UNIVERSIDAD
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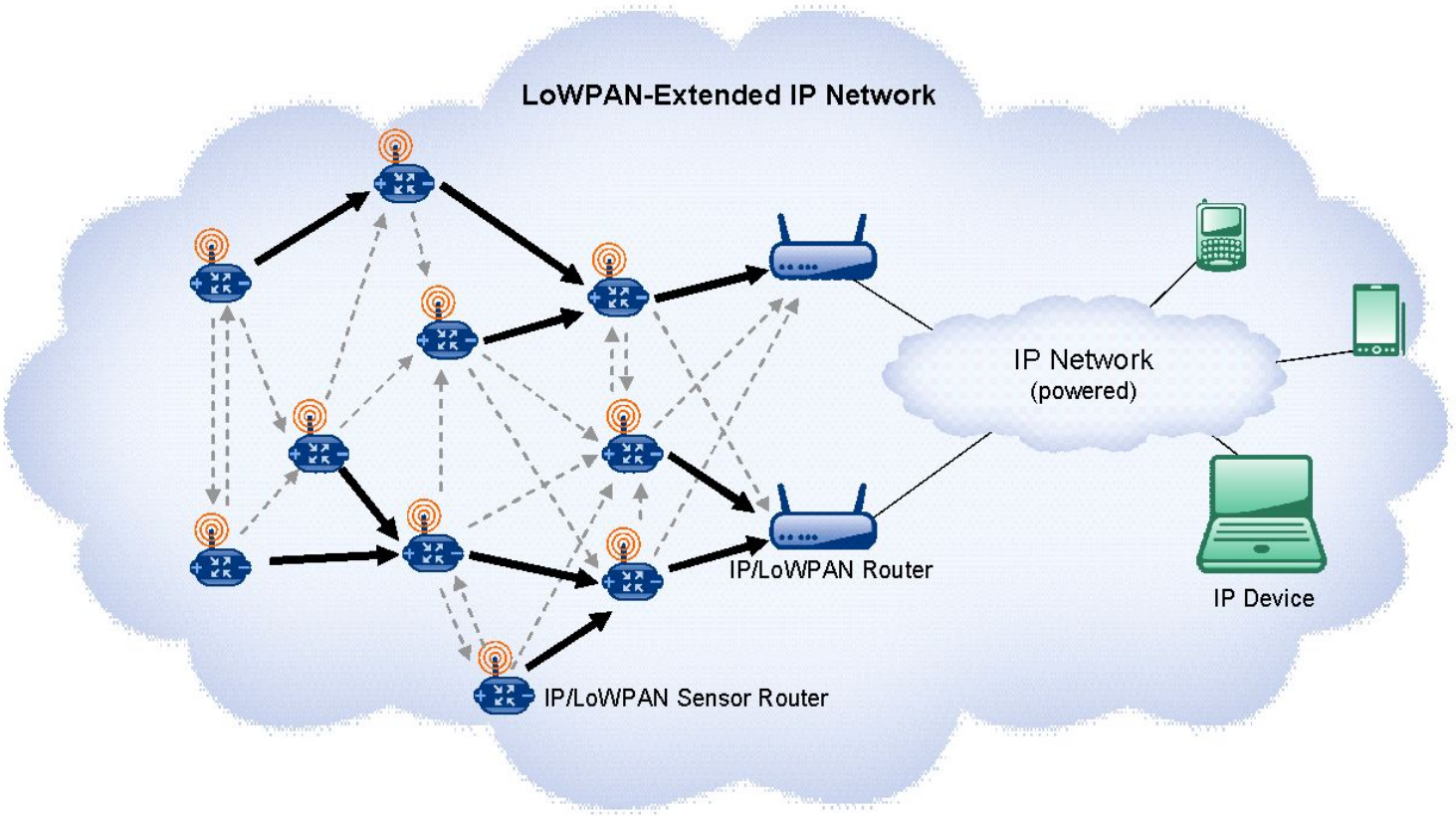
6LoWPAN

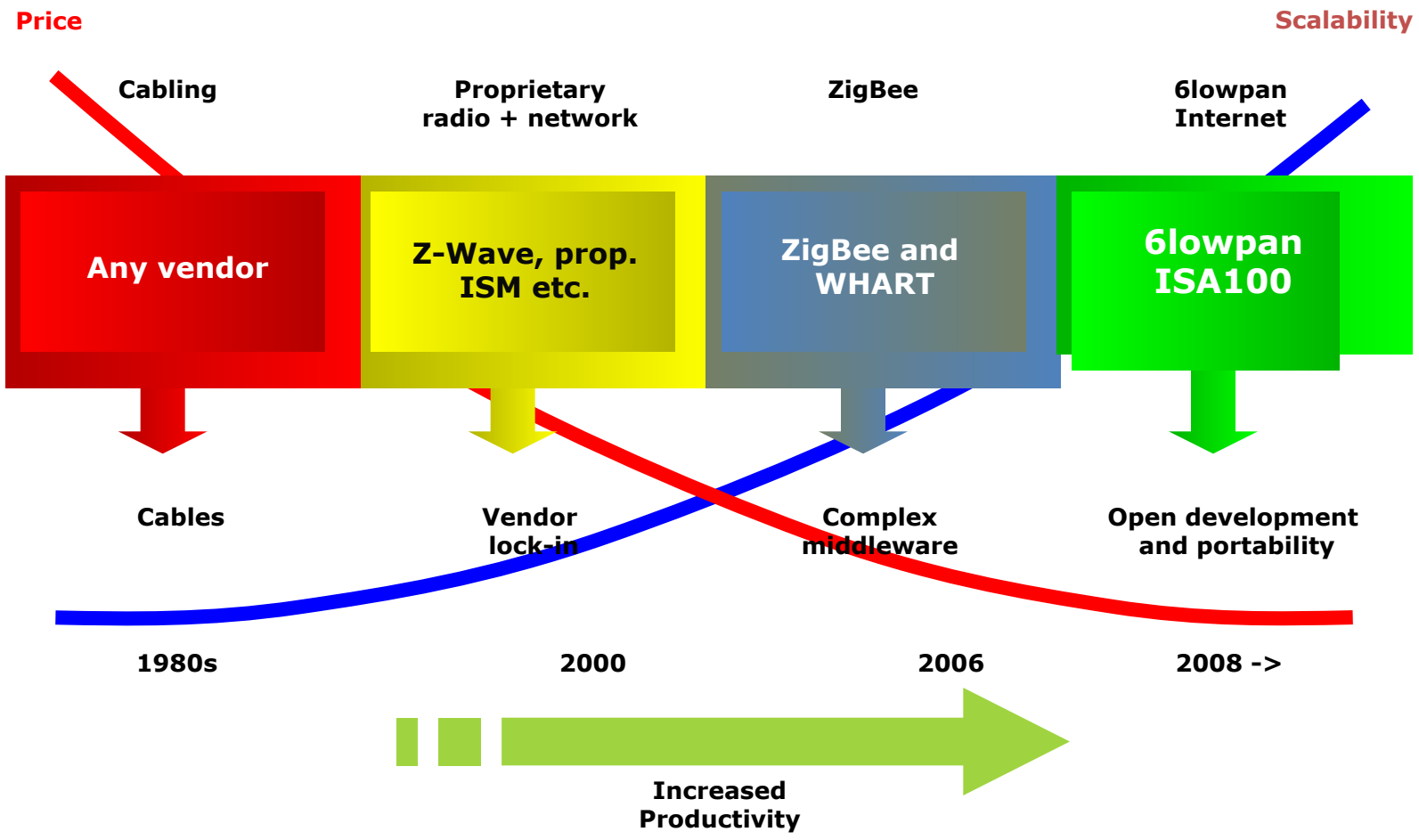
Networks and protocols 1

Facultad de Informática

Low Power Wireless Internet



Sensors networks technology evolution



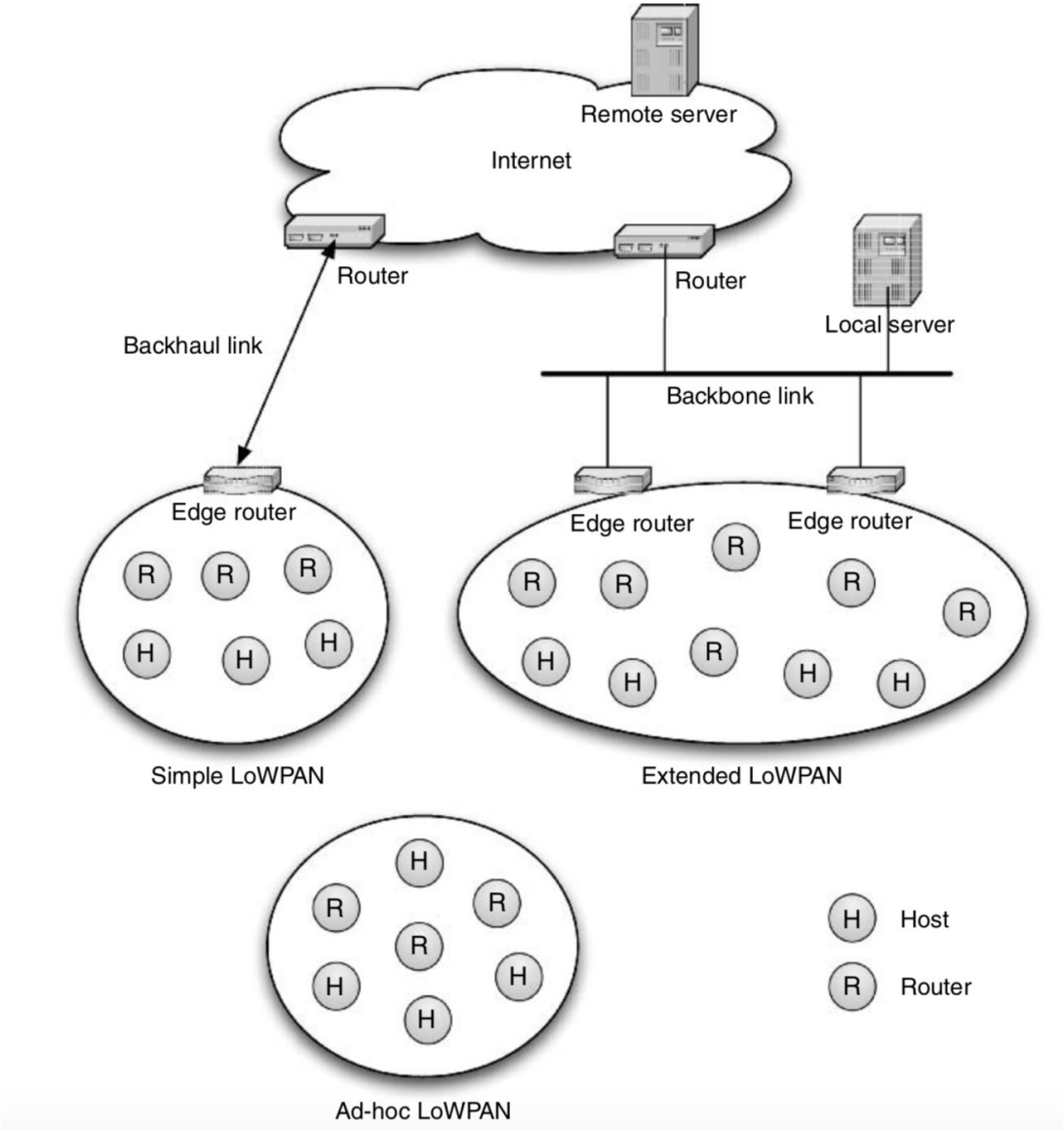
6LoWPAN

- Low power RF + IPv6 = *The Wireless Embedded Internet*
- Benefits:
  - **Open standards**, reliable and long life
  - **Easy learning curve**
  - Transparent integration in the **Internet**
  - Global **scalability**
  - **End-to-end** data flow
    - No **Gateways**

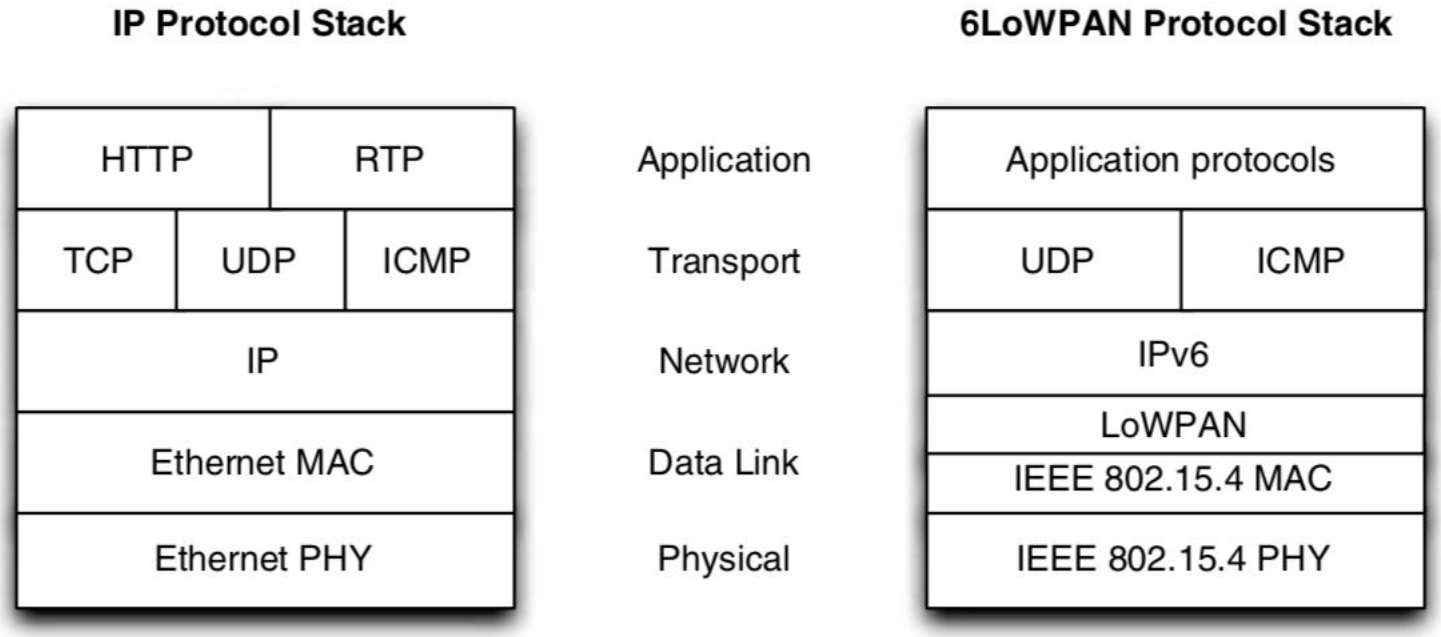
6LoWPAN in IETF

- Specified by the Internet Engineering Task Force (ETF)
  - RFC4919: requirements
  - RFC4944: 6LoWPAN encapsulation
  - RFC6282: update of the RFC4944 with new compressed format
  - RFC6550: RPL
  - RFC6568: 6LowPAN applications and use cases
  - RFC6606: Routing problem specification
  - RFC6775: Neighbour Discovery
  - RFC6066: Header extensions

6LoWPAN architecture



6LoWPAN: IPv6 over LLN



- Light protocols are preferred
  - UDP instead of TCP
  - Light alternatives to other application protocols (http, rest, soap, …)

IPv6 addressing

- 128 bits (16 bytes) addresses, several notations
  - Huge space: the population of the world is reaching 2^{34} people, each of them could have 2^{94} IPv6 addresses

Binary	10000000010110110010110110011101110111000010100000000000000000 00000000000000001111110001010111110101001100100000011111111111111

Dotted Decimal	128	91	45	157	220	40	0	0	0	0	252	87	212	200	31	255

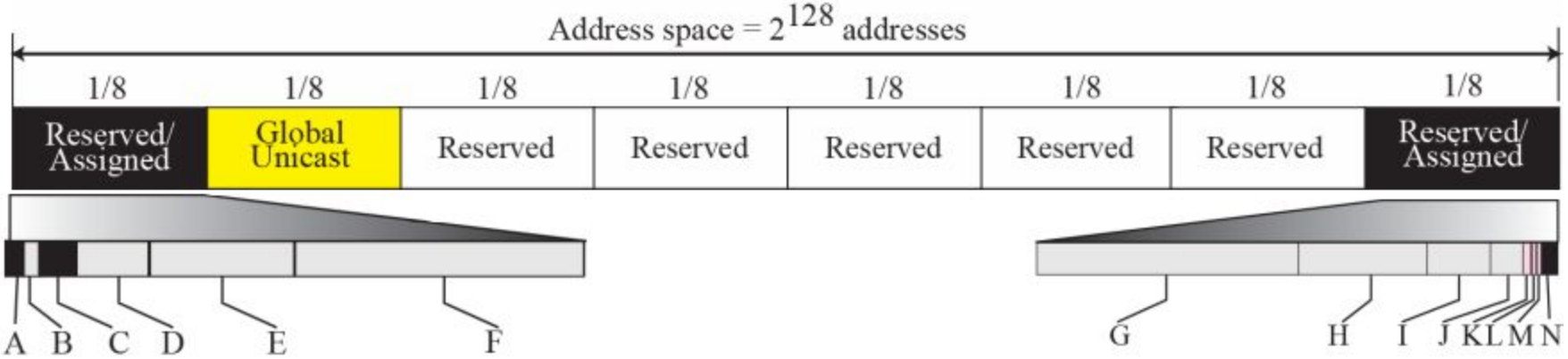
Hexadecimal	0			32			64			96			128
Straight Hex	805B	2D9D	DC28	0000	0000	FC57	D4C8	1FFF					
Leading-Zero Suppressed	805B	2D9D	DC28	0	0	FC57	D4C8	1FFF					
Zero-Compressed	805B	2D9D	DC28	::		FC57	D4C8	1FFF					
Mixed Notation	805B	2D9D	DC28	::		FC57	212	200	31	255			

IPv6 addressing

- Prefixes: common part of the network addresses, indicates the network
  - CIDR (Classless Inter Domain Routing) notation
  - Address/Prefix length in bits

FDEC::BBFF:0:FFFF/60

- Address space organization:



A: 1/256 IPv4 Compatible
B: 1/256 Reserverd
C: 1/128 Reserved
D: 1/64 Reserved
E: 1/32 Reserved
F: 1/16 Reserved
G: 1/16 Reserved
H: 1/32 Reserved
I: 1/64 Reserved
J: 1/128 Unique Local Unicast
K: 1/512 Reserved
L: 1/1024 Link Local
M: 1/256 Reserved
N: 1/256 Multicast

IPv6 prefixes

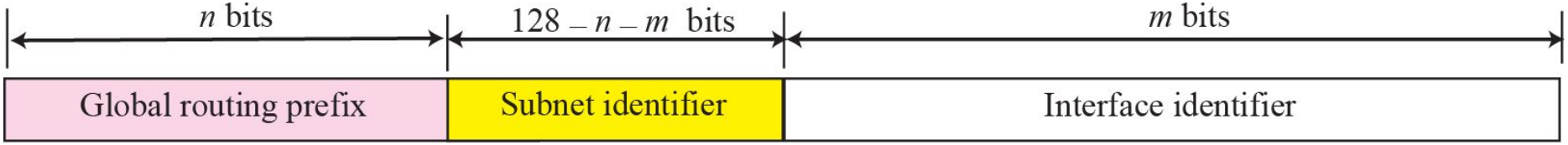
	Block Prefix	*CIDR*	*Block Assignment*	*Fraction*
1	0000 0000	0000::/8	Reserved (IPv4 compatible)	1/256
	0000 0001	0100::/8	Reserved	1/256
	0000 001	0200::/7	Reserved	1/128
	0000 01	0400::/6	Reserved	1/64
	0000 1	0800::/5	Reserved	1/32
	0001	1000::/4	Reserved	1/16
2	**001**	**2000::/3**	**Global unicast**	**1/8**
3	010	4000::/3	Reserved	1/8
4	011	6000::/3	Reserved	1/8
5	100	8000::/3	Reserved	1/8
6	101	A000::/3	Reserved	1/8
7	110	C000::/3	Reserved	1/8
8	1110	E000::/4	Reserved	1/16
	1111 0	F000::/5	Reserved	1/32
	1111 10	F800::/6	Reserved	1/64
	1111 110	FC00::/7	Unique local unicast	1/128
	1111 1110 0	FE00::/9	Reserved	1/512
	1111 1110 10	FE80::/10	Link local addresses	1/1024
	1111 1110 11	FEC0::/10	Reserved	1/1024
	1111 1111	FF00::/8	Multicast addresses	1/256

IPv6 addresses: types and scopes

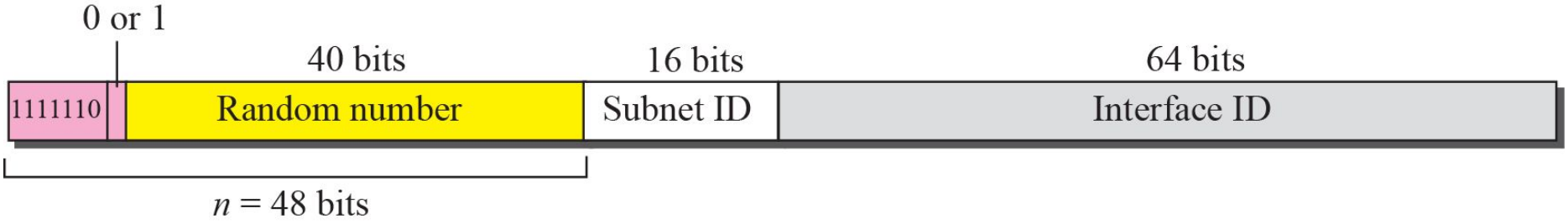
- Types
  - **Unicast**: addresses a single interface of a node
  - **Multicast**: addresses a group of interfaces. A datagram sent to a multicast address has to reach all the nodes that belong to the group
  - **Anycast**: addresses a group of interfaces. A datagram sent to an anycast address has to be delivered to only one of the devices in the group
- Scopes
  - **Link local**: identifies a node in its level 2 domain (link)
  - **Unique local**: identifies a node in its administrative domain
  - **Global**: identifies a node in the global Internet (unique in the whole Internet)

IPv6 Unicast Addresses

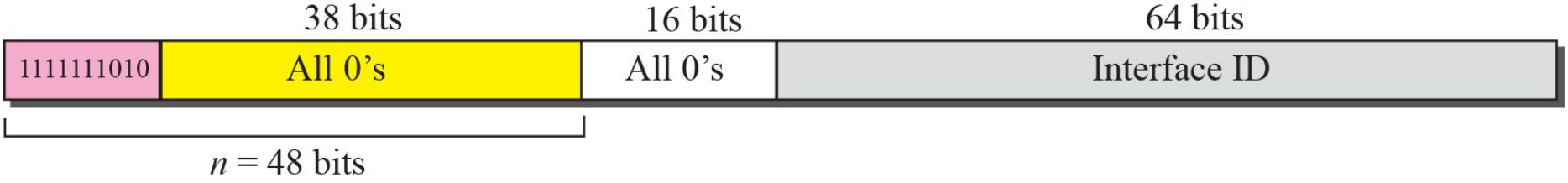
- Global unicast



- Unique local unicast

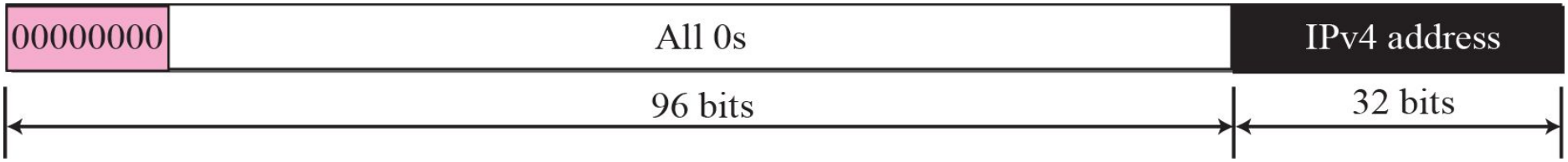


- Link local unicast

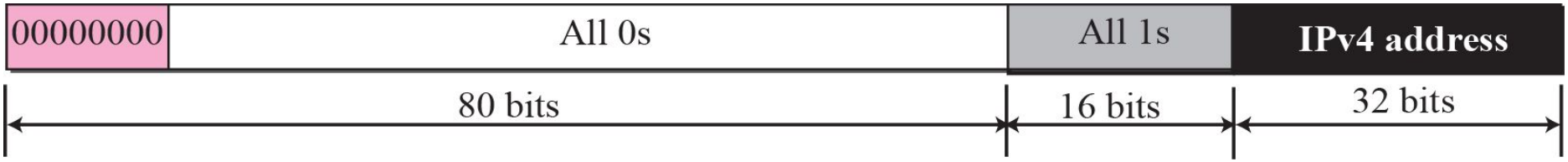


IPv6 other unicast Addresses

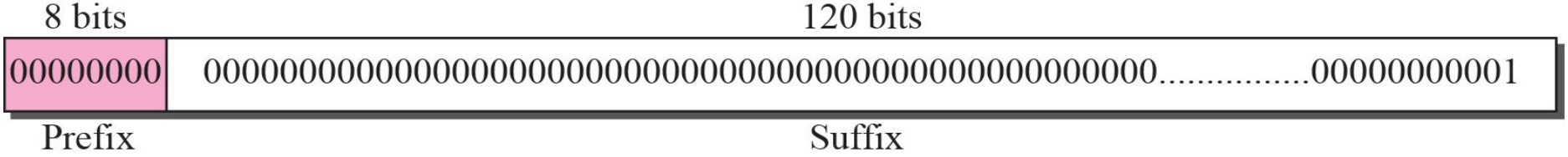
- IPv4 compatible



- IPv4 mapped



- Loopback

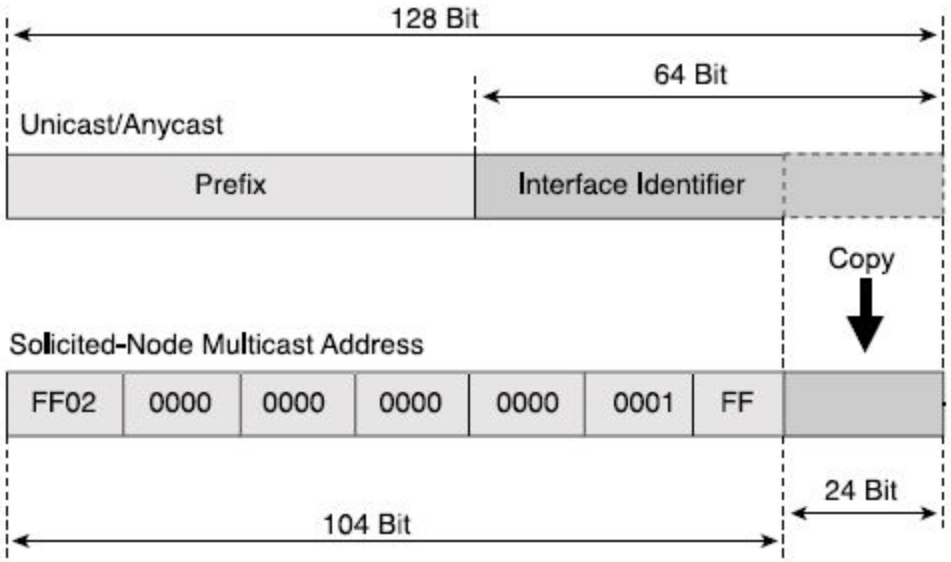


- Site-local (deprecated, in favour of the unique local)

IPv6 Multicast Addresses

- Multicast Address

- Solicited-Node Multicast Address (used in NDP)



IPv6 Neighbor Discovery Protocol

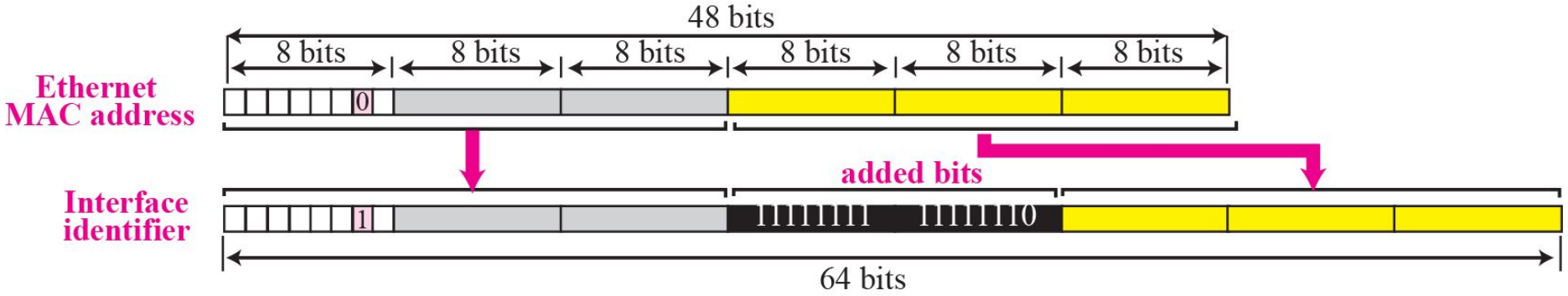
- IPv6 defines its own *Neighbor Discovery Protocol (NDP)*
  - A node uses the NDP to discover other devices in its link, obtain their MAC addresses and find routers
- NDP services
  - Router discovery
  - Prefix discovery
  - Parameter discovery (MTU, hop limit…)
  - Address autoconfiguration
  - Address resolution: obtain mac addresses from IPv6 addresses
  - DAD (Duplicate Address Detection)

IPv6 NDP messages

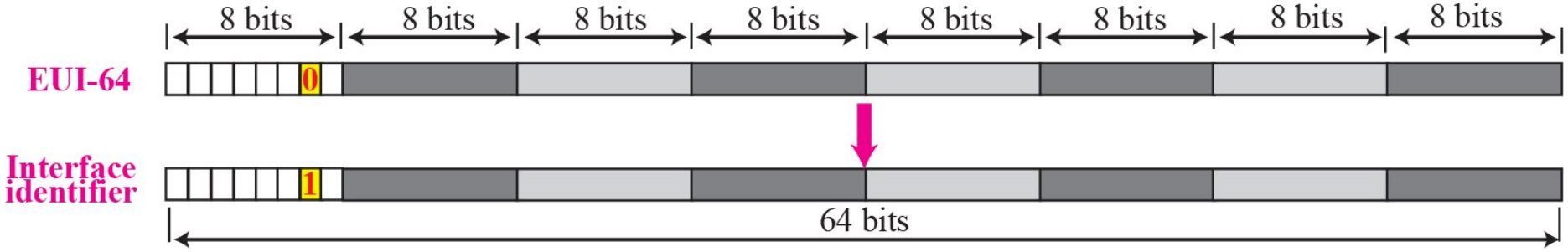
- Neighbor Solicitation Message (NS)
  - Used for address resolution, DAD, and neighbor detection
  - Sent by a node to obtain or confirm the MAC address of a neighbor known its IPv6 address
  - The neighbor responds with a NA message
- Neighbor advertisement (NA)
  - Provides the MAC address after a NS request
- Router Advertisement (RA)
  - Send periodically by the routers
  - Announce the presence of the routers and the parameters of the network (like network prefix, or if DHCP6 shall be used)
  - Send also as a response to a RS
- Router Solicitation (RS)
  - Send by a node to obtain a RA from the router
  - Destination address is usually the *all-routers multicast* (FF02::2)

IPv6 Autoconfiguration

- The nodes can configure their interface id part of the address:
  - From a 48 bits mac address



  - From a EUI-64 id



- The prefix used can be the one for a link local address or a unique local address

IPv6 Autoconfiguración

- Before an address can be used, the device must confirm that it is unique (DAD)
  - Interchange of NS and NA messages
- To obtain the *global unicast* address the node has to request the network prefix
  - Can wait to receive a RA message or request one sending a RS to all *routers*

IPv6 Autoconfiguration

Interface ID = 00:14:B1:FF:FE:CA:8E:47 (64 bits)

1) Compute the interface identifier EUI-64 format
2) Assign the solicited-node multicast address to the interface: FF02:0:0:0:0:1:FFCA:8E47
3) Assignment of a link local address: FF80:0:0:0:0014:B1FF:FECA:8E47

RA: IP Dest: FF02::1, Prefix=2002:E0:2:3::/64

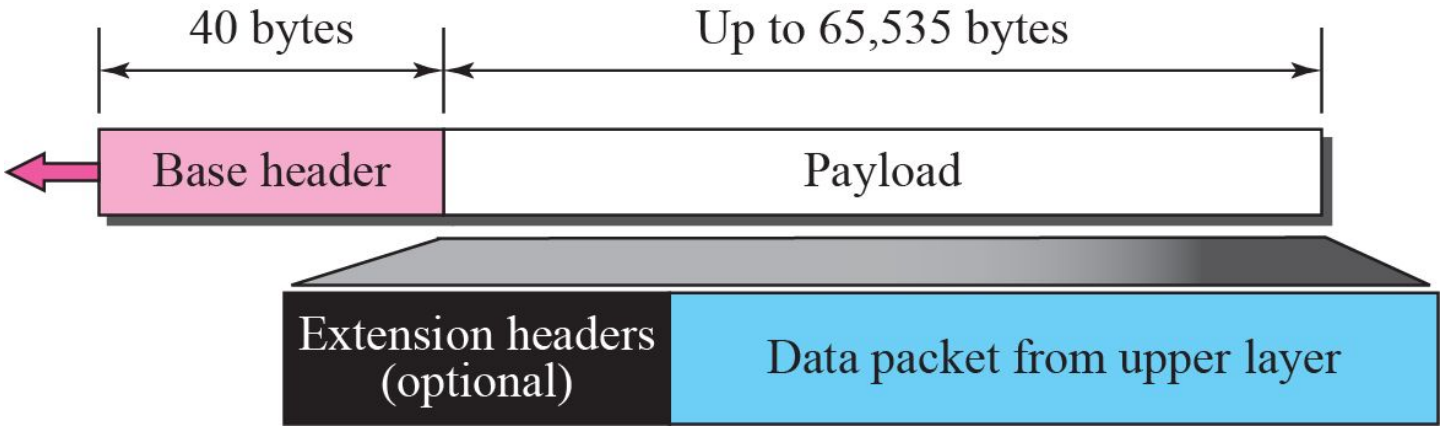
4) Building of the global unicast address: 2002:E0:2:3:14:B1FF:FECA:8E47

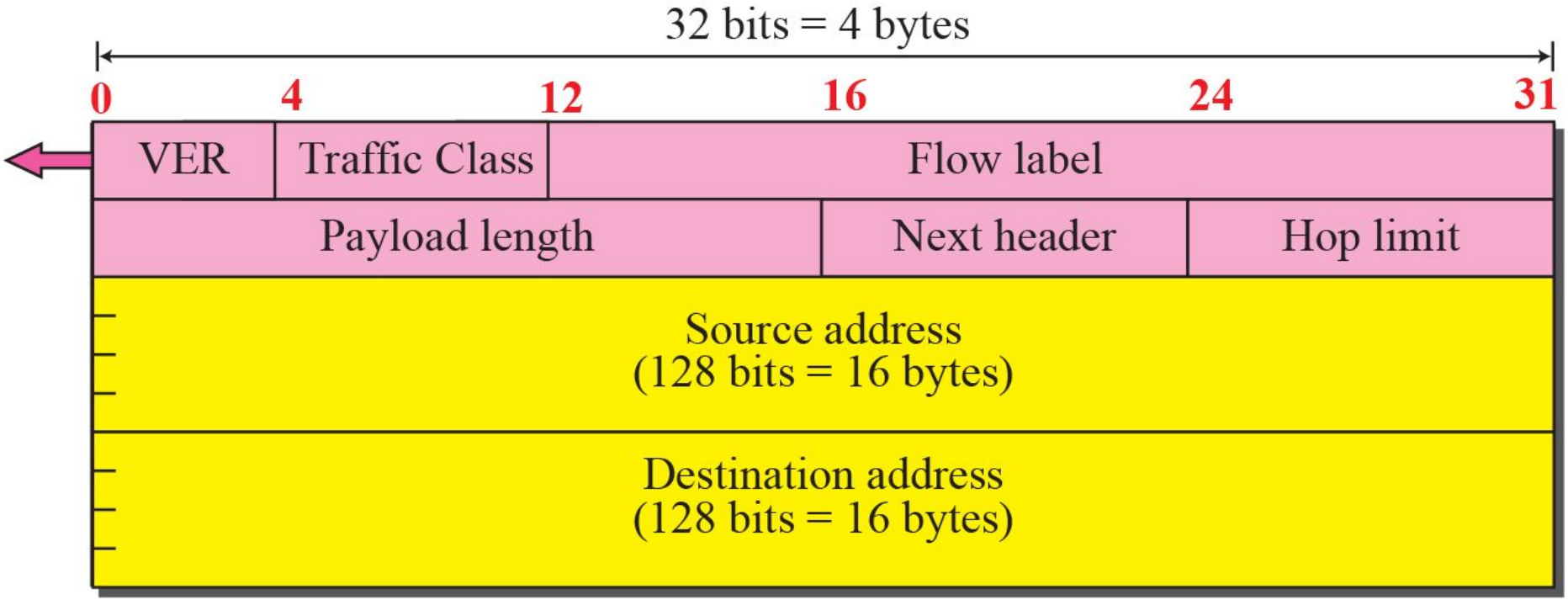
NS: IP Src: :: (unspecified) - IP Dest: FF02::1:FFCA:8E47, target address: 2002:E0:2:3:14:B1FF:FECA:8E47

5) DAD process (shown for the global unicast address only)

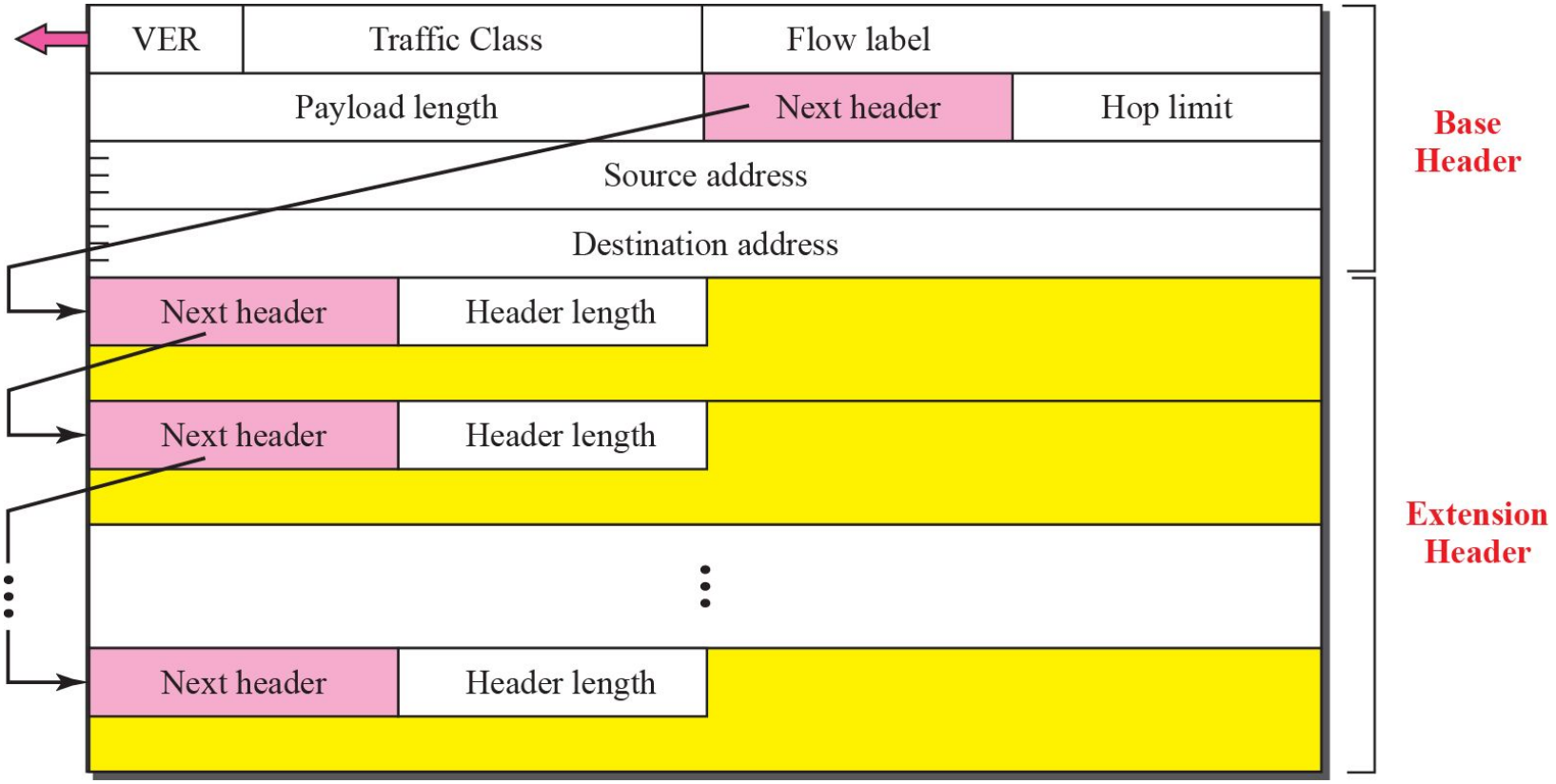
6) In the absence of reply the global unicast address (2002:E0:2:3:14:B1FF:FECA:8E47) is assigned to the interface

IPv6 datagram



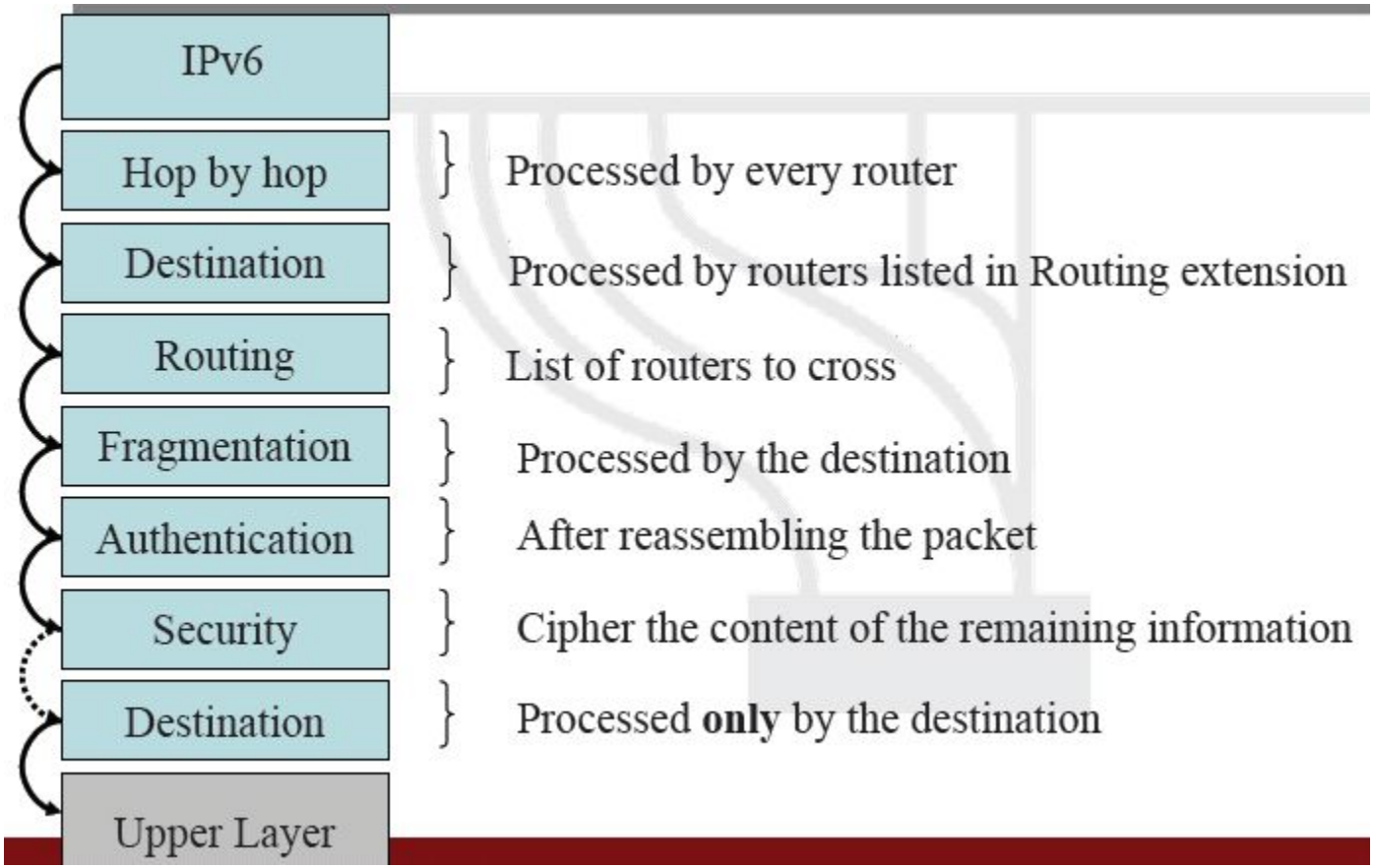


IPv6 datagram



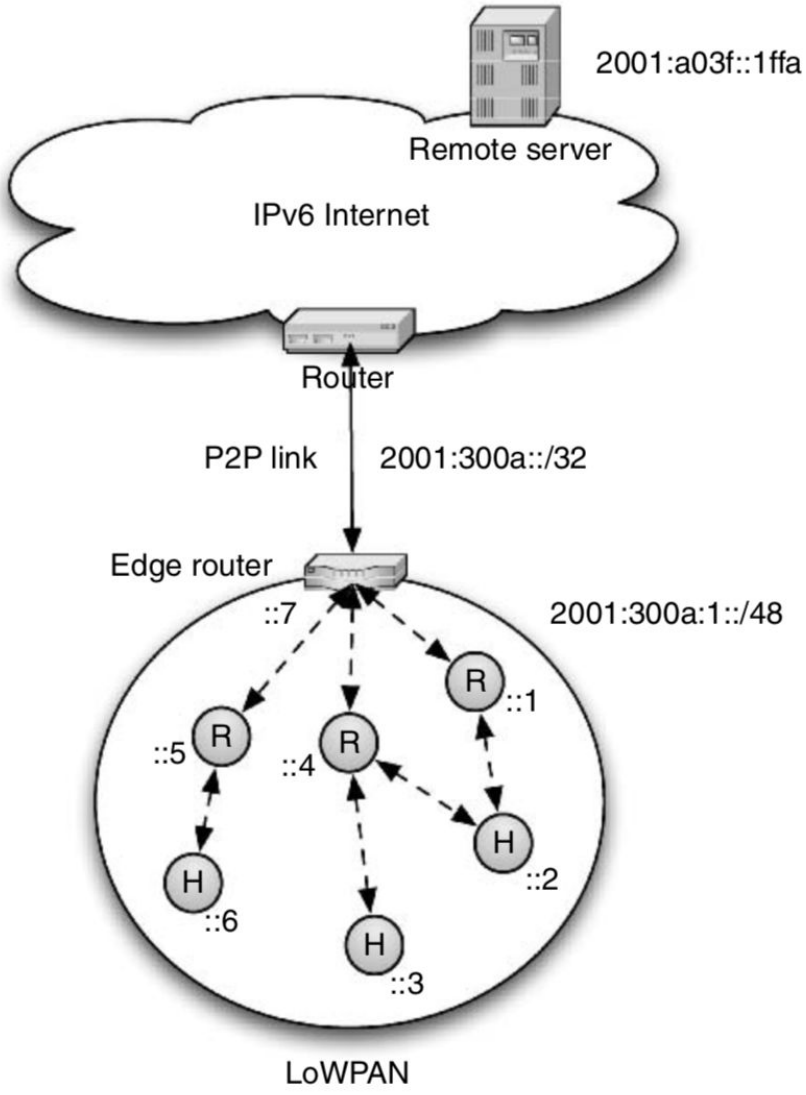
Code	*Next Header*	*Code*	*Next Header*
0	Hop-by-hop option	44	Fragmentation
2	ICMP	50	Encrypted security payload
6	TCP	51	Authentication
17	UDP	59	Null (No next header)
43	Source routing	60	Destination option

IPv6 datagram: order is relevant



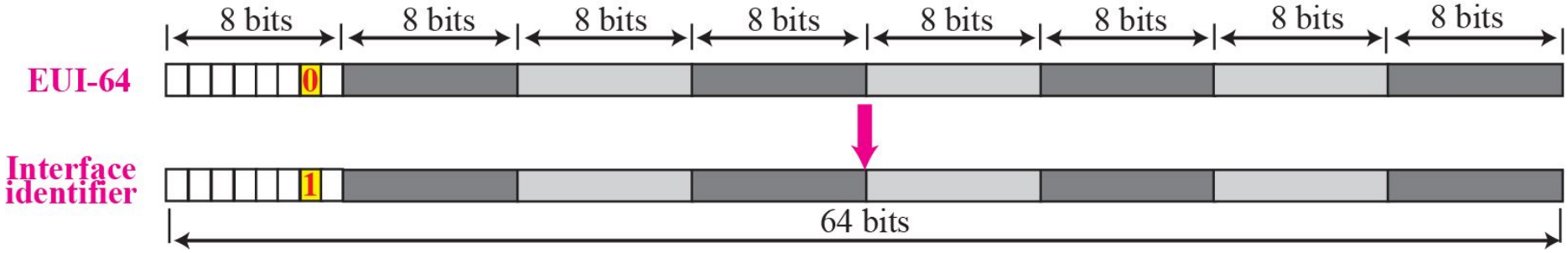
6LoWPan network example

- Edge router, 3 node *routers* and 3 host nodes
- IPv6 prefix known by all nodes
  - 2001:300a:1::/48
  - Edge router announces it to all routers
    - And they to the nodes
- The devices register they addresses in the edge router
  - Receive 16 bits ids
    - 2 IPv6 addresses

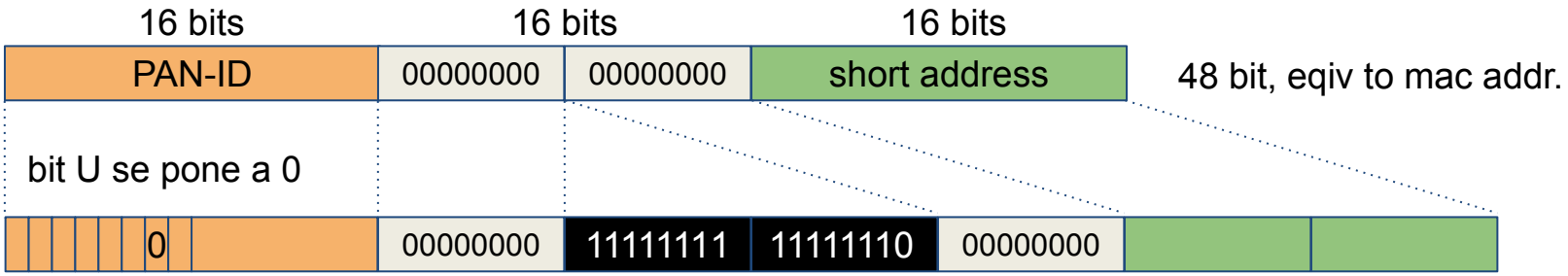


Interface ID for link-local address

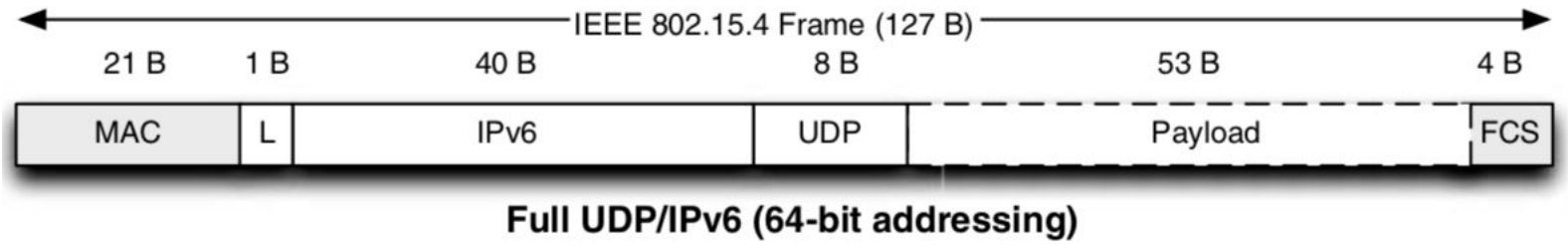
- From its EUI64 (standard IPv6)



- From the 16 bits id assigned by the PANC



Challenges for 6LoWPAN

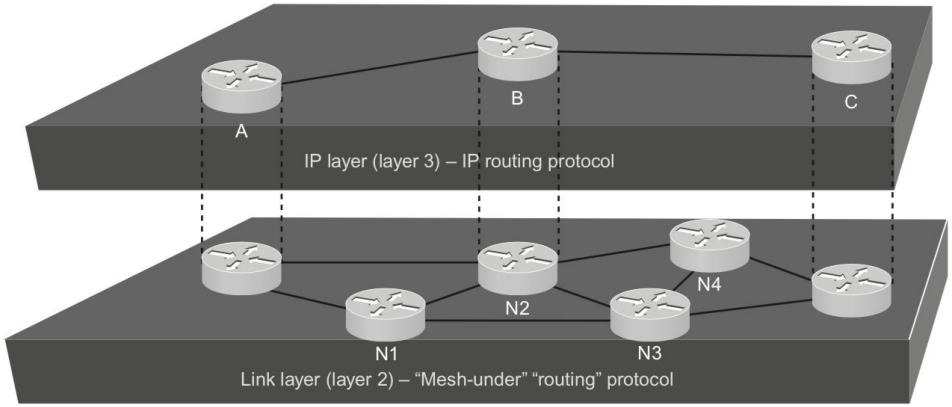


Full UDP/IPv6 (64-bit addressing)

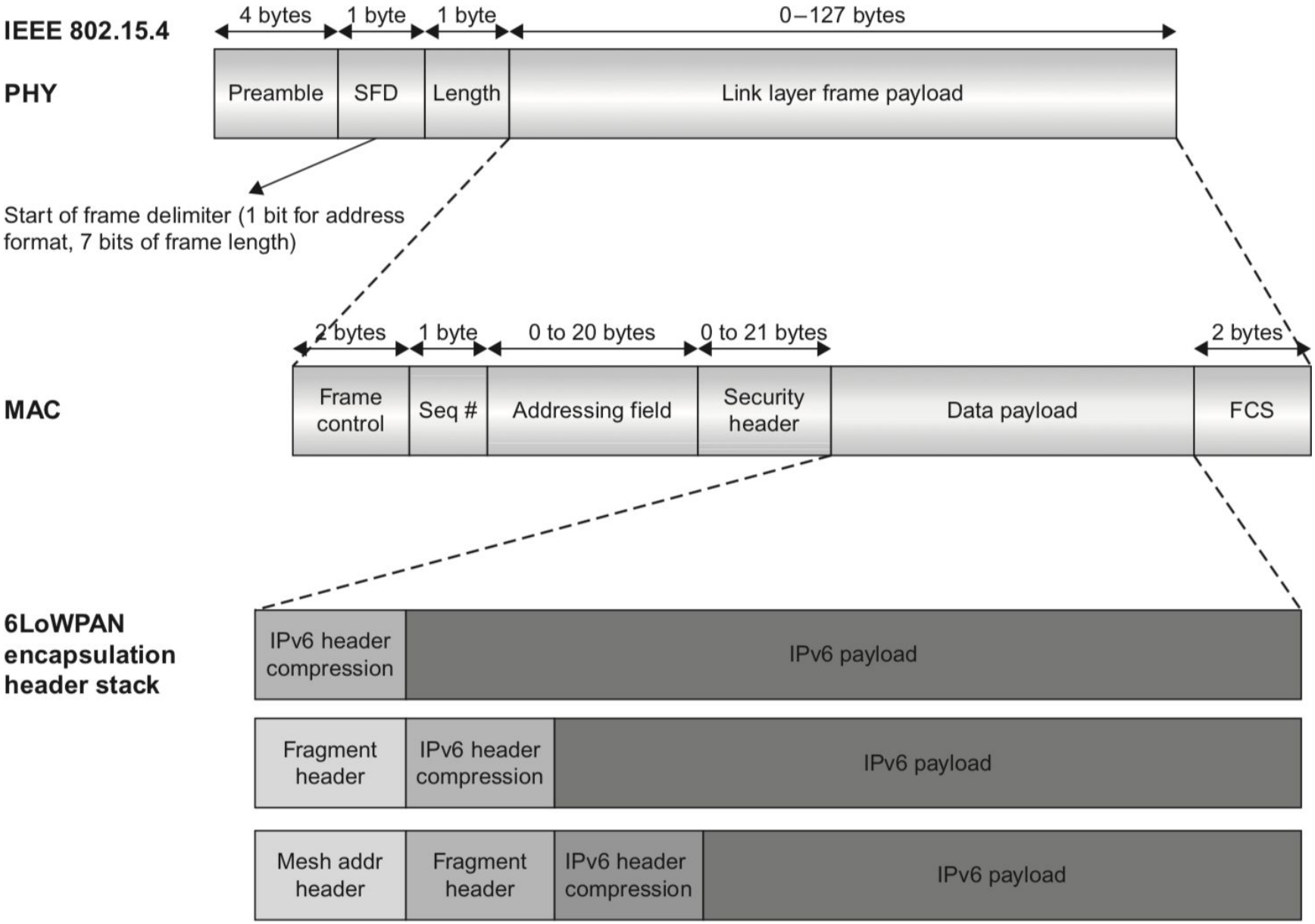
- MTU for 6LowPAN is 1280B
  - 802.15.4 packets are 127B, MSDU of 102B, removing security header (21B) remain 81B, removing 40B from the IPv6 header remain 41B, removing the 8B of the UDP header remain only 33B for the application
    - Header compression
    - Take advantage of L2 addresses -> 16 bit short address / 64 bit EUID
  - Fragmentación
- Stateless autoconfiguration
- Short reach => Múltiples Hops
  - Routing at several level (IP + link)

6LoWPAN: routing

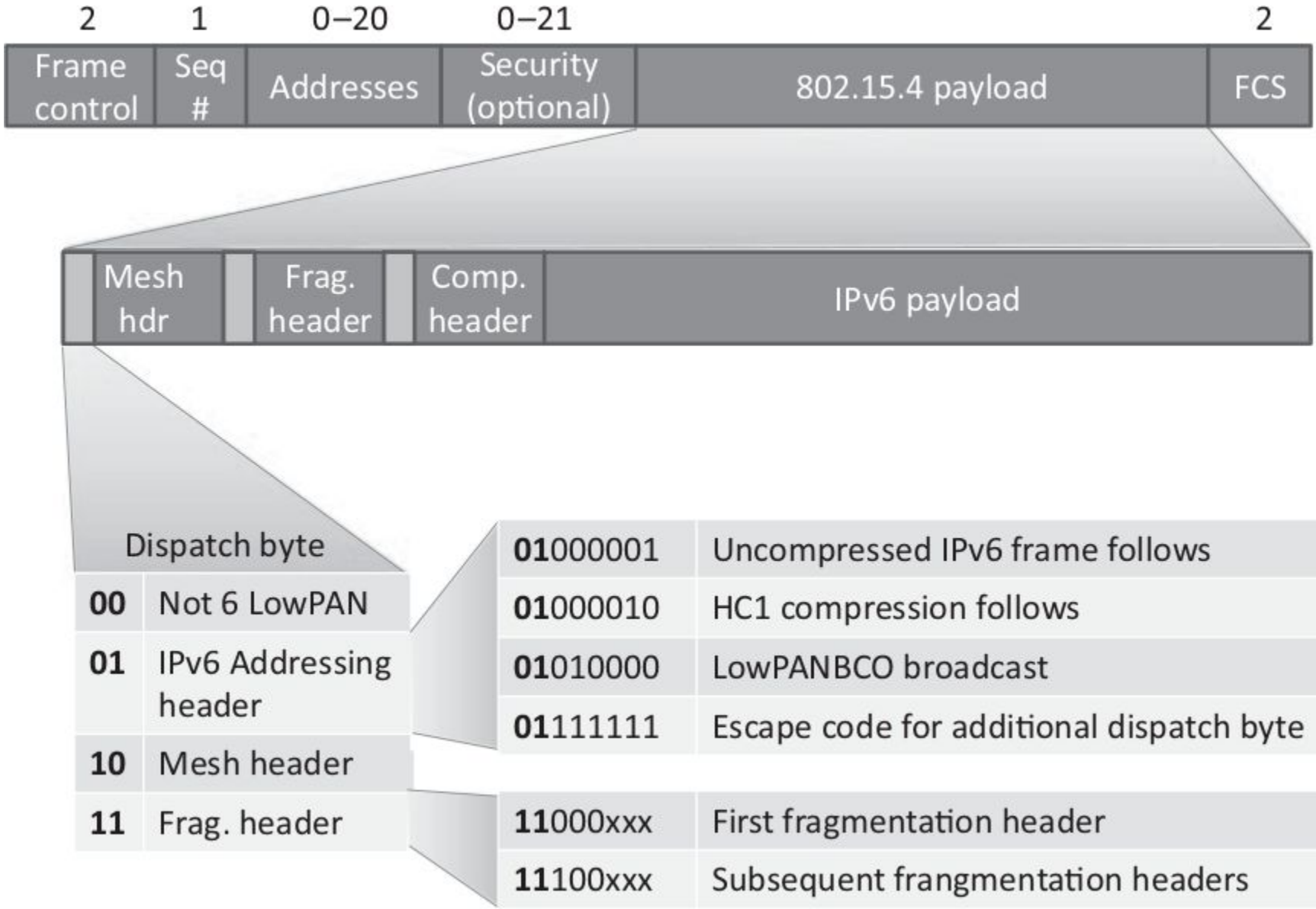
- Two types according to where is the routing done
  - Router-over -> L3
  - Mesh-under -> L2
  - Mixed



6LoWPAN encapsulation

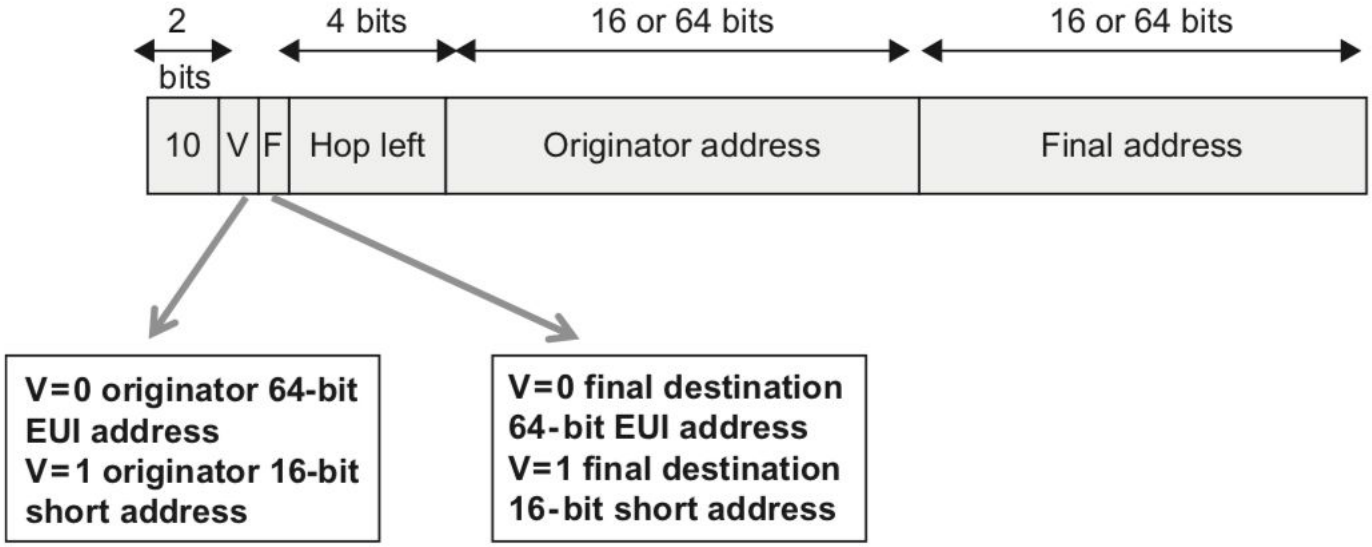


6LoWPAN encapsulation



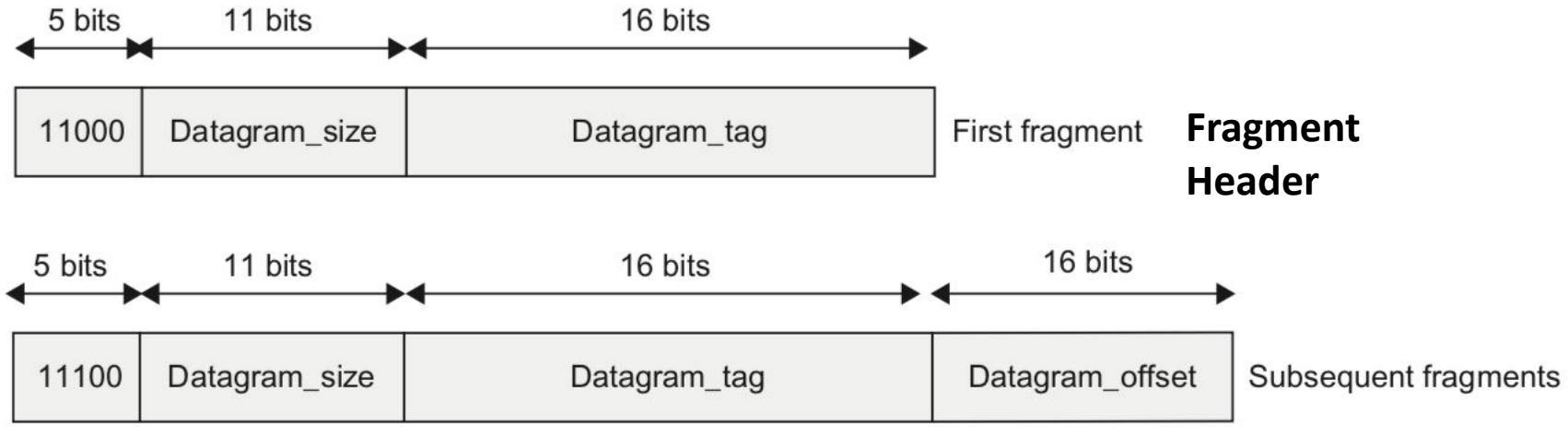
Mesh Addressing header

- L2 Routing Protocol (*mesh-under*)
  - Only FFDs
  - Not used currently but the support for it is there
- Adds source and destination addresses to the header
  - Originator, the original source of the address
  - Final, the final destination for the packet
  - The 802.15.4 header will contain the source and destination for the current hop



Fragmentation

- Necessary when the payload of the IPv6 package does not fit in a single 802.15.4 frame
  - The frame is divided into several fragments
  - The size of the fragments are expressed in multiples of 8 bytes
    - Datagram_size: size of the original IPv6 datagram
    - Datagram_tag: id for the datagram. The same for all fragments
      - Used together with the source and destination addresses to identify the original datagram to which the fragment belongs
    - Datagram_offset: in blocks of 8 bytes

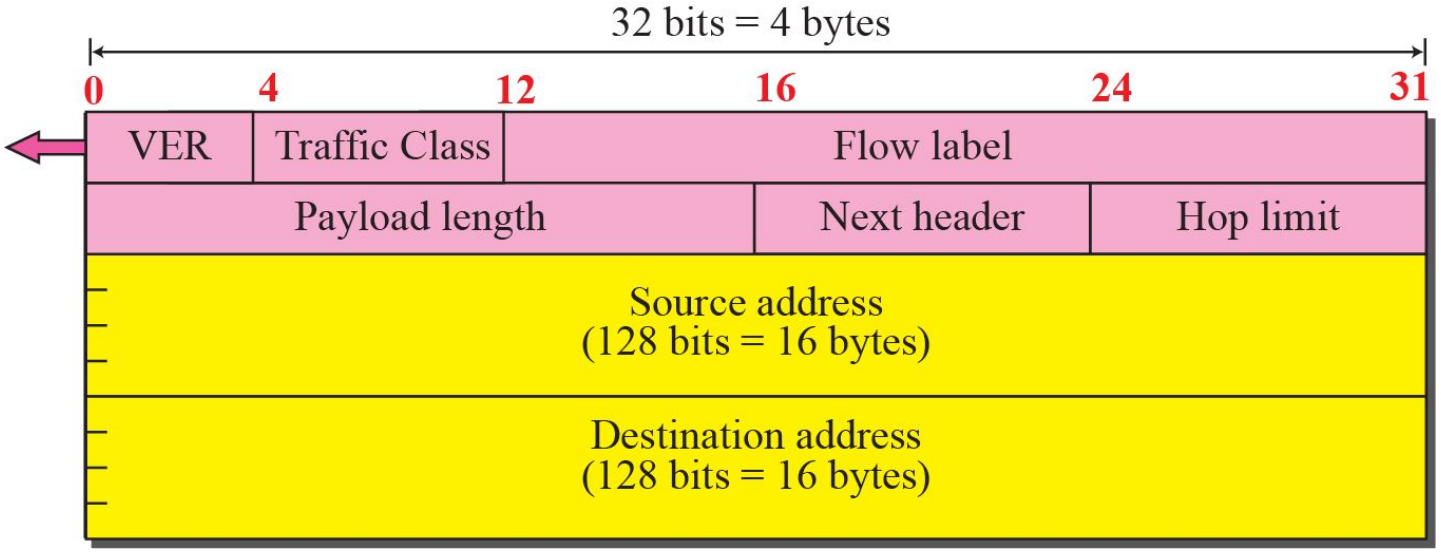


6LoWPAN: header compression

- Several compression techniques exist
- Most of them use state information to achieve higher compression rates
- A stateless compression was first designed
  - Only uses the information in each packet
  - Codes with less bits the most frequent values
  - Takes advantage of the redundancies in the lower layers

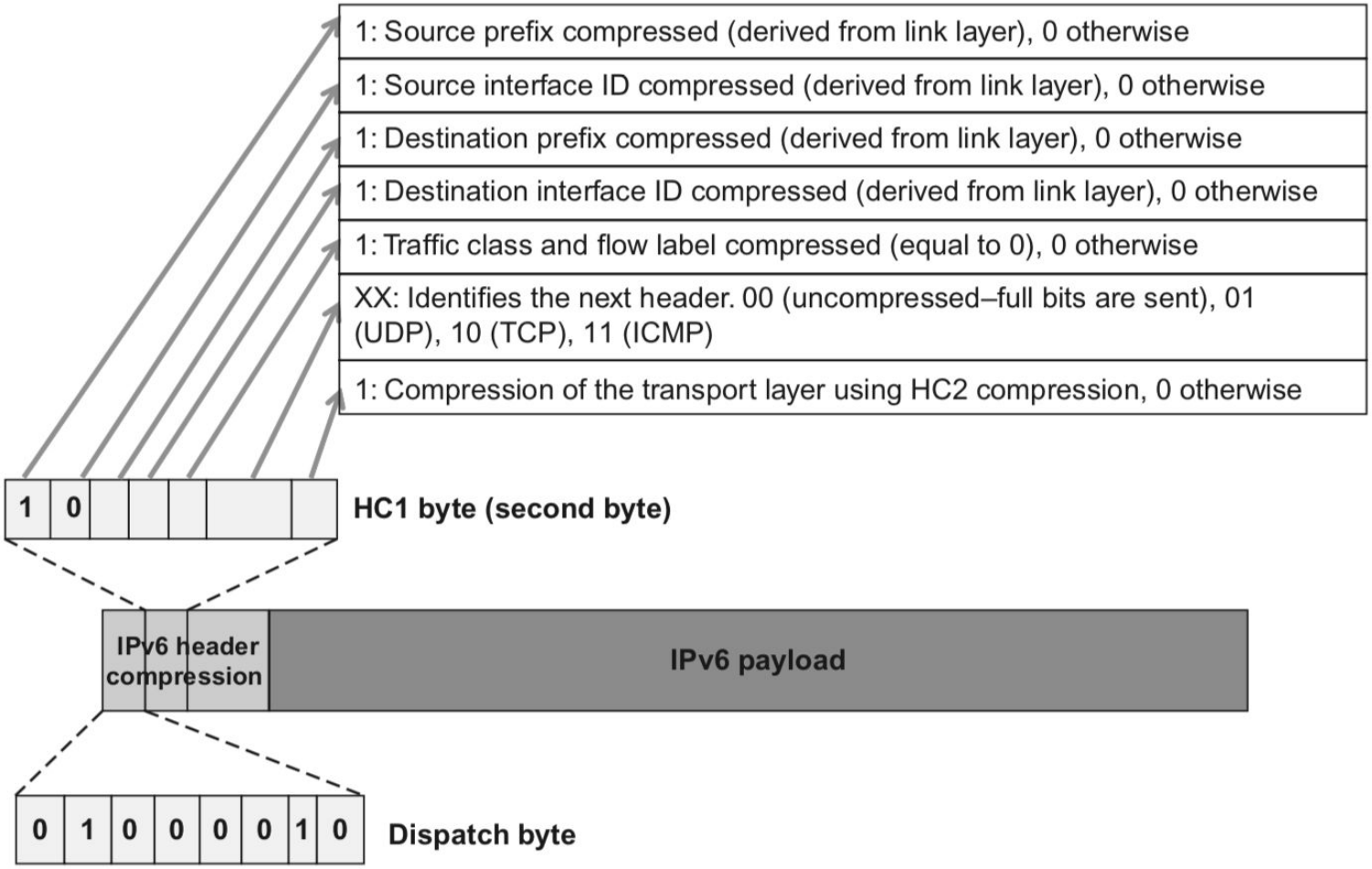
HC1: observations on the IPv6 header

- Version: is always 6
- Source and destination addresses are frequently link-local
  - Interface ID can be obtained from the 802.15.4 header
- Length: can be obtained from the phy header in the 802.15.4 frame or the UDP header if present
- Traffic Class and Flow Label are usually 0
- Next Header usually is UDP, TCP or ICMP



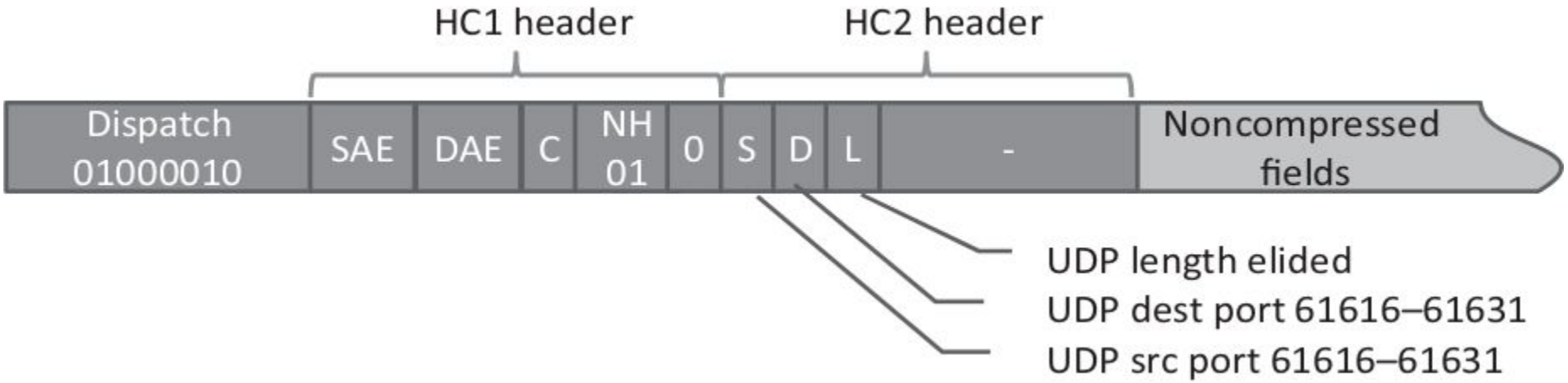
HC1 IPv6 compressed header: 3 bytes

- Only the hop limit remains unmodified
  - Plus the dispatch byte and the HC1 signature a total of 3 bytes

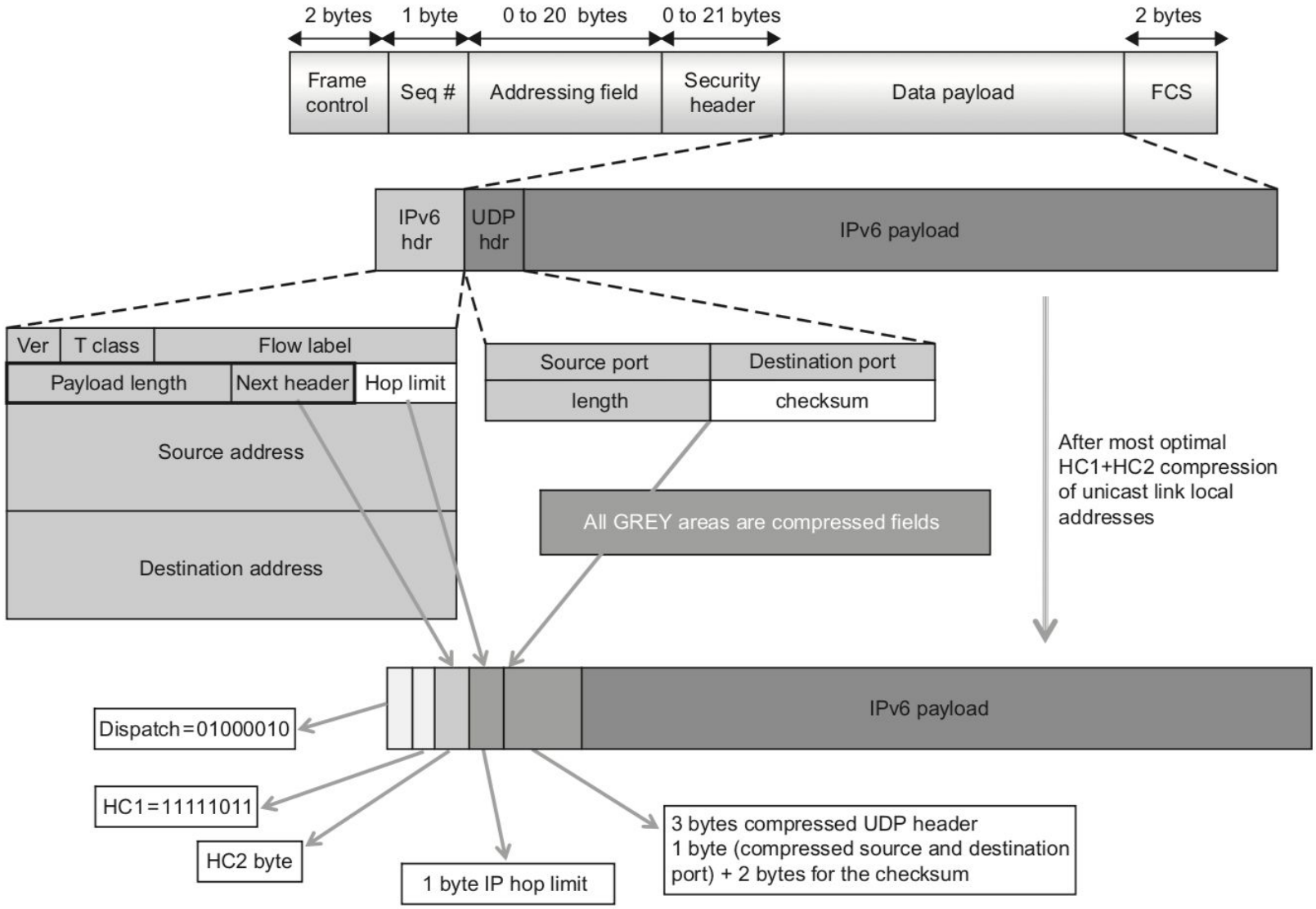


UDP compressed header (HC2)

- S,D: 1 bit, indicate if the source and destination ports are in the range 62616 - 62631, and can then be encoded with only 4 bits
- L: 1 bit, indicates if the length field of the datagram has been removed

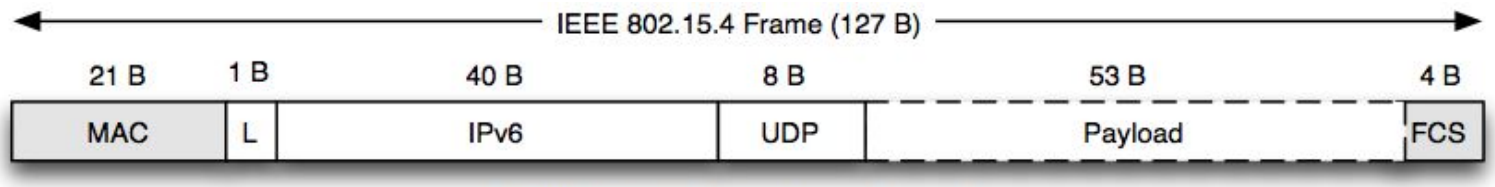


UDP datagram with HC1 and HC2

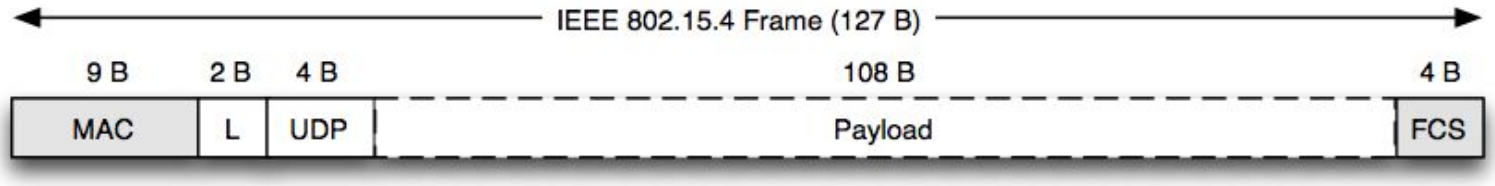


HC1/HC2 header compression summary

- Optimal compression for *unicast link-local* packets
  - From 48 bytes to 7 bytes (dispatch + 2 ip + 4 UDP)



Full UDP/IPv6 (64-bit addressing)

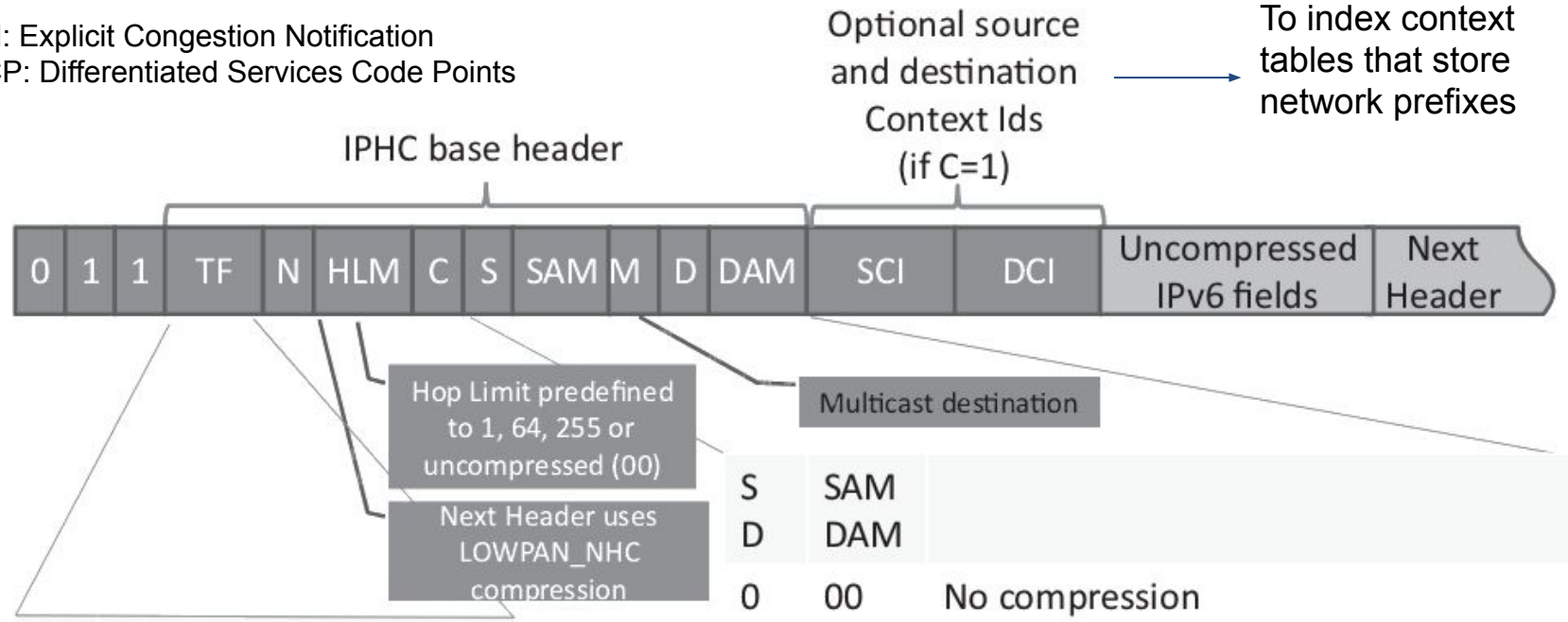


Minimal UDP/6LoWPAN (16-bit addressing)

- Low effectiveness for Global Unicast addresses

Context based IPHC compressed header

ECN: Explicit Congestion Notification
DSCP: Differentiated Services Code Points



00	ECP|DSCP|Flowlabel uncompressed
01	ECN|FlowLabel uncompressed, DSCP elided (=0)
10	ECN|DSCP| Flow label elided (=0)
11	ECN, flowlabel and ECN elided (=0)

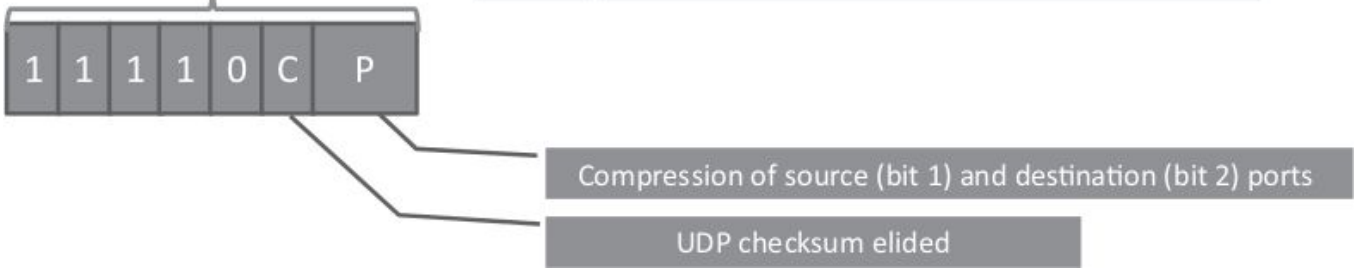
S D	SAM DAM	
0	00	No compression
0	01	FE80::/64+64-bit interface ID inline
0	01	FE80::/112+16-bit short address inline
0	11	FE80::/64+source address from L2
1	00	reserved
1	01	64 bit context+64-bit interface ID inline
1	10	112 bit context+16-bit short address
1	11	64 bit context+source address from L2

LOWPAN_NHC compressed options

LOWPAN_NHC
base header for IPv6 extensions

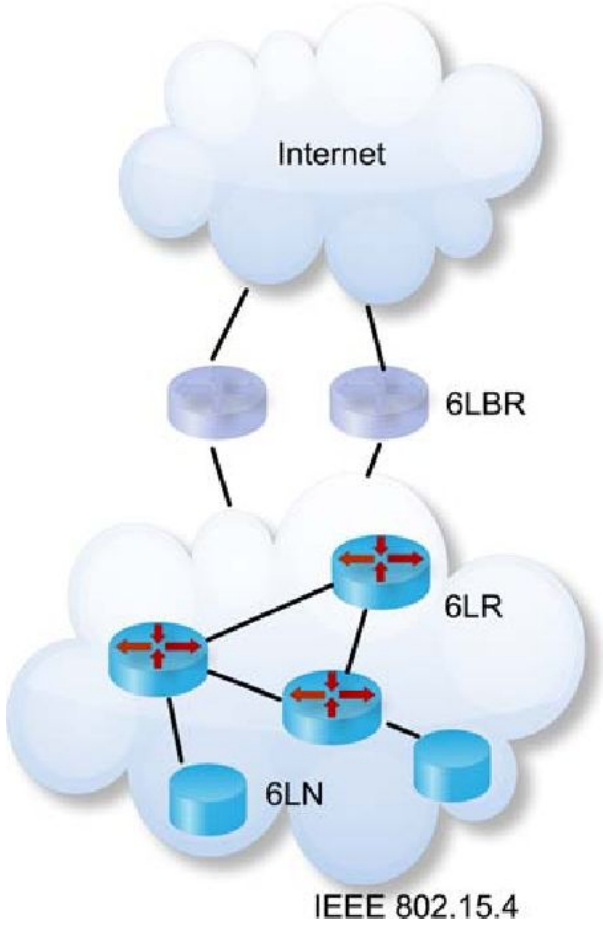
EID	
000	IPv6 Hop by Hop options (RFC2460)
001	IPv6 routing (RFC2460)
010	IPv6 Fragment (RFC2460)
011	IPv6 destination options (RFC 2460)
100	IPv6 mobility header (RFC3775)
101	reserved
110	reserved
111	Nested IPv6 header

LOWPAN_NHC
UDP header



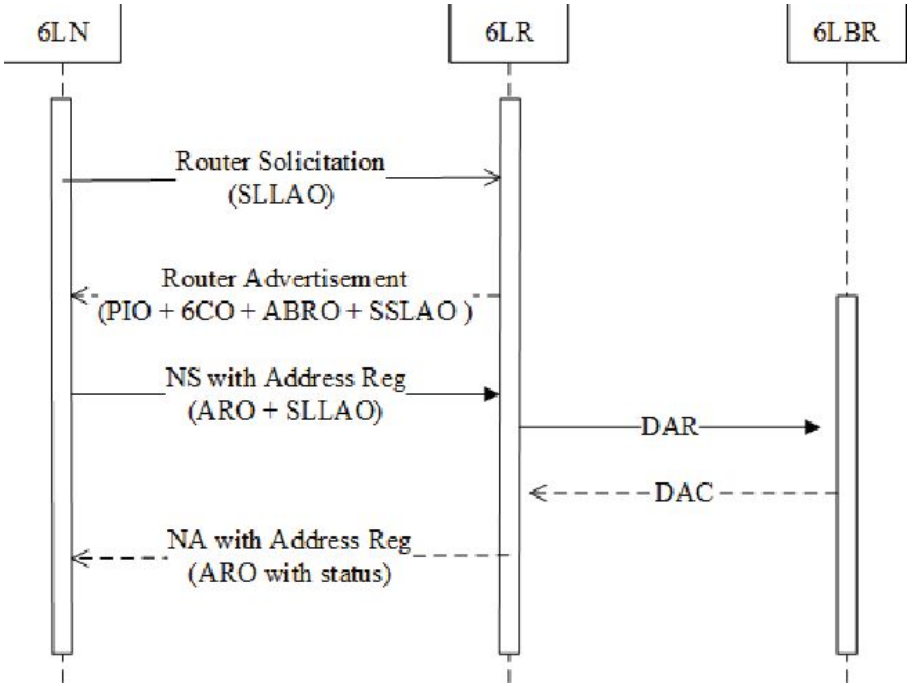
Neighbour Discovery (ND) in 6LoWPAN

- RCFC 6775
- 6LoWPAN Border Router (6LBR)
  - Or Edge Router
  - Has the authority to establish the prefix
- 6LoWPAN Router (6LR)
  - Intermediate routers
  - Only in route-over
- 6LOWPAN Node (6LN)
  - The rest of the nodes



Neighbour Discovery (ND) in 6LoWPAN

- No multicast for 6LN
  - The 6LN do not use the multicast solicited-node address
- Addresses are registered
  - Avoids the use of multicasts in ND
  - The 6LN can stay asleep
  - Short live time for mobile devices
- 6LR: cache the addresses
  - Route over: send requests to the 6LBR
  - Duplicate Address Request (DAR) and Confirmation (DAC)



SLLAO: Source Link Layer Address Option

ABRO: Authoritative Border Router Option

6CO: 6LoWPAN context options

PIO: Prefix information options

ARO: Address Registration Option