IPv6

Réseaux Avancés

IPv6
(Internet Protocol version 6)

IPv6

- **IP version 6 is the new version of the Internet Protocol (IP)**
- **The standardization process started in the '90s**
- **The main elements of IPv4 are still there, but there are some important changes**
- **… and, more important, the IP address length is now 128 bits, instead of only 32**
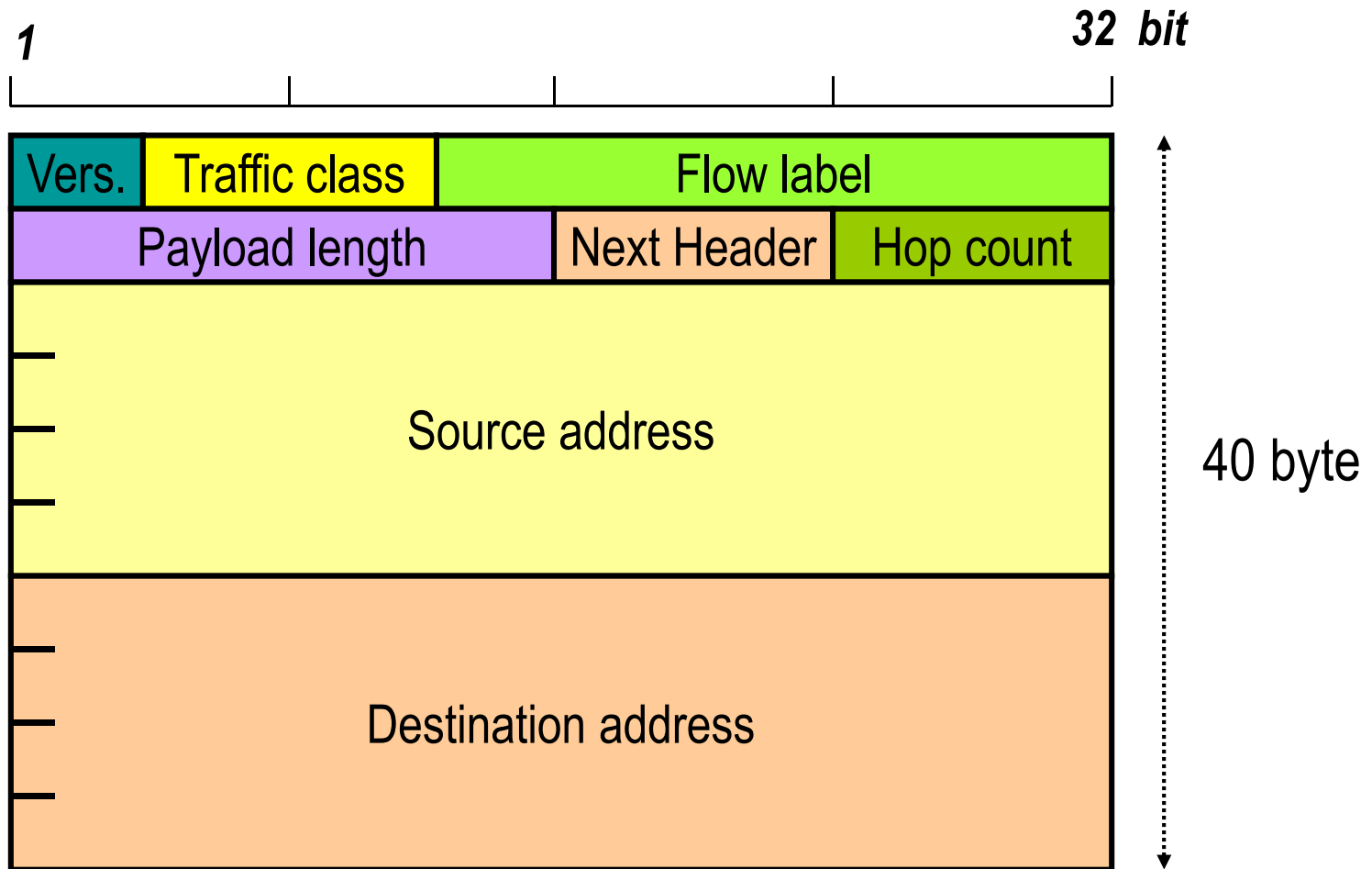
Motivations to introduce IPv6

- **IPv4 address space exhaustion**

- **Introduction of supports to Real-Time applications**

- **Supports for authentication (necessary, for example, for E-Commerce applications)**

IPv6: the main novelties

- **IPv6**
  - **Address length, options management, fragmentation management, introduction of flow identifiers, traffic classes, no header checksum, etc.**
- **ICMPv6:**
  - **New version of ICMP with enhanced functionalities**
- **ARP:**
  - **Eliminated. At his place we have ICMPv6 Address Resolution**
- **DHCPv6**
  - **Modified for the new protocol (some functionalities are performed by ICMPv6)**
- **Routing**
  - **RIPng and OSPFv6**

Base Header IPv6

1   *32 bit*

Vers.	Traffic class	Flow label		
Payload length		Next Header	Hop count	

Source address

Destination address

40 byte

- **The Base Header length is <u>FIXED</u> (<u>40 bytes</u>)**

IPv6 Header

Field	Length (bits)	Description
Version	4	Protocol Version (6)
Traffic Class	8	Used to identify different types of traffics in Differentiated Services (DS) networks
Flow Label	20	Used to identify a flow of packets (like *labels* in MPLS)
Payload Length	16	Payload length in bytes (except headers, Base+eventually extension headers)
Next Header	8	Identifies the type of header that follows the Base header
Hop Limit	8	Same function as Time To Live in IPv4
Source Address	128	Source IPv6 address
Destination Address	128	Destination IPv6 address

Next Header
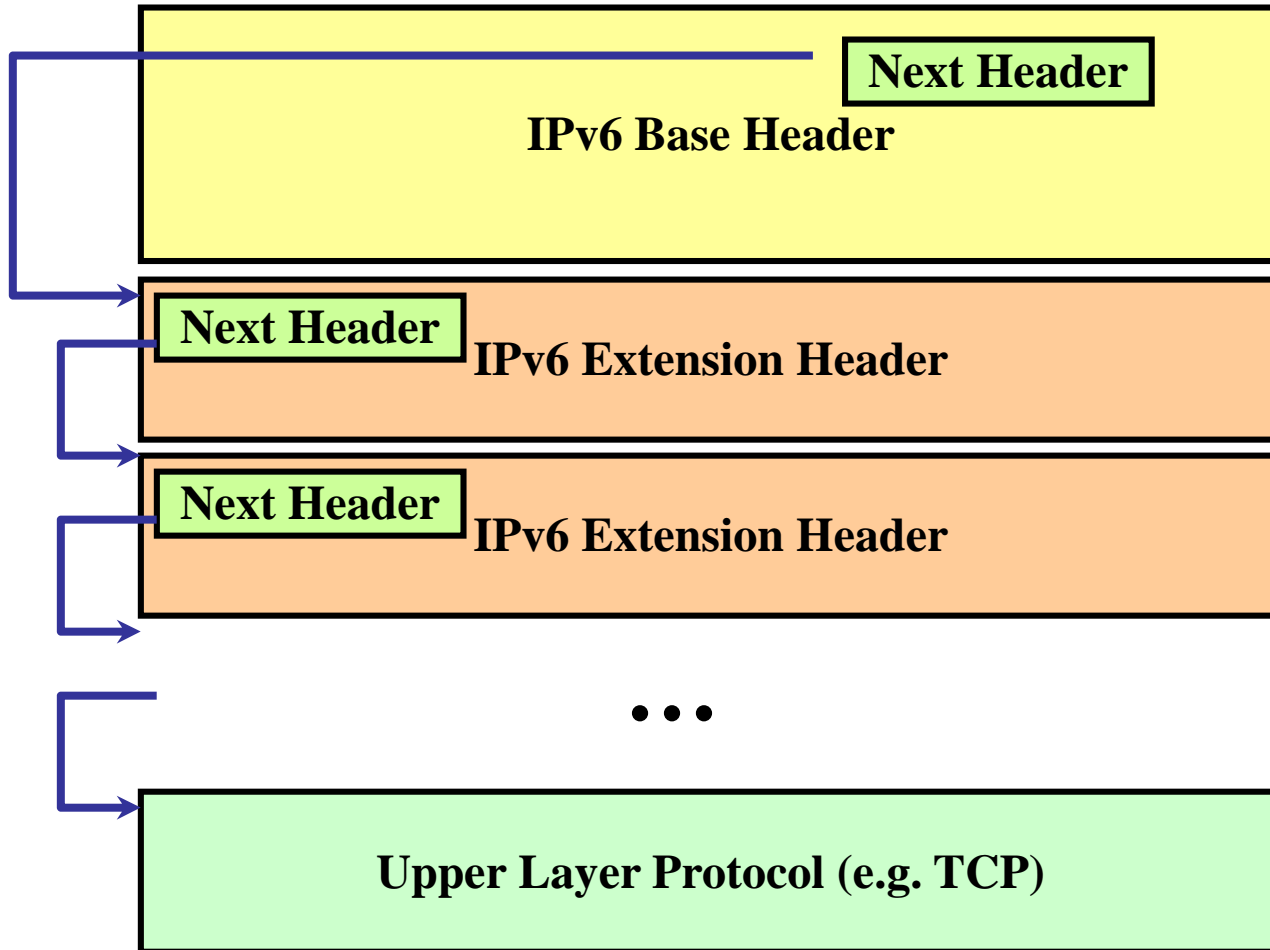
IPv6 Extension Headers

- **Routing Header:**
  - **IPv6 can implement, exactly like IPv4, a loose source routing**
  - **Differently from IPv4, where we had an option for this, in IPv6 there is an Extension Header for this functionality**
  - **The Routing Header is used by the IPv6 source node (the packet sender) to specify one or more intermediate nodes (routers) that must be traversed by a packet in its way towards the destionation**
  - **Very similar to the Loose Source and Record Route options in IPv4**
  - **The Routing header is identified with a Next Header value of 43**

IPv6 Extension Headers

- **Fragment Extension Header:**
  - **It is used to manage fragmentation. In IPv6 <u>only the sender</u> can fragment a packet, differently from IPv4 where *any router* along the path can fragment a packet**
  - **This permits to reduce the overhead caused by such operation in routers**
  - **To know if fragmentation is needed or not, the sender must know the MTU of the whole path (this is obtained using the <u>MTU Path discovery message of ICMPv6</u>)**
  - **When a route changes, the MTU can diminish, so that fragmentation would still be needed**
  - **In such case, ICMPv6 has been extended: the router can tell the packet sender (using an appropriate ICMPv6 message) that fragmentation is needed.**
  - **IPv6 standard does not encourage the utilisation of fragmentation. It encourages applications to send packets with length inferior to the path MTU**
  - **The Fragment Header is identified with a Next Header value of 44**

IPv6 Extension Headers

- **Authentication Header**
  - **To authenticate the sender**
- **Encapsulating Security Payload (ESP)**
  - **To cypher the payload (another IP packet or upper layer TCP/UDP messages)**

IPv6 Addresses

Synthetic Notation:

- **The classic IPv4 notation (dotted decimal) is not efficient:**

  104.230.140.100.255.255.255.255.0.0.17.128.150.10.255.255

- **The Colon Hexadecimal Notation is introduced:**

  68E6:8C64:FFFF:FFFF:0:1180:96A:FFFF

- **Consecutive Zeros can be omitted (only one time in the address!):**

  FF05:0:0:0:0:0:0:B3 ⟶ FF05::B3

- **Special notation to support transition from IPv4**

  0:0:0:0:0:0:128.10.2.1 ⟶ ::128.10.2.1

  last 32 bits

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Using Synthetic Notation

- **The following addresses…**

3080:0:0:0:8:800:200C:417A	unicast-address
FF01:0:0:0:0:0:0:43	multicast-address
0:0:0:0:0:0:0:1	loopback-address
0:0:0:0:0:0:0:0	unspecified-address

- **…can be expressed as follows:**

3080::8:800:200C:4170	unicast-address
FF01::43	multicast-address
::1	loopback-address
::	unspecified-address

IPv6 Addreses

- **Addressing space in IPv6:**
  - ✓ $2^{128}=3.4*10^{38}$
- **Number of addresses for square meter on the Earth:**

  $7x10^{23}$ (greater than Avogadro number!!!)

- **If we assign 1 million addresses for each nanosecond**
  - ✓ We need 10^{16} years to assign them all

IPv6 Address Types

- **IPv6 has a rich set of addresses. Each interface normally has more than 1 address assigned**

- **Address types:**
  - **Unicast (*only 1 destination*)**
  - **Multicast (*all those who belong to a group*)**
  - **Anycast**
    - ✓ **Like multicast addresses, they identify a group of nodes**
    - ✓ **Differently from multicast, a packet destined to an anycast address will be delivered to the node (belonging to the anycast group) CLOSER to the source node (based on routing metrics)**
    - ✓ **In this way it is possible to identify the closer router, the closer DNS server …**

Address Space in IPv6

Reserved for:
✓Unspecified
✓Loopback
✓IPv6 addresses
compatible with IPv4

Unicast addresses for
local use:
✓Link Local: used for
autoconfiguration and
neighbor discovery
✓Site Local: similar to
private addresses in IPv4
(class 10.0.0.0)

prefix (binary)	usage	fraction
0000 0000	Reserved	1/256
0000 0001	Unassigned	1/256
0000 001	Reserved for NSAP Allocation	1/128
0000 010	Reserved for IPX Allocation	1/128
0000 011	Unassigned	1/128
0000 1	Unassigned	1/32
0001	Unassigned	1/16
001	Aggregatable Global Unicast addr.	1/8
010	Unassigned	1/8
011	Unassigned	1/8
100	Unassigned	1/8
101	Unassigned	1/8
110	Unassigned	1/8
1110	Unassigned	1/16
1111 0	Unassigned	1/32
1111 10	Unassigned	1/64
1111 110	Unassigned	1/128
1111 1110 0	Unassigned	1/512
1111 1110 10	Link local Unicast Addresses	1/1024
1111 1110 11	Site local Unicast addresses	1/1024
1111 1111	Multicast	1/256

Special Addresses (Reserved)

- **Unspecified address (0:0:0:0:0:0:0:0)**
  - **Used as *source* address during bootstrap phase (the node does not have other addresses)**
  - **It CANNOT be used as destination address**
- **Loopback address (0:0:0:0:0:0:0:1)**
  - **Analogous to 127.x.y.z in IPv4**
- **IPv4-compatible IPv6 address (::IPv4_addr) (deprecated)**
  - **The host with such address has ALSO a valid IPv6 address**
  - **Used to permit communications between IPv6 hosts when an IPv4 network is traversed**
  - **Disabled in Windows by default. To enable, use the command netsh interface ipv6 set state v4compat=enabled**
  - **Format: 80 zeros + 16 zeros + 32 bit IPv4_address**
- **IPv4-mapped IPv6 address (::FFFF:IPv4_addr)**
  - **The host has ONLY an IPv4 address**
  - **Used to make IPv6 hosts communicate with IPv4 hosts**
  - **Format: 80 zeros + 16 ones + 32 bit IPv4_address**

Aggregatable Global Unicast Address (RFC 3587)

- **Global unicast address format**
- **It has a hierarchical structure, to permit aggregation and reduce scalability problems with routing tables**
- **<u>Global Routing Prefix</u> (organized hierarchically): it is assigned to a Site/Organization**
- **<u>Subnet ID</u>: identifies a Subnet inside the Site.**
  - **This field is used by organizations to define a hierarchy inside the AS, defining the subnets**
  - **16 bits are available: up to 65536 subnets can be defined**
- **<u>Interface ID</u>**
  - **64 bits with format derived from IEEE EUI-64 (EUI: Extended Unique Identifier)**

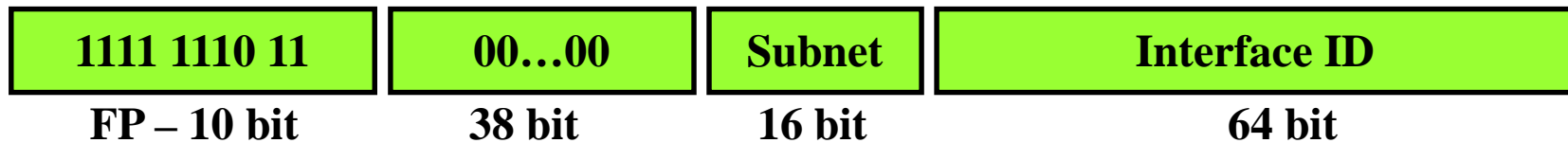| 001	Global Routing Prefix	Subnet ID	Interface ID
3 bit	45 bit	16 bit	64 bit

FP (Frame Prefix)
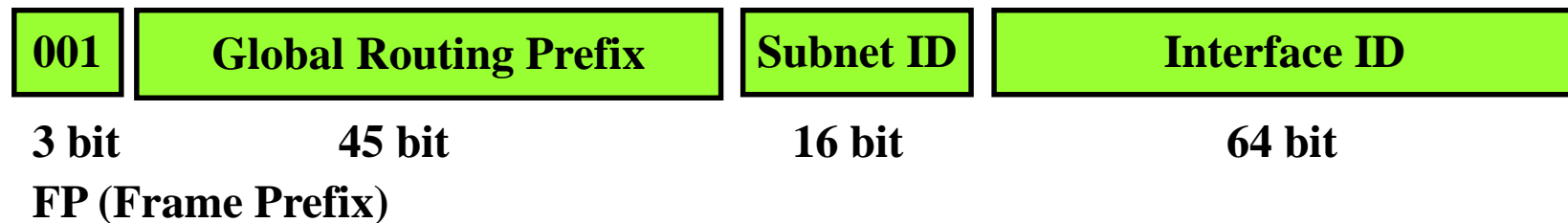
Link-Local Unicast Address

- **FP = 1111 1110 10**
- **They are used ONLY to address machines on a single link (which means, for example, on a single LAN segment)**
- **In IPv6 each interface has at least one link-local unicast address**
  - **Which is normally defined using autoconfiguration, starting from the physical address (IEEE EUI-64) (EUI= Extended Unique Identifier)**
- **These addresses are fundamental in the Neighbor Discovery process**

1111 1110 10	00…00	Interface ID
FP – 10 bit	**54 bit**	**64 bit**

Site-Local Unicast Address

- **FP = 1111 1110 11**
- **Also these addresse are destined to a local use**
- **They define a private address space (equivalent, for example, to class 10 in IPv4)**

1111 1110 11	00…00	Subnet	Interface ID
FP – 10 bit	38 bit	16 bit	64 bit

- **Note that: if the prefix of a Site-Local address is replaced by the Global Routing Prefix, we obtain a global address very easily**

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EUI-64 format

- The "Interface ID" field identifies an interface; hence it must be unique

- The EUI-64 identifier is a 64 bit number that identifies both the manifacturer and the "serial number" of the card (in a similar way to Ethernet MAC addresses)

1. If a card already has an EUI-64 identifier, then it <u>almost</u> has its Interface ID.

2. For Ethernet cards, there exists a procedure which starts from the MAC-Address (48 bits long) and permits to obtain the EUI-64 format
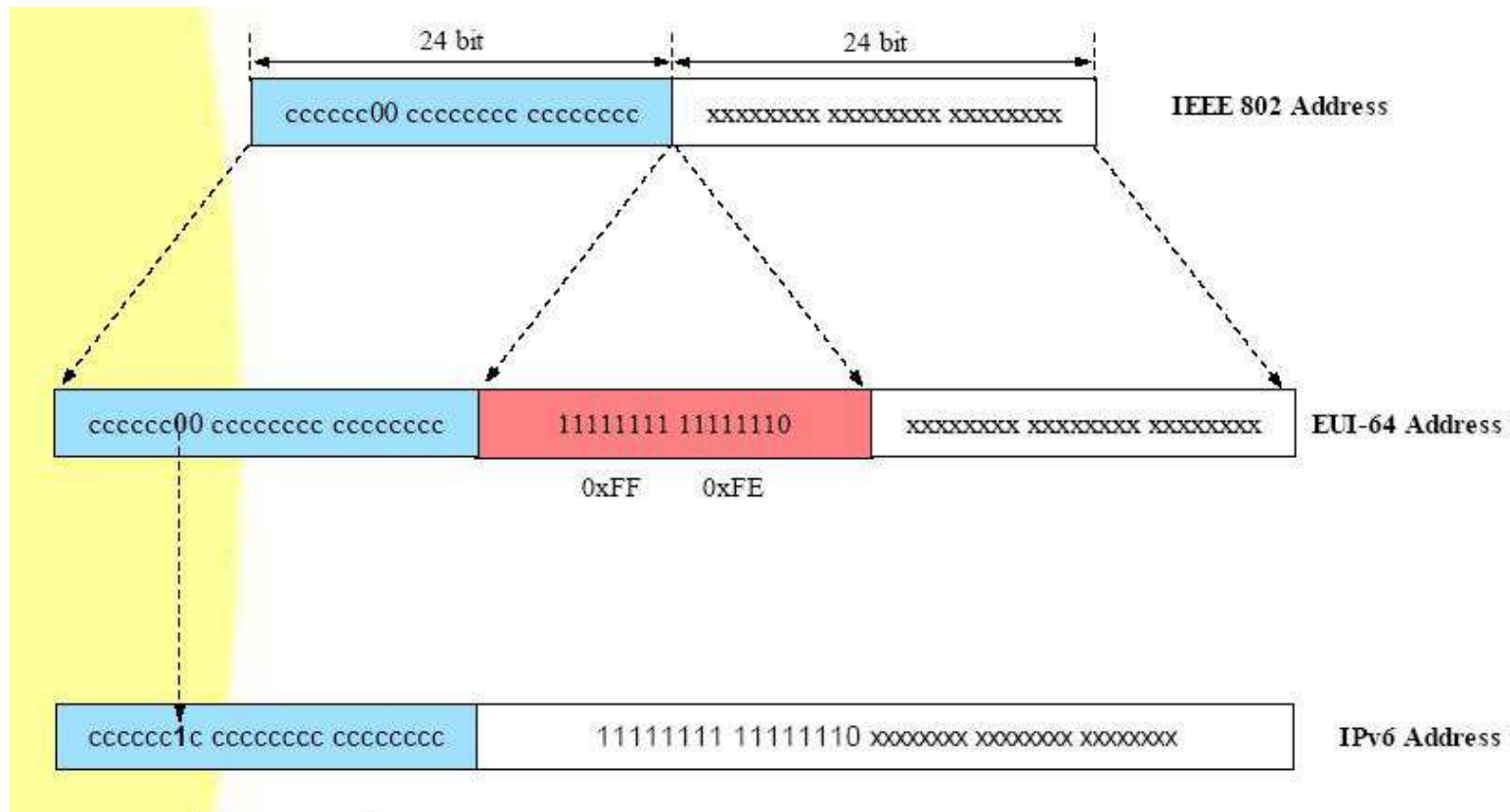
Building the Interface-ID (1)

- **Very easy!**

- **The Interface-ID in IPv6 is obtained from the EUI-64 inverting the Universal/Local bit (the 7th bit)**
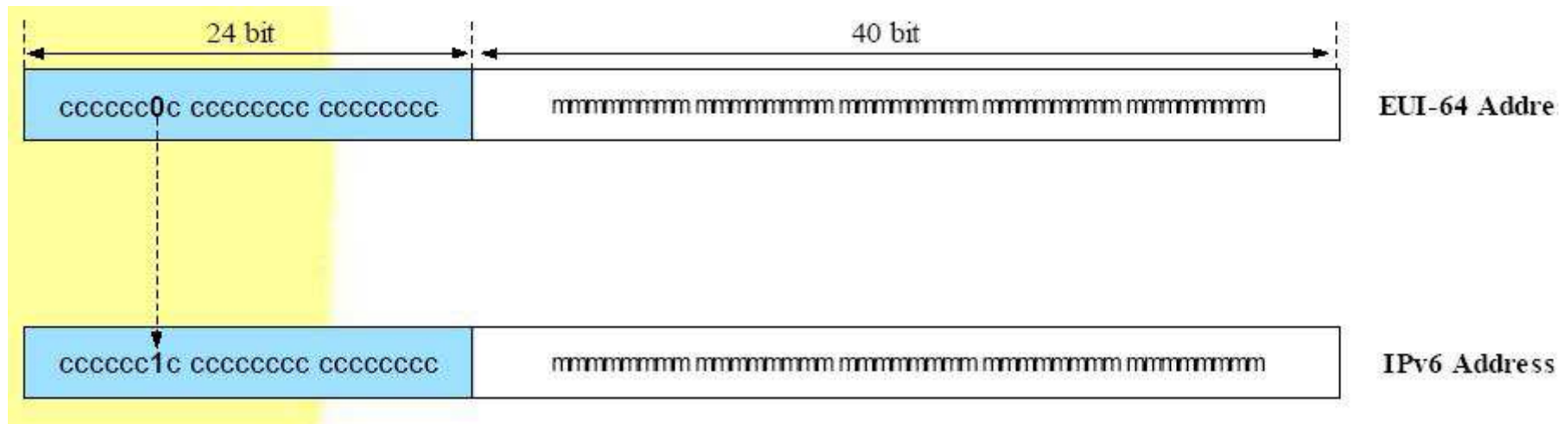
Building the Interface-ID (2)

- **Starting from a MAC address**

Example

- **MAC Address:** 00-AA-00-3F-2A-1C
- **EUI-64 Address:** 00-AA-00-FF-FE-3F-2A-1C
- **Inverting U/L bit:** 02-AA-00-FF-FE-3F-2A-1C
- **Using IPV6 notation:** 2AA:FF:FE3F:2A1C

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Multicast Address
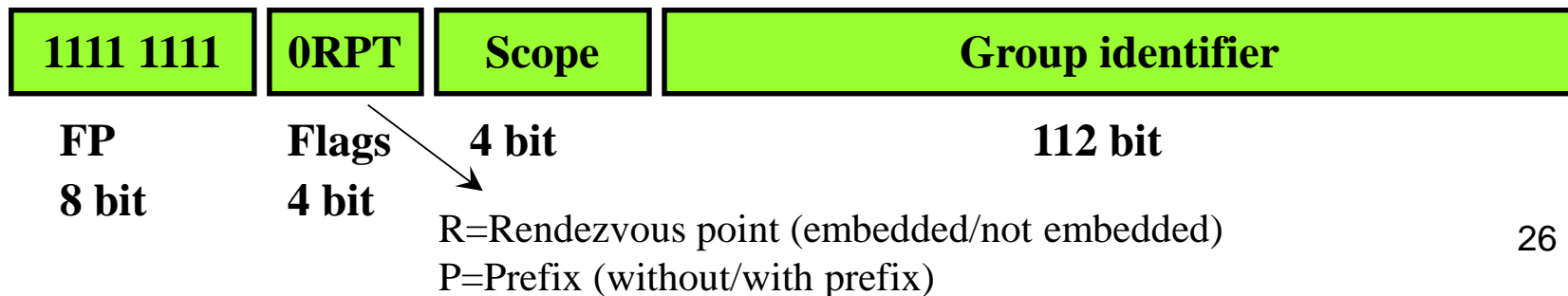
- **FP = 1111 1111 (or equivalently, in hexadecimal: "FF")**
- **Different sub-types of Multicas Addresses**
    - **Multicast global**
    - **Multicast link-local**
    - **Multicast site-local**
- **There exist several addresses reserved for special uses**

1111 1111	0RPT	Scope	Group identifier
FP 8 bit	Flags 4 bit	4 bit	112 bit

Multicast Address

- **Flags:**
  - **T=1** *non–permanent* **(Transient) address**
  - **T=0** *permanent* **address**
- **Scope (4 bits field):**
  - **0: reserved**
  - **1: interface-local scope**   ⟶ Packets with this destination address may not be sent over any network link, but must remain within the current node. It is the multicast equivalent of the unicast loopback address.
  - **2: link-local scope**
  - **5: site-local scope**
  - **8: organization-local scope**
  - **E: global scope**
  - **All others: unassigned**

1111 1111	0RPT	Scope	Group identifier
FP 8 bit	Flags 4 bit	4 bit	112 bit

R=Rendezvous point (embedded/not embedded)
P=Prefix (without/with prefix)

Special Multicast Addresses

- **FF01::1 = all systems node-local scope**
- **FF02::1 = all systems link-local scope**
- **FF01::2 = all-routers node-local scope**
- **FF02::2 = all-routers on the local network segment**
- **FF05::2 = all-routers site-local scope**

All these addresses are used in a similar way as local broadcast addresses, distinguishing between all systems and all routers

Special Multicast Addresses

- **Solicited-Node Multicast address**
  - **Each IPv6 node must have a "solicited-node multicast address" for each unicast or anycast address configured on the node itself**
  - **It is meant to facilitate efficient querying of network nodes during address resolution**
  - **Such address is built authomatically concatenating the prefix**

    FF02::1:FF00:0/104

  - **… with the last 24 bits of the corresponding unicast or anycast address**

XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXyy	yyyy

| FF02	0000	0000	0000	0000	0001	FFyy	yyyy

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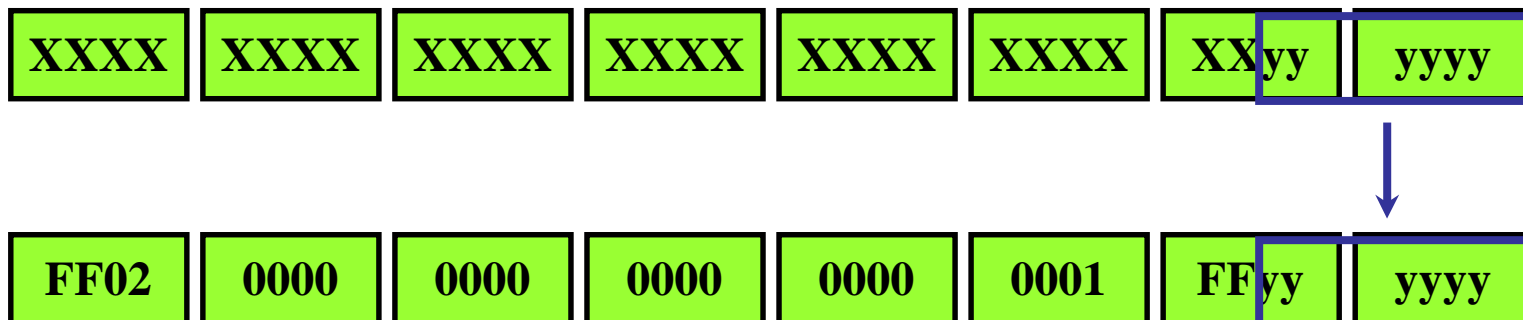
Several addresses for different functions

- **IPv6 has several self-configuration processes**
- **Normally, each node must:**
    - **Self-configure a link-local address starting from its physical address (Ethernet or EUI-64)**
    - **Self-configure a solicited-node multicast address for each of its unicast/anycast address**
    - **It can further self-configure other addresses using different procedures (ICMP/ DHCP)**

ICMP version 6

- **ICMP has a greater importance in IPv6 than in IPv4**
- **Some of its functions are:**
    - **Error reporting and network diagnostic**
    - **Address resolution**
    - **Self-configuration of IPv6 addresses**
    - **PATH-MTU computation (to manage fragmentation)**

ICMPv6: message structure

| Next header =58 |

ICMP_Type	ICMP_Code	Checksum
Message Body		
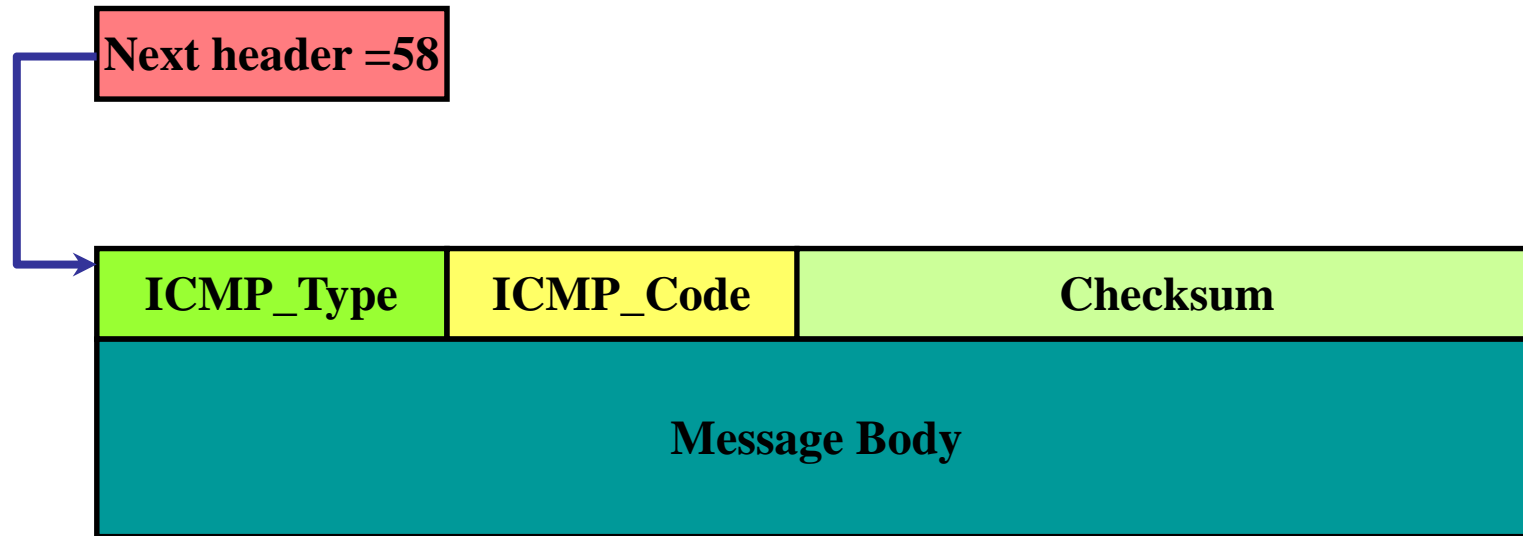
Some common types

- **Type=1 – destination unreachable**
- **Type=2 – Packet too big**
- **Type=3 – Time excedeed**
- **Type=4 – Parameter problem,**
- **Type=128 – Echo request**
- **Type=129 – Echo reply**

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ICMPv6 Neighbor Discovery

- **There are several Neighbor Discovery procedures in IPv6**
  - **Address Resolution**
    - ✓ **Analogous to ARP for IPv4**
  - **Router Discovery**
    - ✓ **To signal and discover the presence of routers on a network link**
  - **Redirection**
    - ✓ **Similar to redirection in IPv4**
  - **Neighbor Unreachability Detection**

ICMPv6 Neighbor Discovery

- **Several special addresses are used (link-scope):**
  - **All-Systems Multicast Address (FF02::1)**
  - **All-Routers Multicast Address (FF02::2)**
  - **Solicited-node Multicast Address**
  - **Unicast Link-Local Address**
  - **Unspecified Address (0::0)**

- **5 new message types are introduced:**
  - **Router Solicitation message:**   **type=133**
  - **Router Advertisement message:**   **type=134**
  - **Neighbor Solicitation message:**   **type=135**
  - **Neighbor Advertisement message:**   **type=136**
 - **Redirect message:**   **type=137**

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ICMPv6 Address Resolution

- **Same function as ARP in IPv4**
- **Obviously, multicast/broadcast addresses are needed at the physical level**
  - **We suppose the existence of mapping between multicast IPv6 addresses and multicast/broadcast addresses at the link level**
- **"Neighbor Solicitation" and "Neighbor Advertisement" messages are used**

ICMPv6 Address Resolution

IPv6_addr

FE80::0800:2001:C782

Neighbor Solicitation msg

Who is FE80::0:C033:6382?

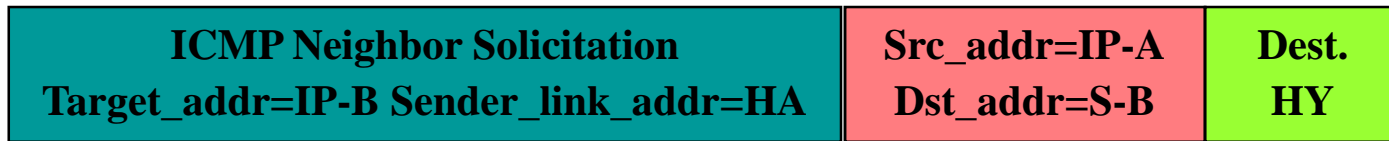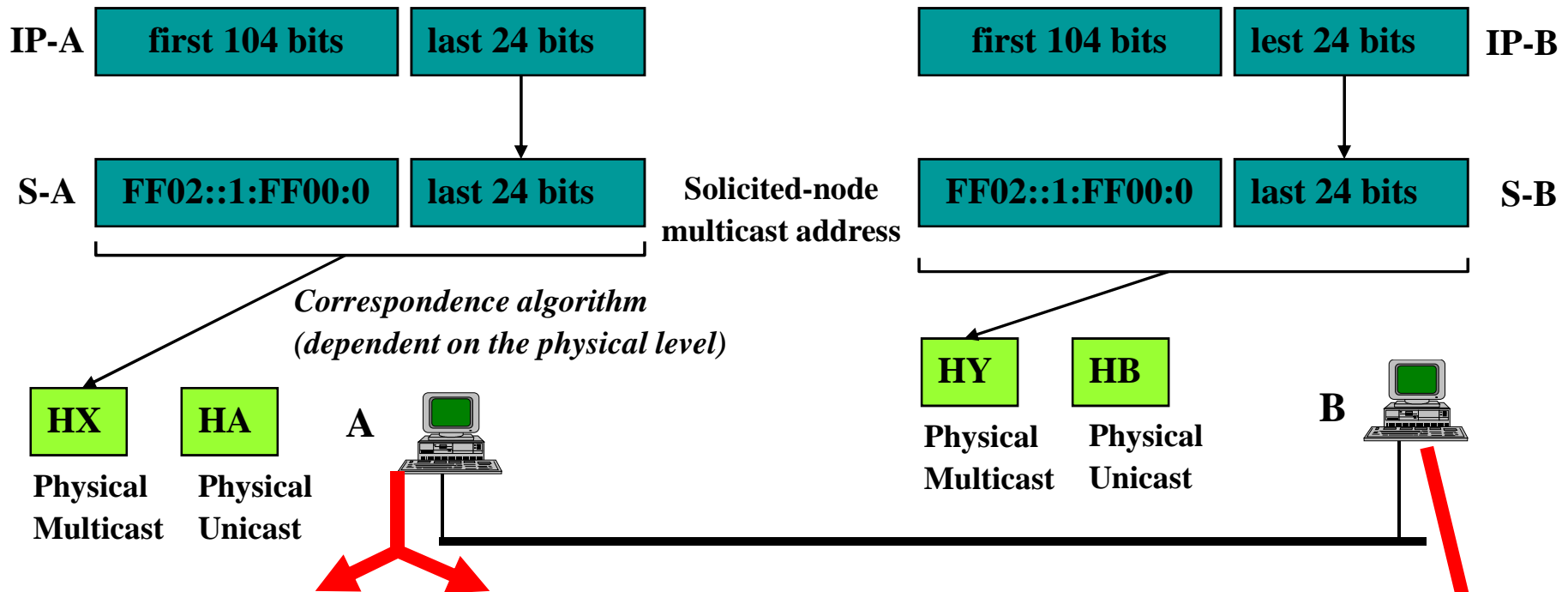**Neighbor Advertisement msg**

I am FE80::0:C033:6382

IPv6_addr

FE80::0:C033:6382
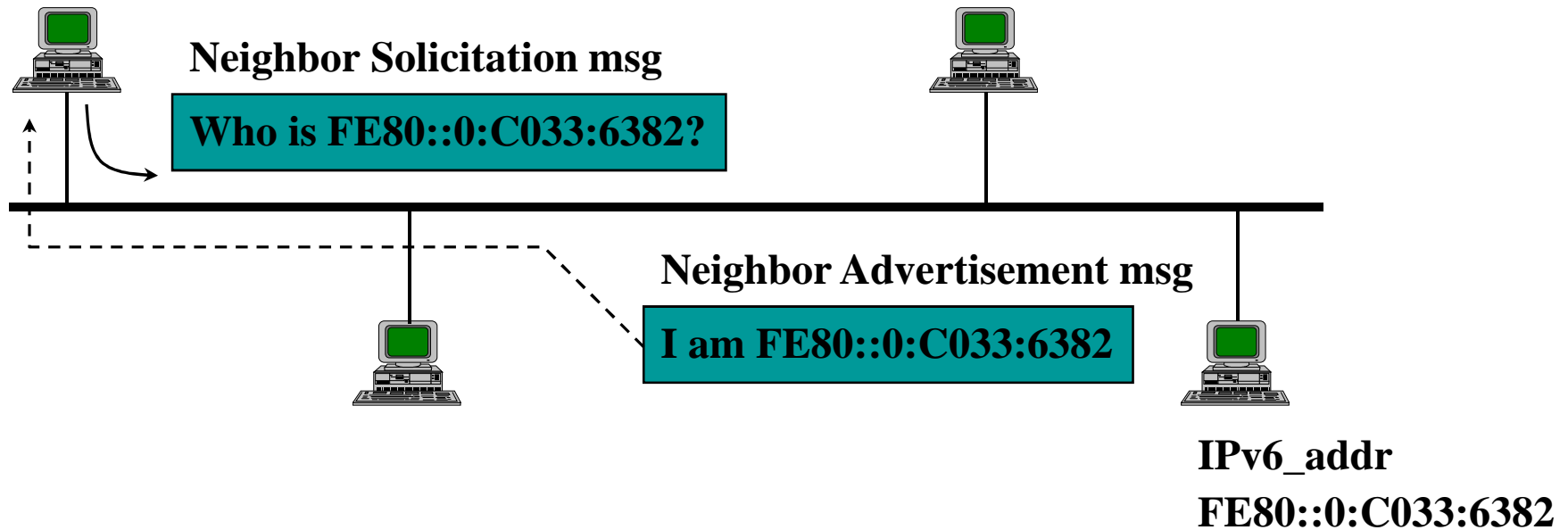
- **The Neighbor Solicitation message is sent at the Solicited-Node multicast address, which can be obtained also by the sender**
- **The Neighbor Advertisement message is sent to the IPv6 address of the requester**

ICMPv6 Address Resolution

IP-A	first 104 bits	last 24 bits

S-A	FF02::1:FF00:0	last 24 bits

first 104 bits	lest 24 bits	IP-B

Solicited-node multicast address

FF02::1:FF00:0	last 24 bits	S-B

Correspondence algorithm (dependent on the physical level)

HX   **HA**   **A**

Physical Multicast   Physical Unicast

HY   **HB**   **B**

Physical Multicast   Physical Unicast

ICMP Neighbor Solicitation Target_addr=IP-B Sender_link_addr=HA	Src_addr=IP-A Dst_addr=S-B	Dest. HY

Dest. HA	Src_addr=IP-B Dst_addr=IP-A	ICMP Neighbor Advertisement Target_addr=IP-B Sender_link_addr=HB

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MTU Path Discovery

- **The sender must know what is the smallest MTU along the path**

- **It sends one packet with the same length as the MTU of the first link**

- **If the ICMP error message ''Packet too big'' comes back, then the MTU is reduced, and a new packet is sent out again …**

- **… until no error message is received**

Transitioning from IPv4 to IPv6

- **It is based mainly on the following elements:**
  - **Dual stack:**
    - ✓**Systems with double stack, IPv4 and IPv6**
  - **Tunneling:**
    - ✓**IPv4 networks are traversed using tunneling**
  - **Header translation:**
    - ✓**Header translation between the two formats**