHCPv6-PD (Prefix Delegation)
- In IPv6 no private IP + NAT. A GUA prefix is needed
- DHCPv6-PD allows scalable configuration of IPv6 prefixes in routers
- Same as for IP addresses: client-server, etc.
- Only changes the requested object: a prefix (IA-PD)
- Example: CPE connected to an ISP



Thanks!

- Questions?

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