

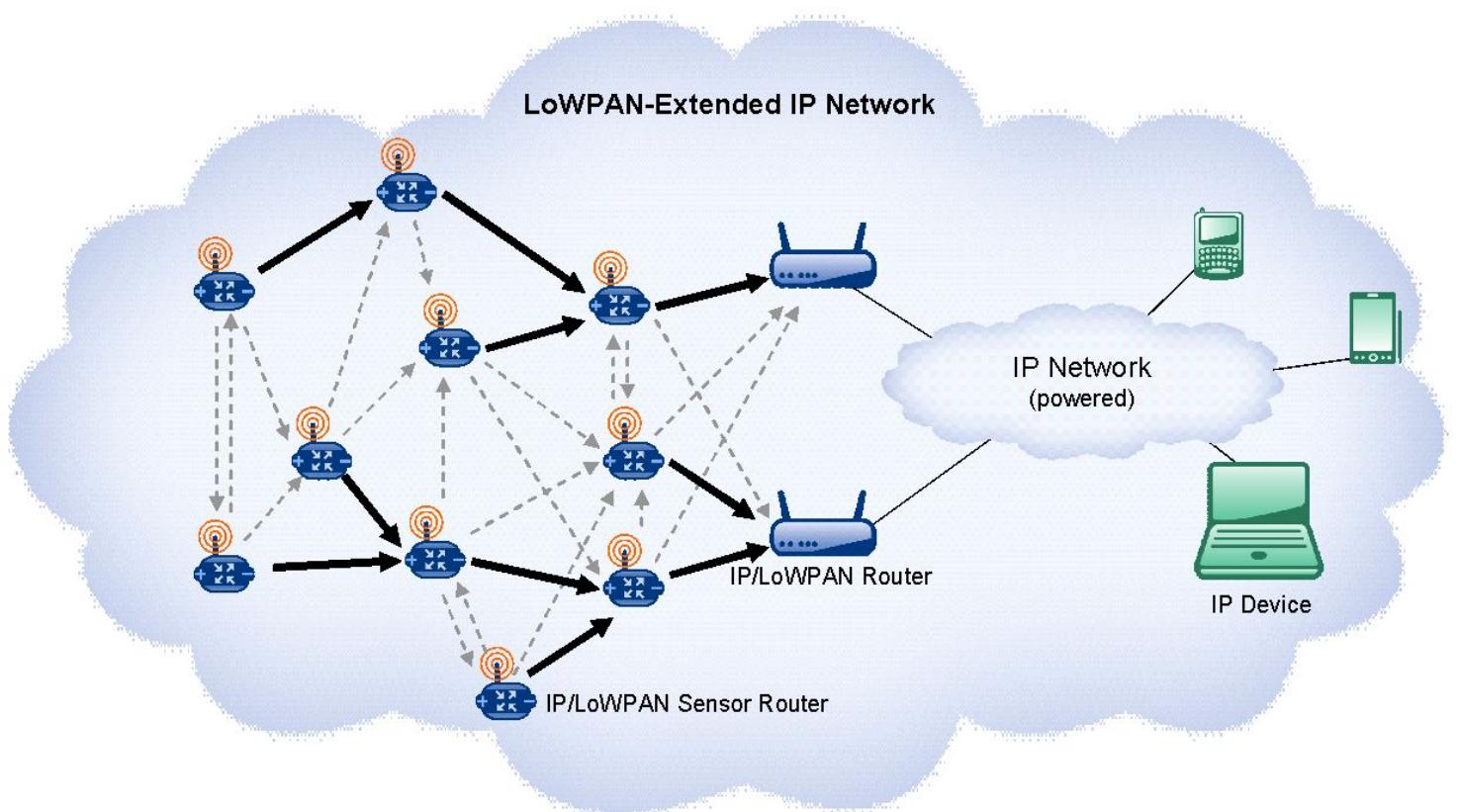


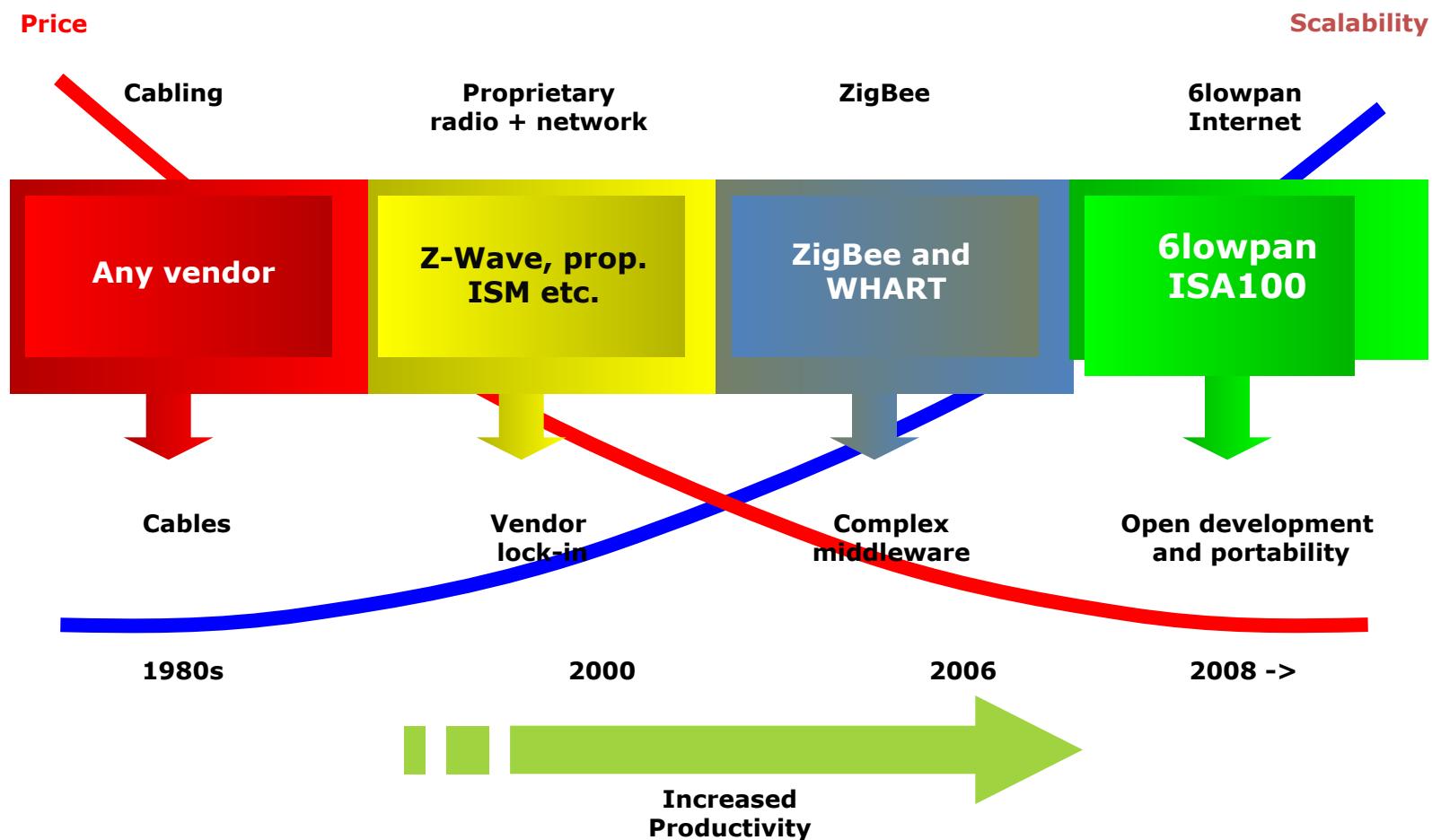
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6LoWPAN

Networks and protocols 1

Facultad de Informática



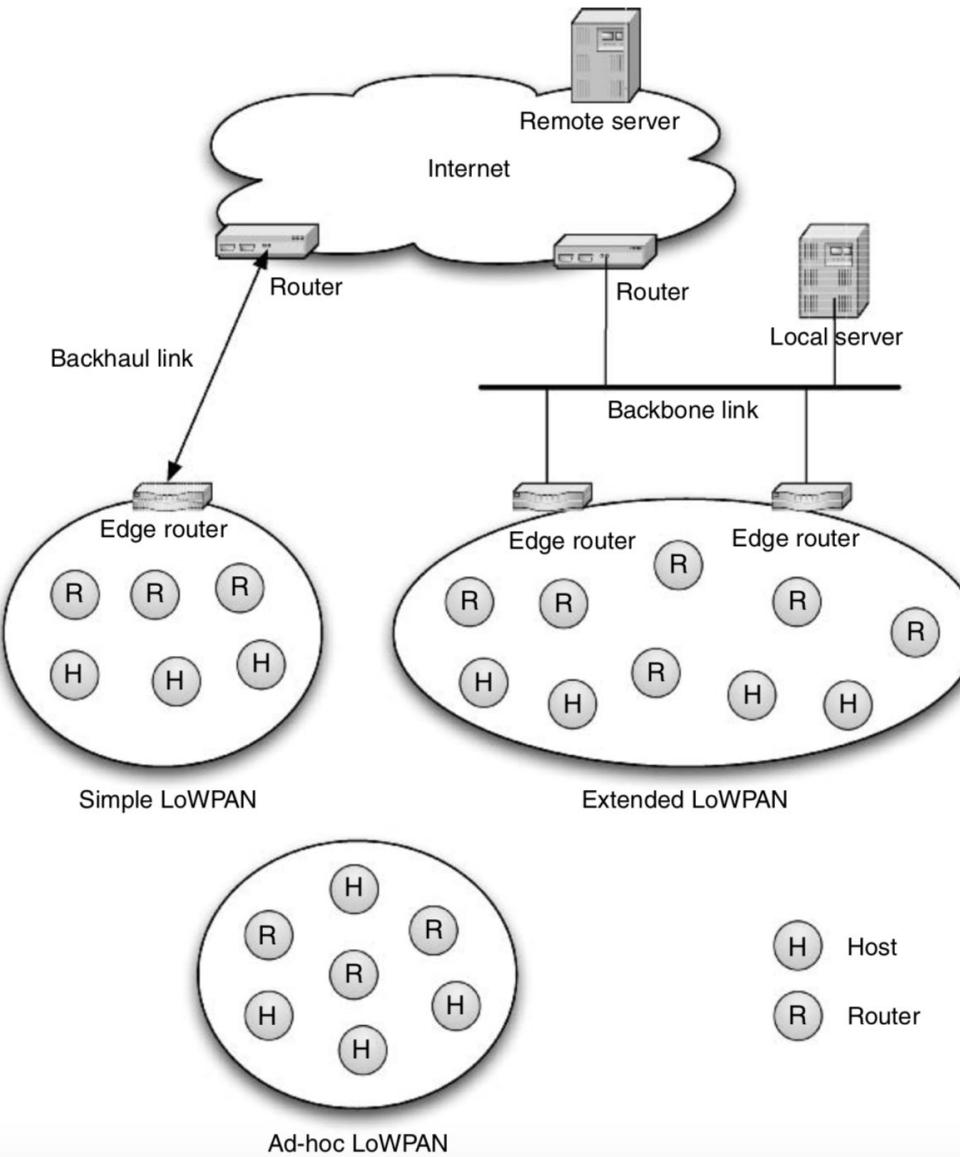


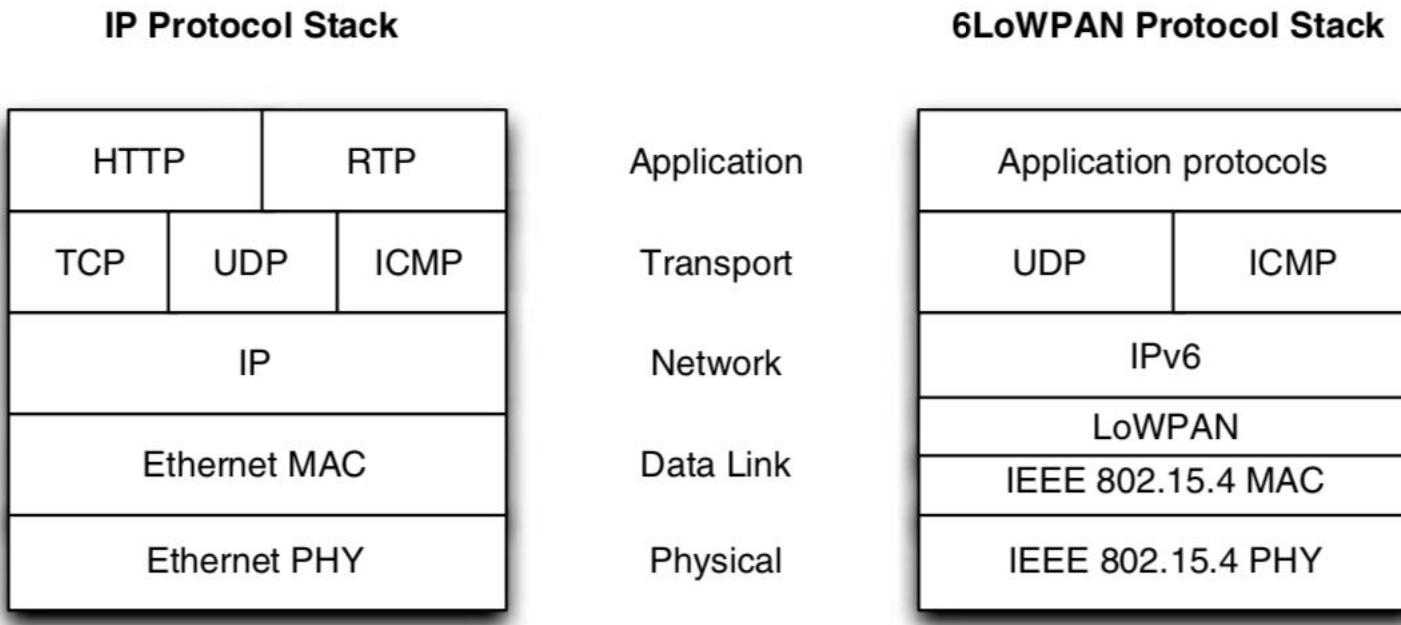
- Low power RF + IPv6 = *The Wireless Embedded Internet*
- Benefits:
 - **Open standards**, reliable and long life
 - **Easy learning curve**
 - Transparent integration in the **Internet**
 - **Global scalability**
 - **End-to-end** data flow
 - No **Gateways**



- 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





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

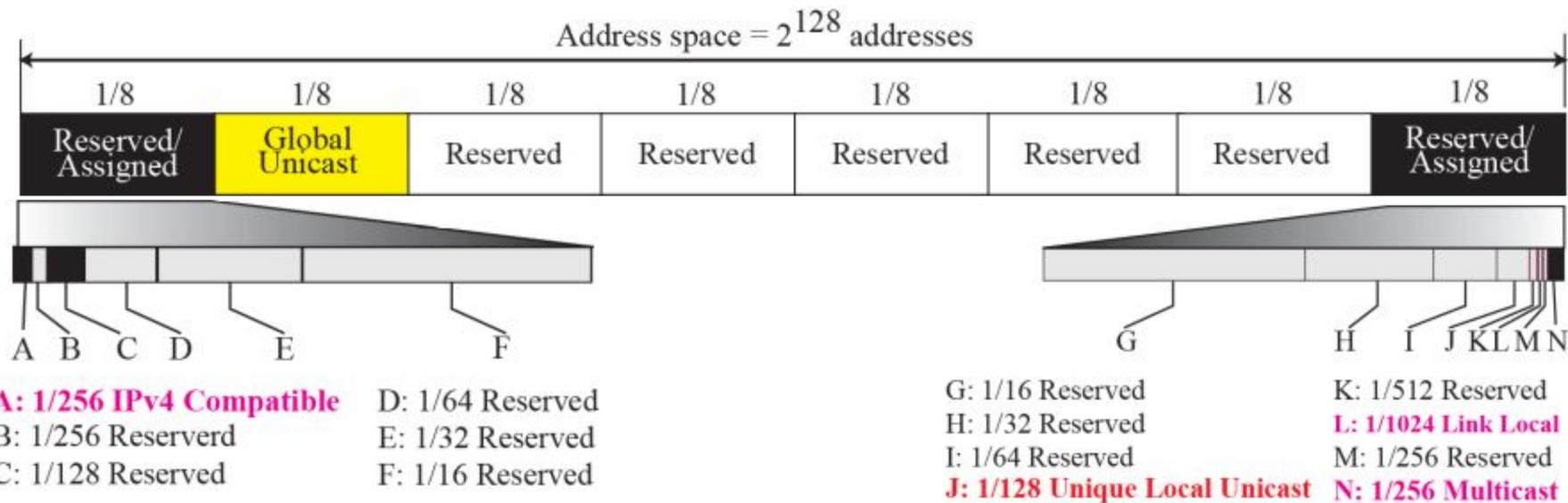
- 128 bits (16 bytes) addresses, several notations
 - Huge space: the population of the world is reaching 2^{34} people, each of them could have 2^{94} IPv6 addresses

Binary	1000000000101101100101101100111011101110000101000000000000000000 0000000000000000111111000101011111010100110010000001111111111111															
Dotted Decimal	128 91 45 157 220 40 0 0 0 0 252 87 212 200 31 255															
<u>Hexadecimal</u>	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							

- 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:

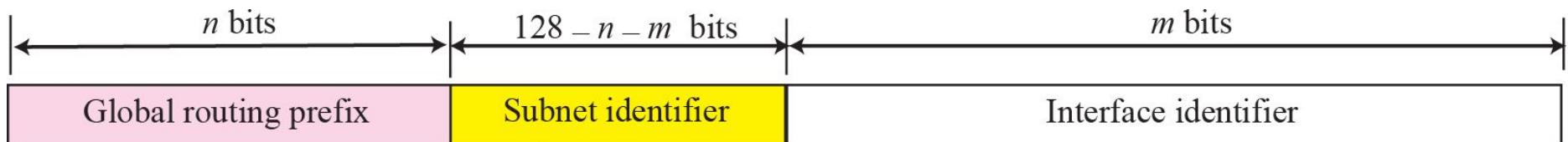


IPv6 prefixes

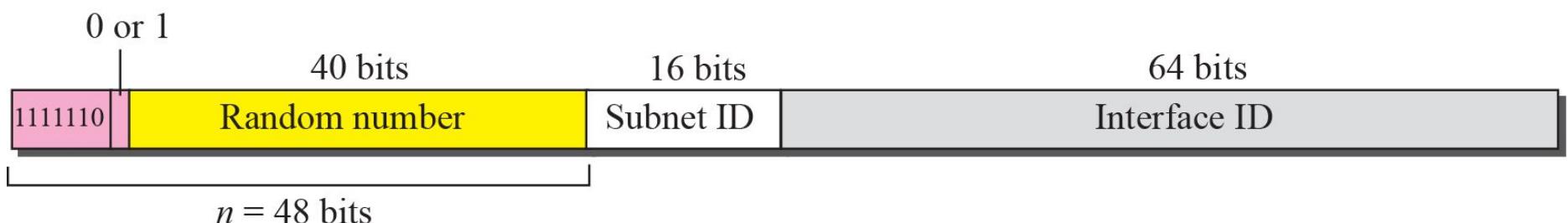
	<i>Block Prefix</i>	<i>CIDR</i>	<i>Block Assignment</i>	<i>Fraction</i>
1	0000 0000	0000::/8	Reserved (IPv4 compatible)	1/256
	0000 0001	0100::/8	Reserved	1/256
	0000 001	0200::/7	Reserved	1/128
	0000 01	0400::/6	Reserved	1/64
	0000 1	0800::/5	Reserved	1/32
	0001	1000::/4	Reserved	1/16
2	001	2000::/3	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

- 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)

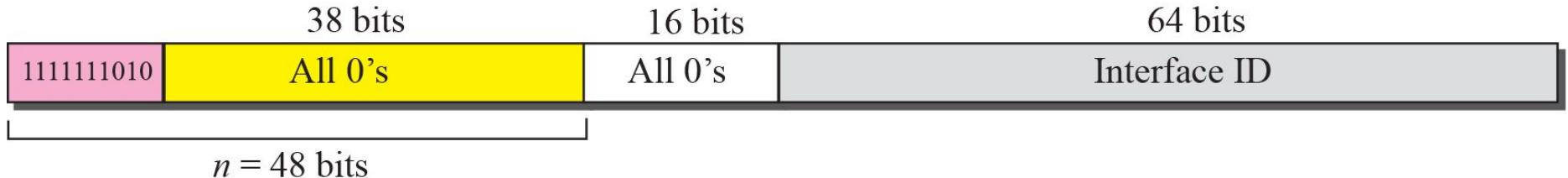
- Global unicast



- Unique local unicast

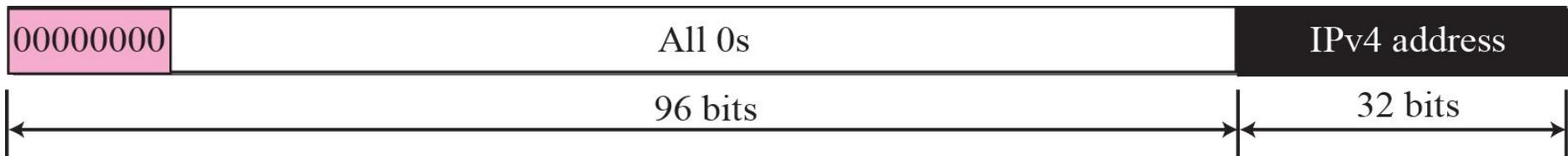


- Link local unicast

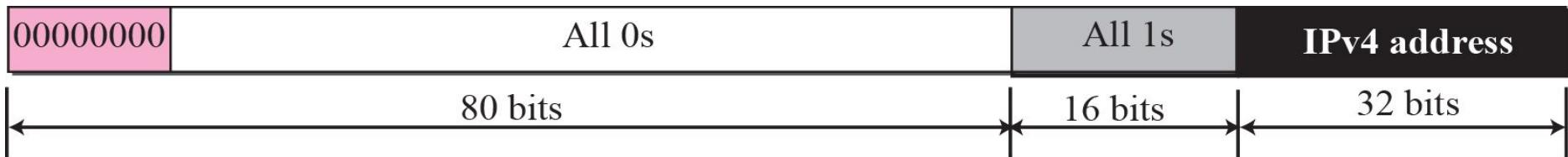


IPv6 other unicast Addresses

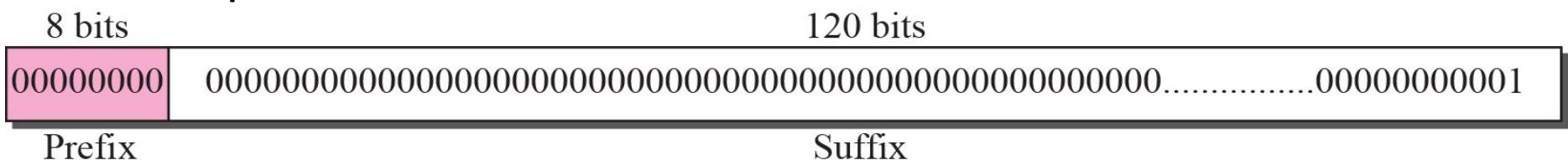
- IPv4 compatible



- IPv4 mapped



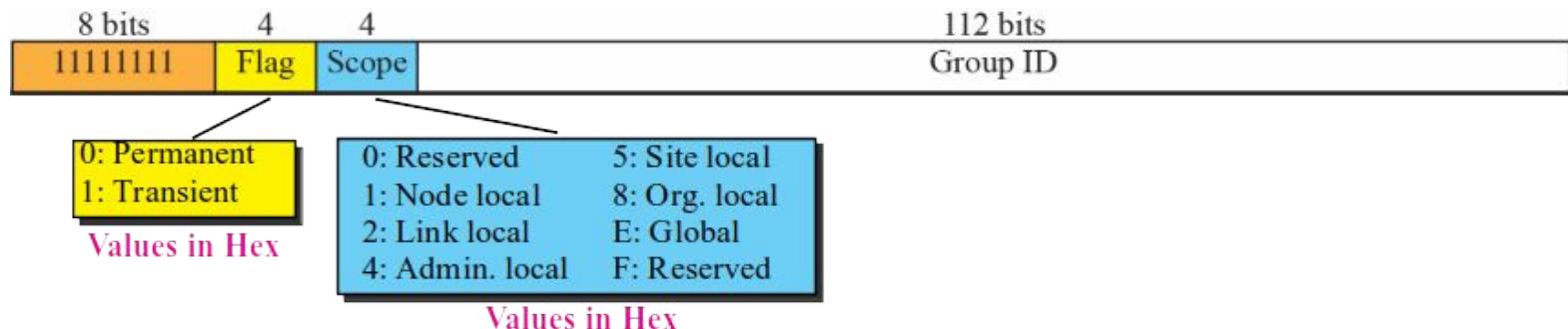
- Loopback



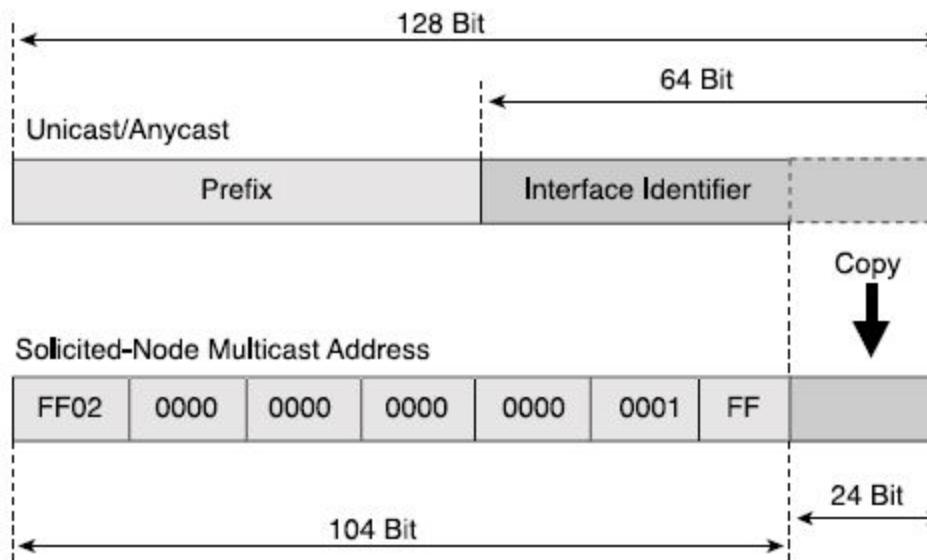
- Site-local (deprecated, in favour of the unique local)



- Multicast Address



- Solicited-Node Multicast Address (used in NDP)

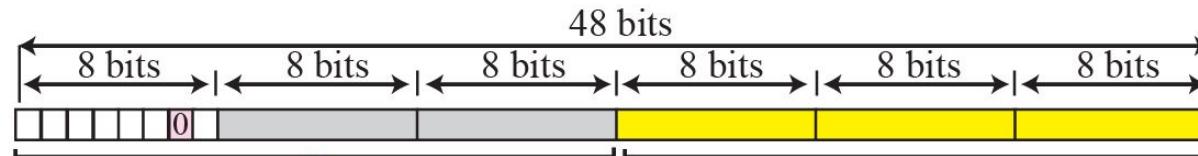


- IPv6 defines its own *Neighbor Discovery Protocol (NDP)*
 - A node uses the NDP to discover other devices in its link, obtain their MAC addresses and find routers
- NDP services
 - Router discovery
 - Prefix discovery
 - Parameter discovery (MTU, hop limit...)
 - Address autoconfiguration
 - Address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

- 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)

- The nodes can configure their interface id part of the address:

- From a 48 bits mac address



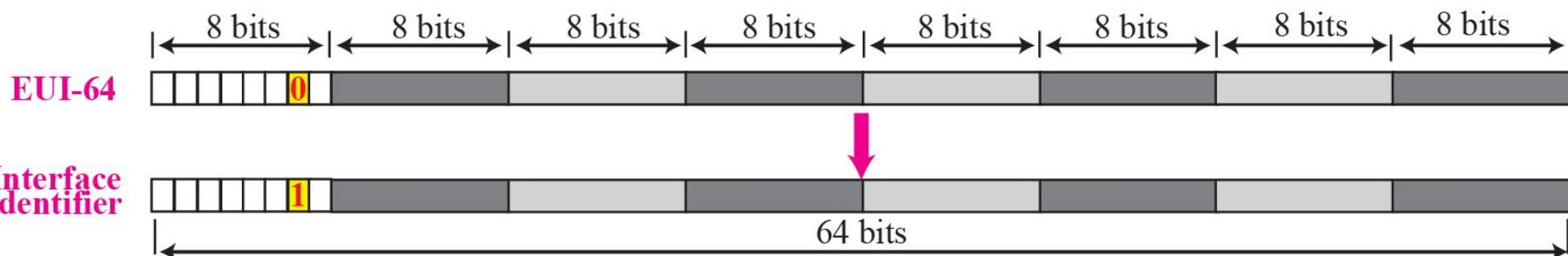
Ethernet
MAC address

added bits

Interface
identifier

64 bits

- From a EUI-64 id

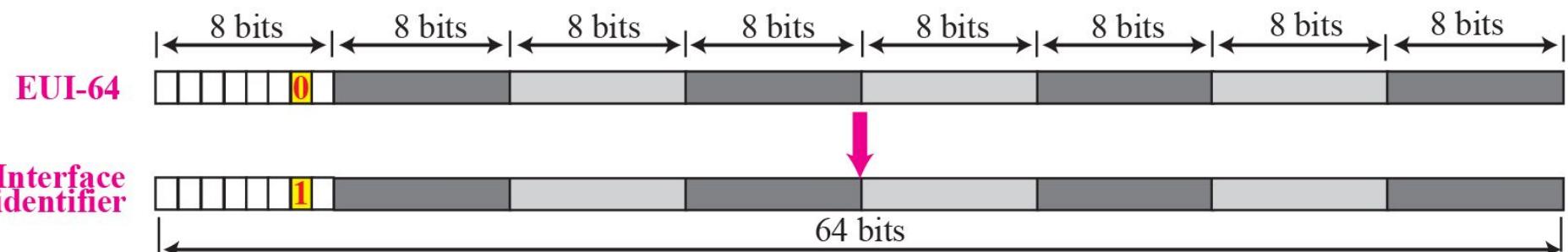


EUI-64

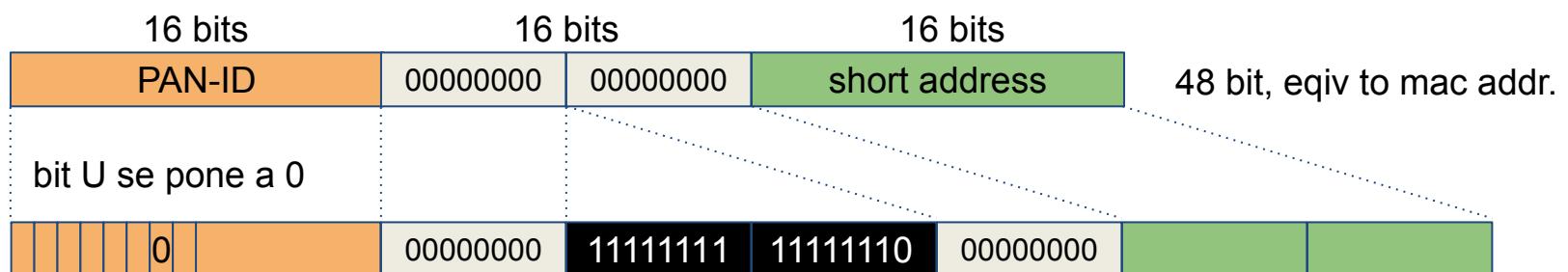
64 bits

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

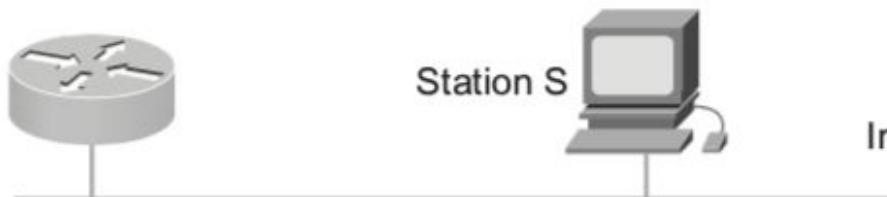
- From its EUI64 (standard IPv6)



- From the 16 bits id assigned by the PANC



- 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*

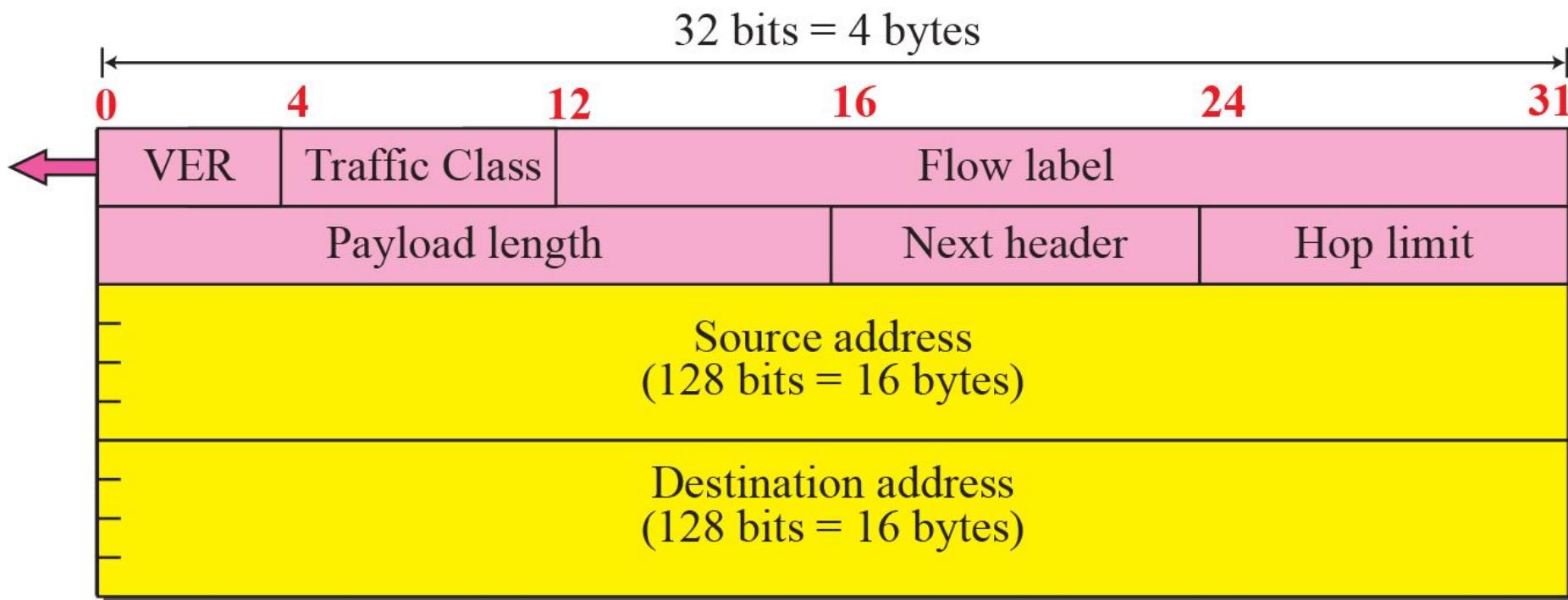
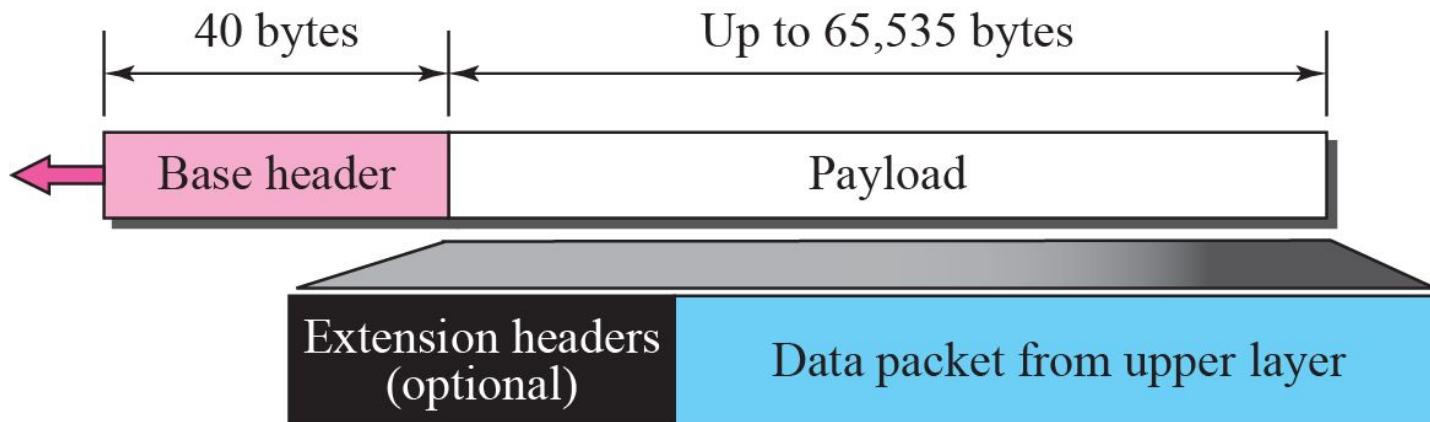


RA: IP Dest: FF02::1,
Prefix=2002:E0:2:3::/64

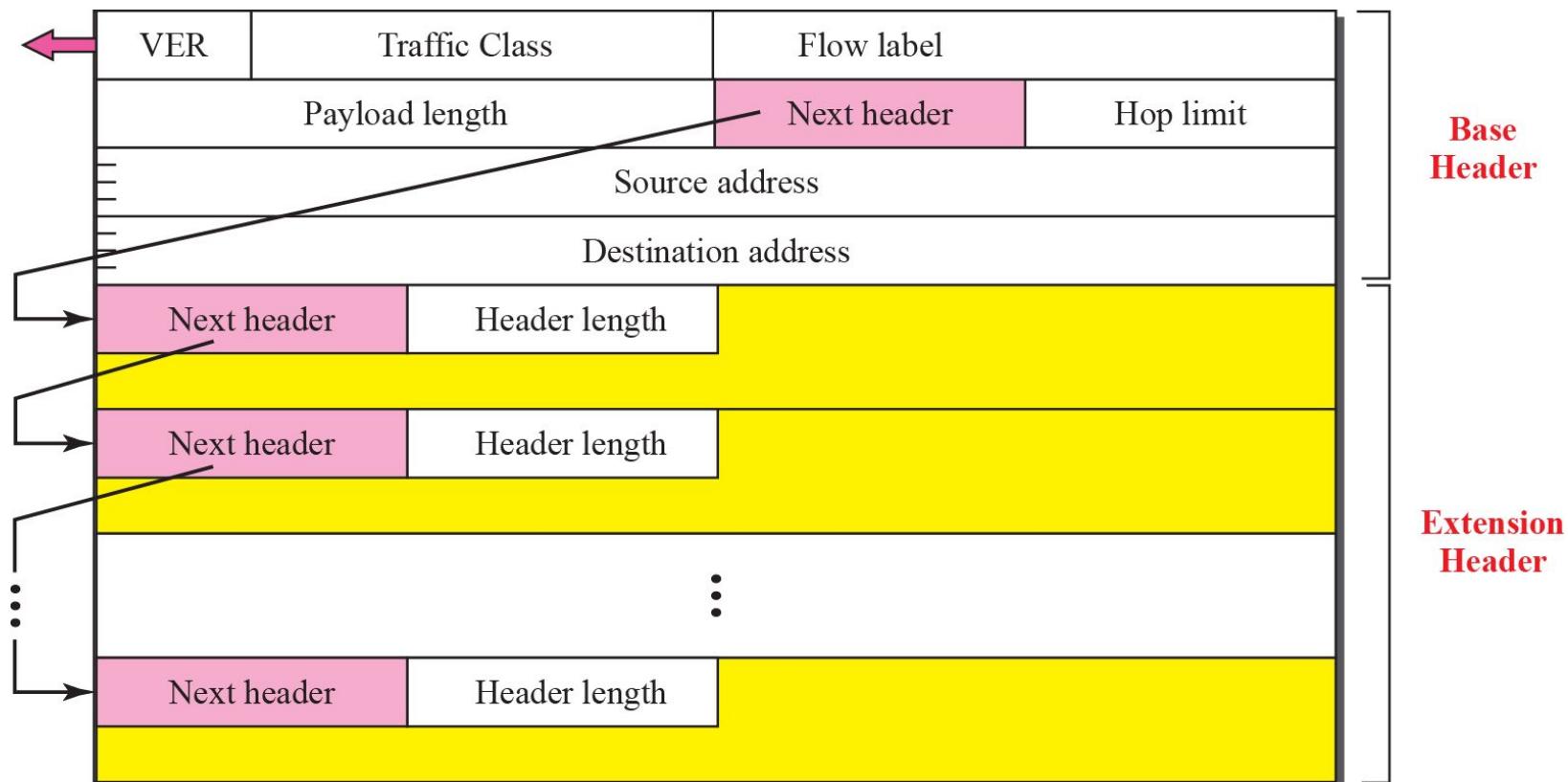
NS: IP Src: :: (unspecified) - IP Dest:
FF02::1:FFCA:8E47, target address:
2002:E0:2:3:14:B1FF:FECA:8E47

- 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
- 4) Building of the global unicast 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

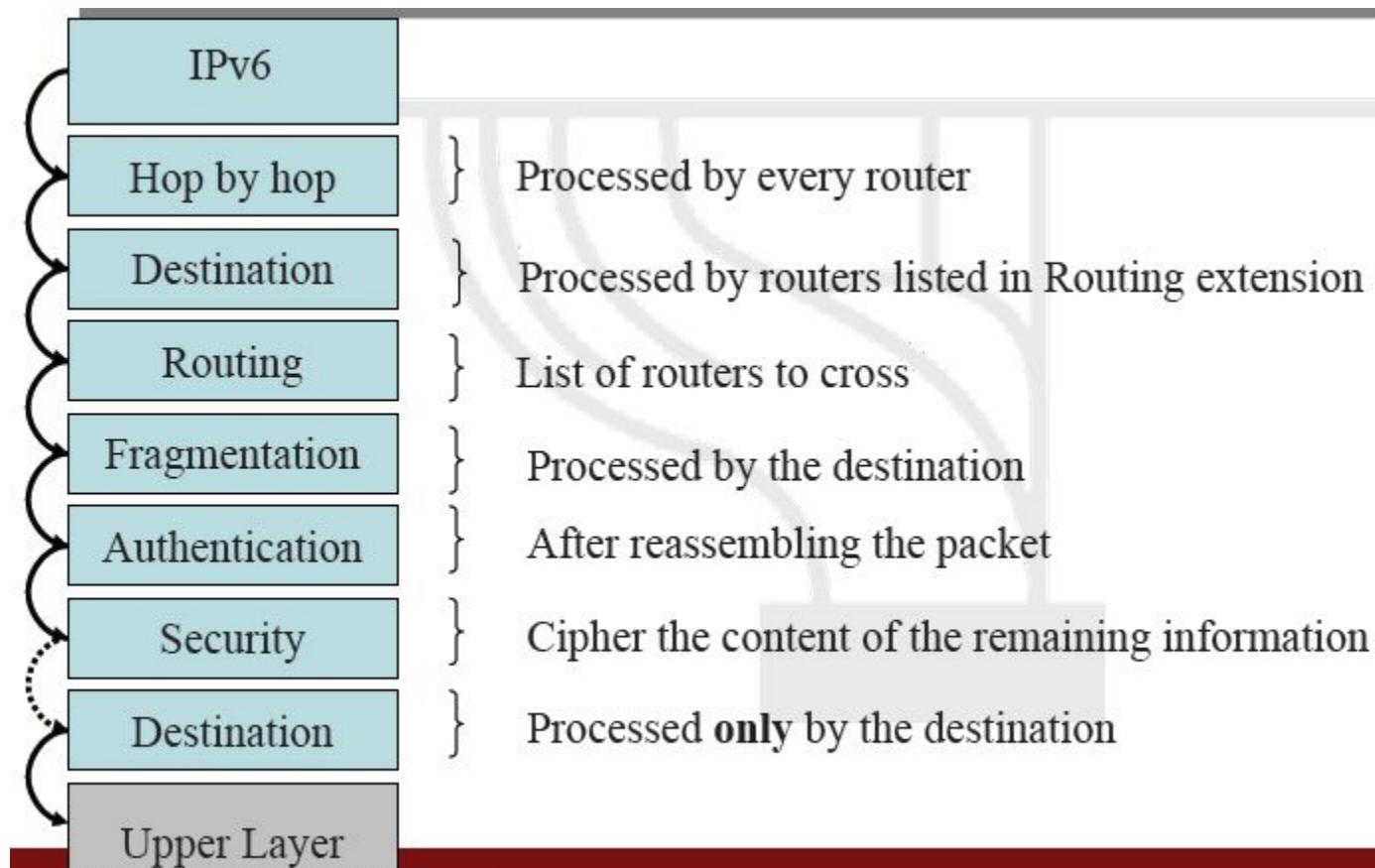


IPv6 datagram

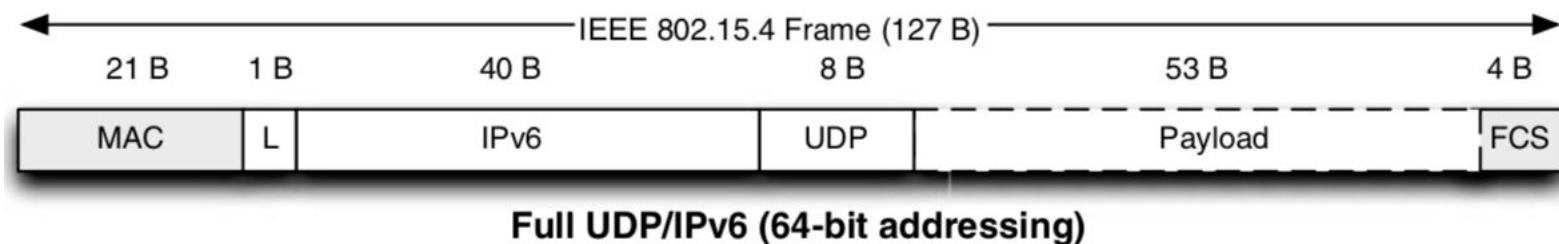


<i>Code</i>	<i>Next Header</i>	<i>Code</i>	<i>Next Header</i>
0	Hop-by-hop option	44	Fragmentation
2	ICMP	50	Encrypted security payload
6	TCP	51	Authentication
17	UDP	59	Null (No next header)
43	Source routing	60	Destination option

IPv6 datagram: order is relevant

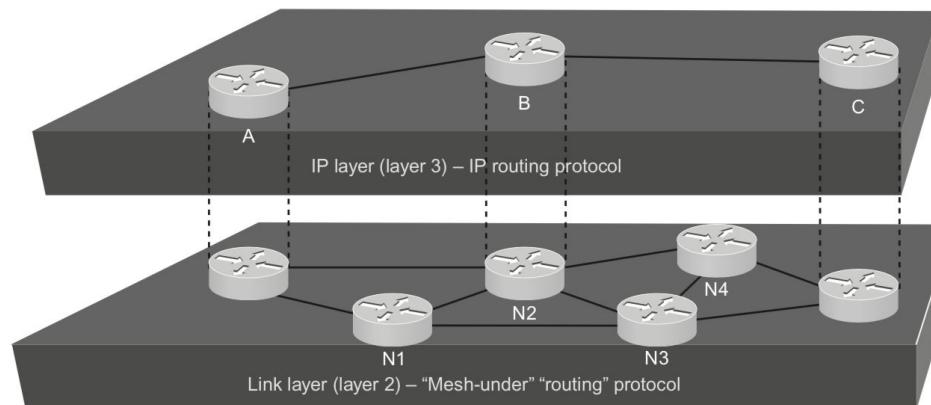


Challenges for 6LoWPAN

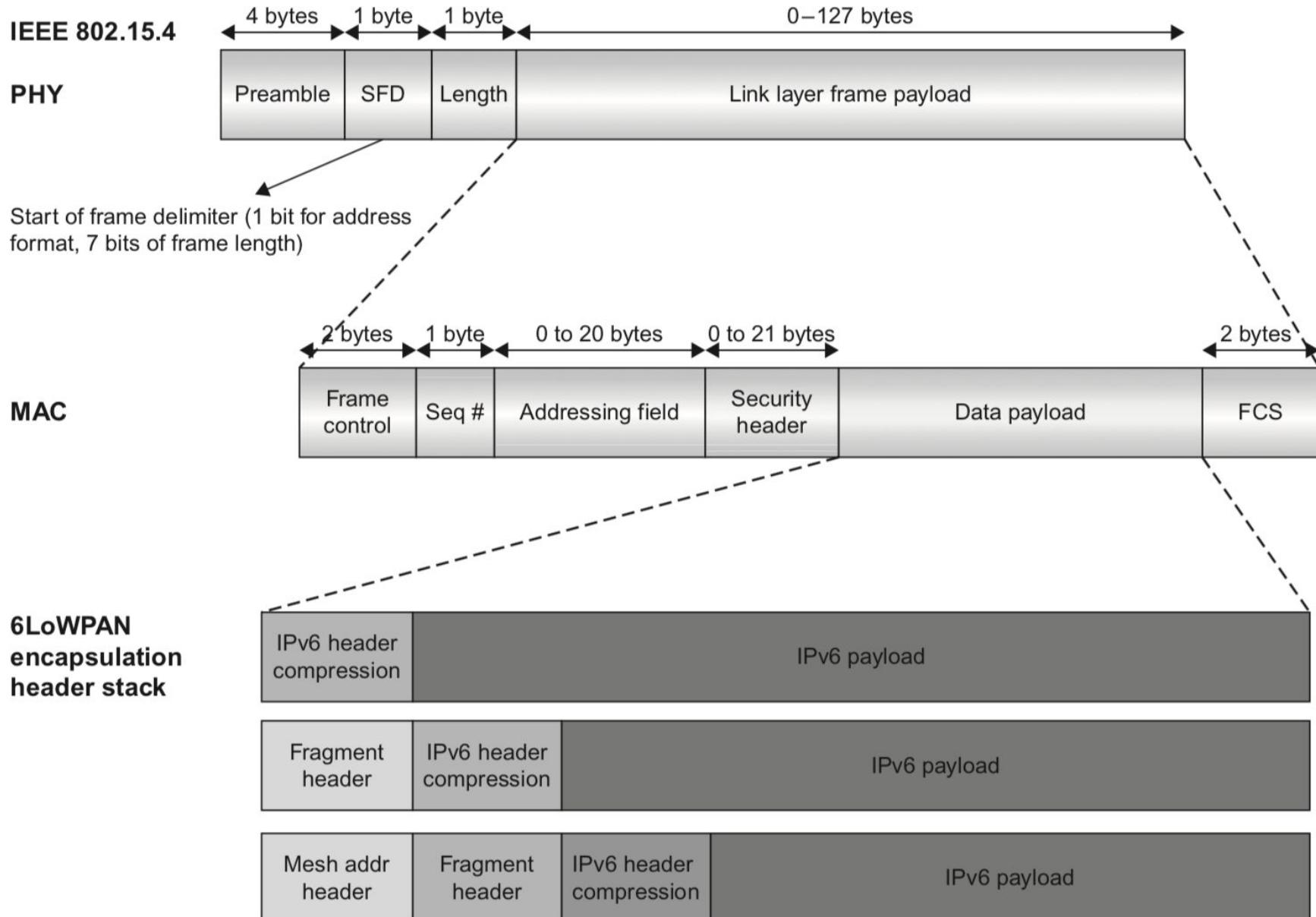


- MTU for 6LowPAN is 1280B
 - 802.15.4 packets are 127B, MSDU of 102B, removing security header (21B) remain 81B, removing 40B from the IPv6 header remain 41B, removing the 8B of the UDP header **remain only 33B** for the application
 - Header compression
 - Take advantage of L2 addresses -> 16 bit short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

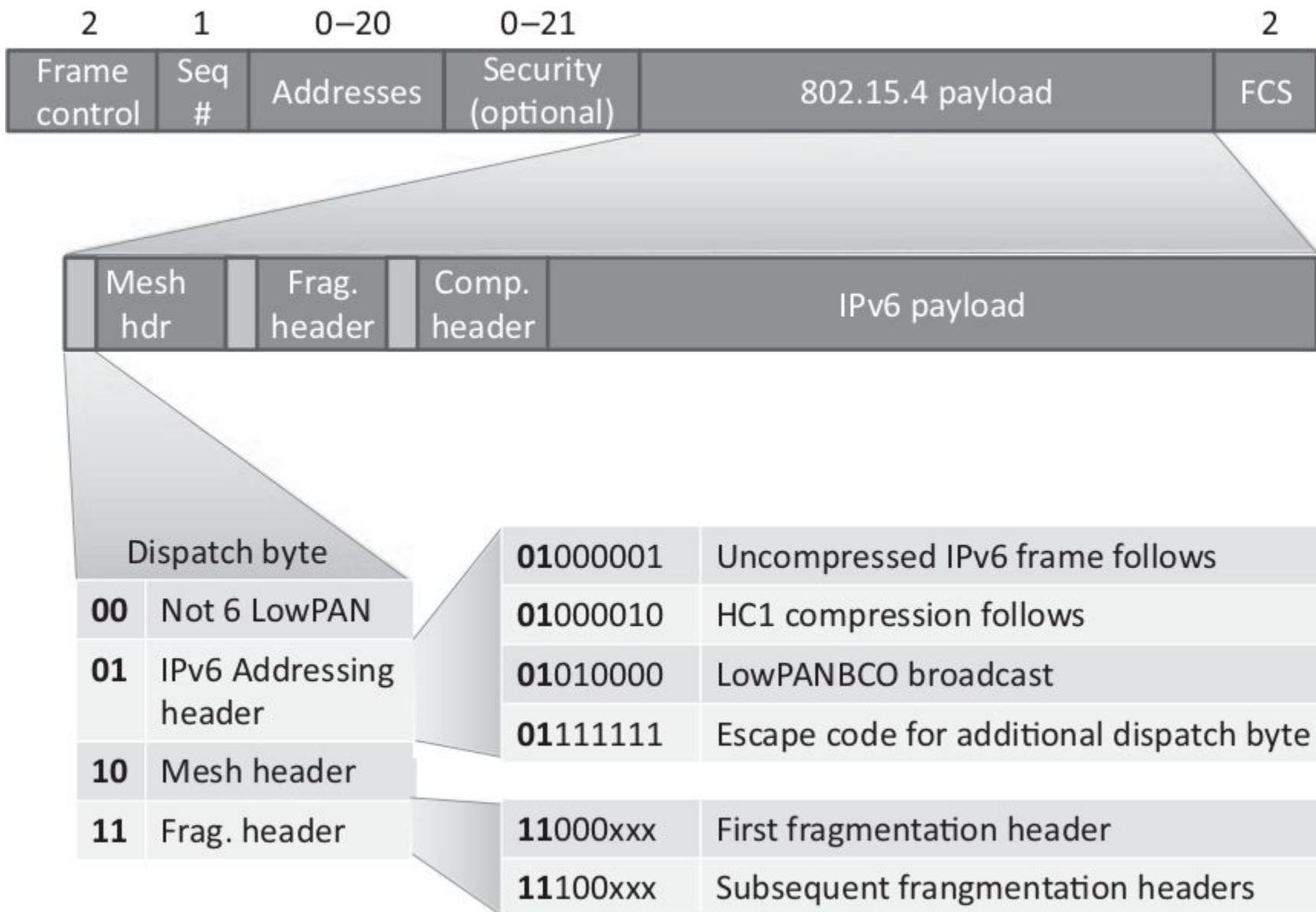
- Two types according to where is the routing done
 - Router-over -> L3
 - Mesh-under -> L2
 - Mixed



6LoWPAN encapsulation

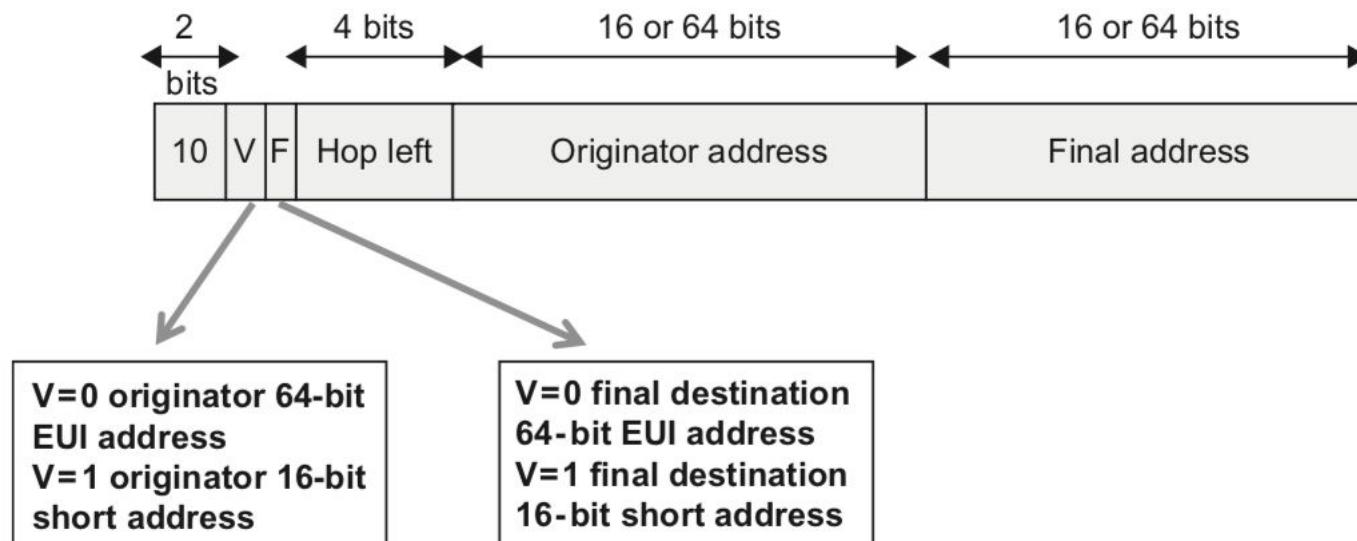


6LoWPAN encapsulation

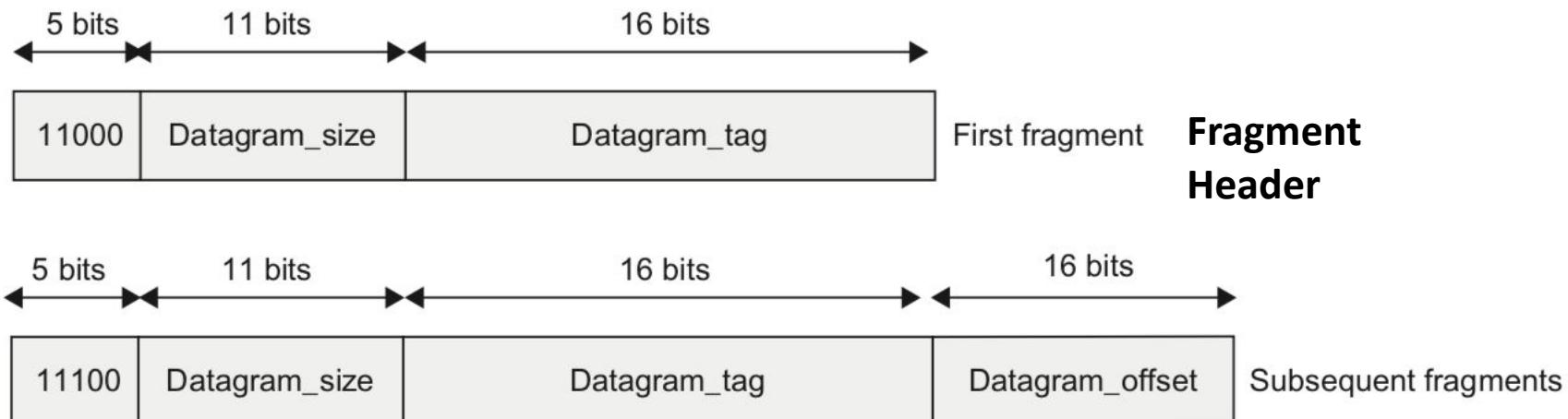


Mesh Addressing header

- 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

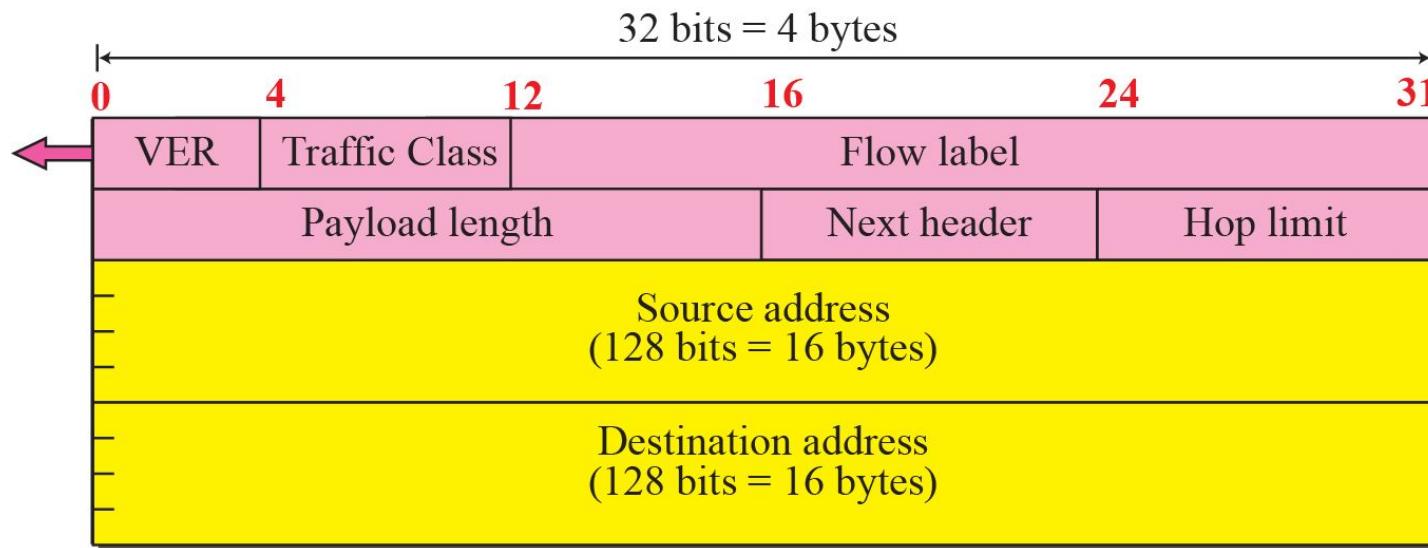


- Necessary when the payload of the IPv6 package does not fit in a single 802.15.4 frame
 - The frame is divided into several fragments
 - The size of the fragments are expressed in multiples of 8 bytes
 - Datagram_size: size of the original IPv6 datagram
 - Datagram_tag: id for the datagram. The same 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



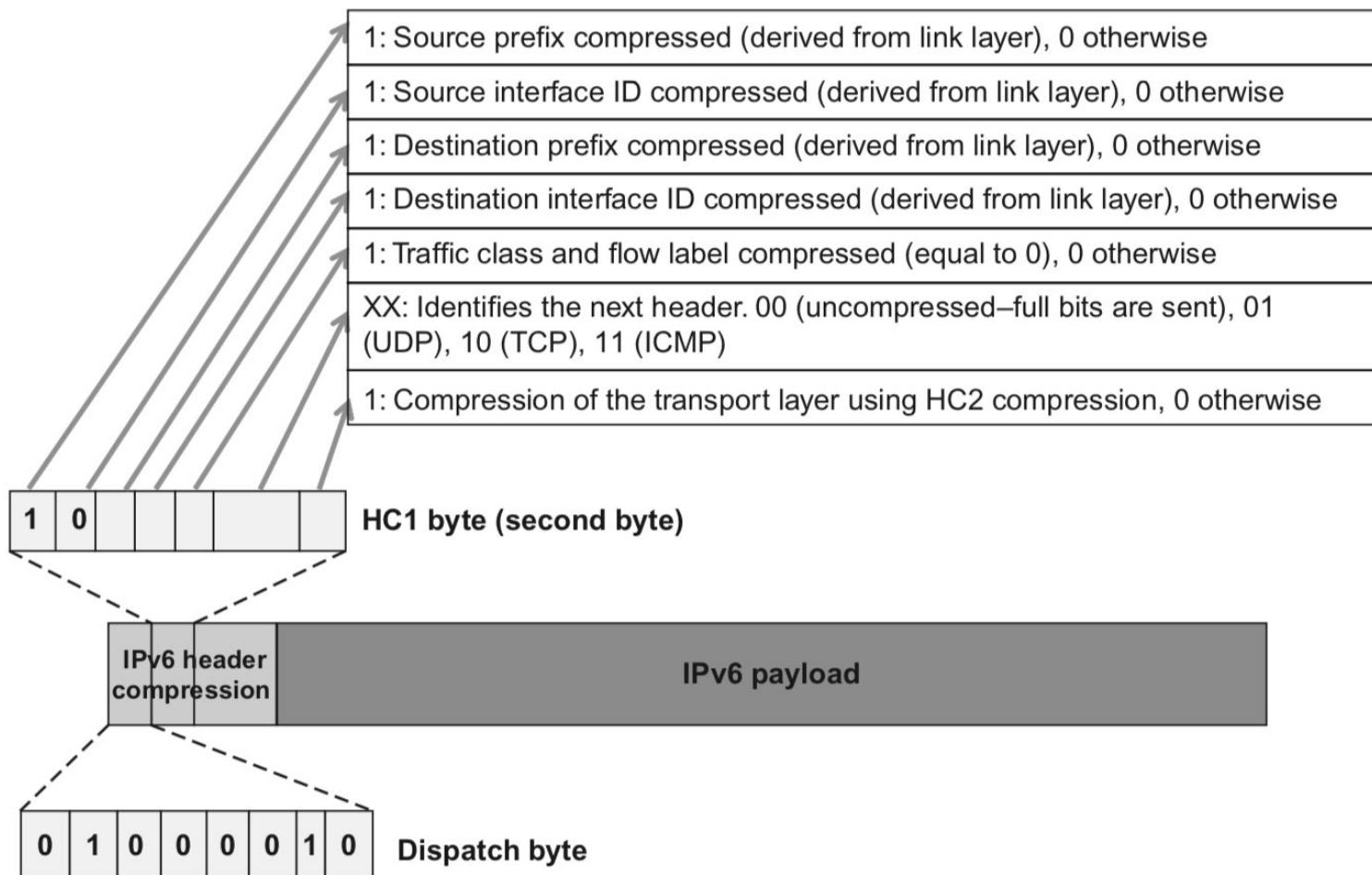
- Several compression techniques exist
- Most of them use state information to achieve higher compression rates
- A stateless compression was first designed
 - Only uses the information in each packet
 - Codes with less bits the most frequent values
 - Takes advantage of the redundancies in the lower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

- 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



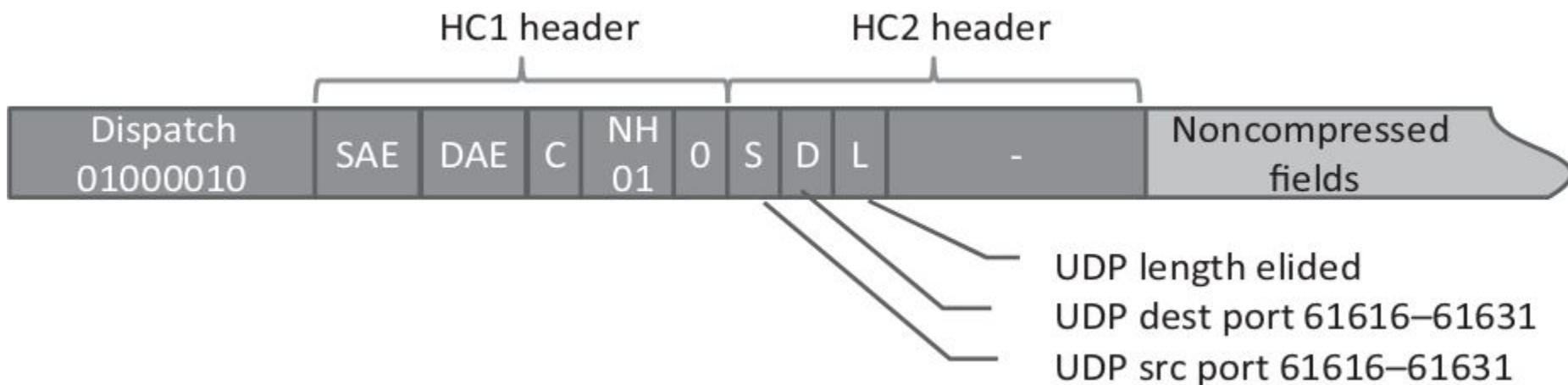
HC1 IPv6 compressed header: 3 bytes

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

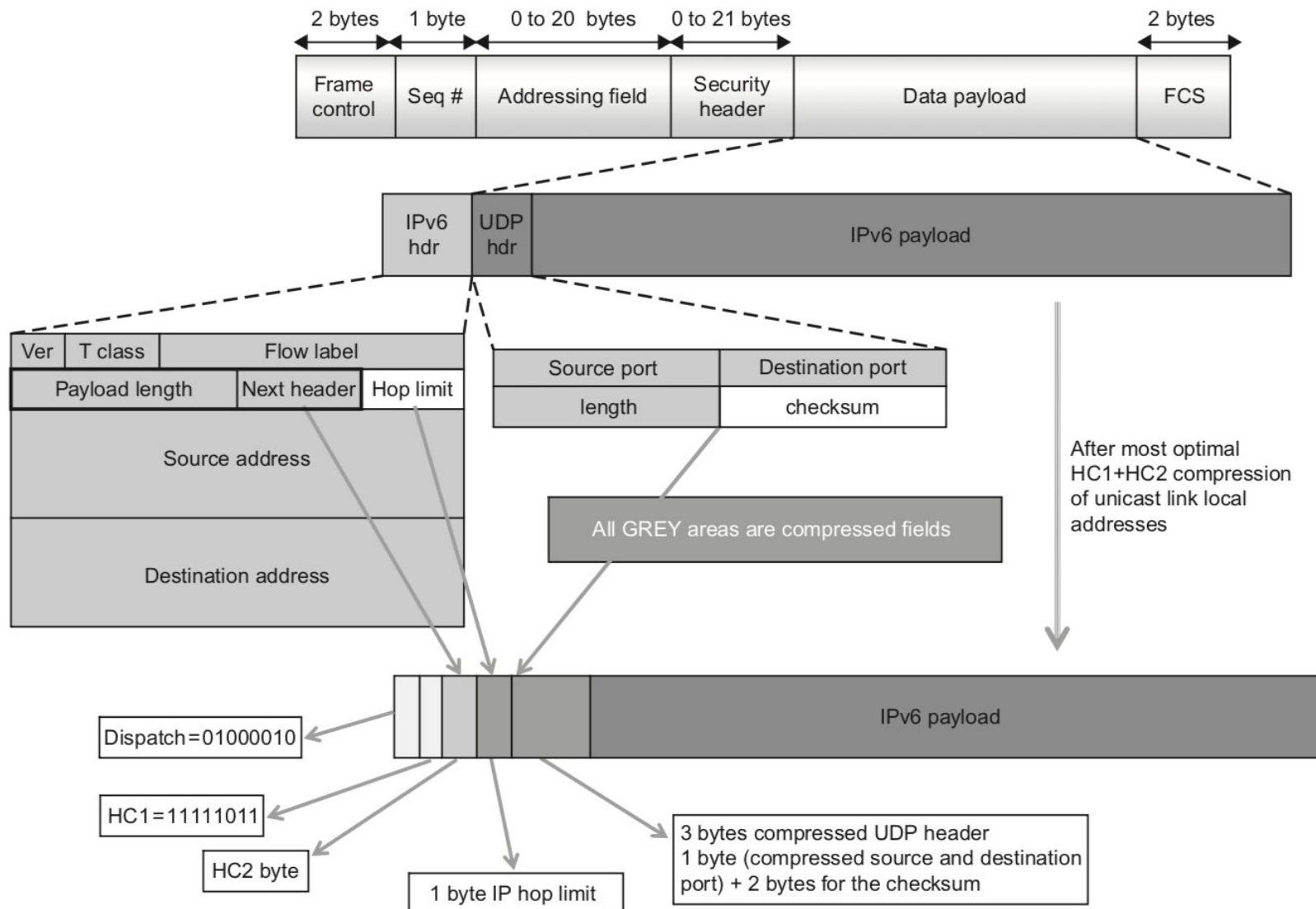


UDP compressed header (HC2)

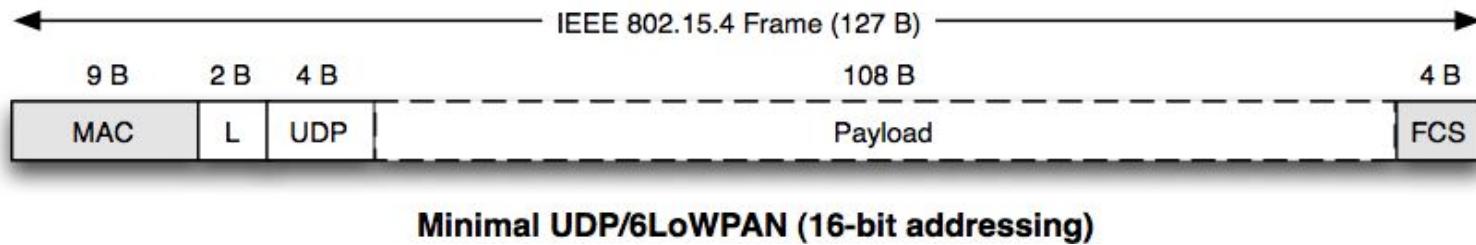
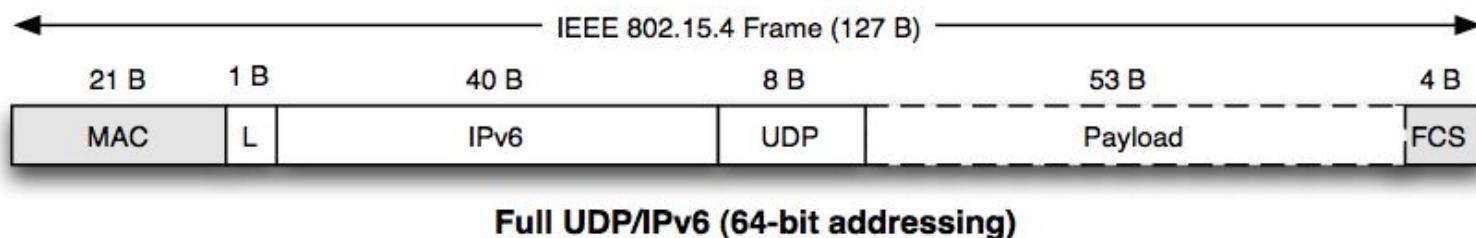
- S,D: 1 bit, indicate if the source and destination ports are in the range 62616 - 62631, and can then be encoded with only 4 bits
- L: 1 bit, indicates if the length field of the datagram has been removed



UDP datagram with HC1 and HC2



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

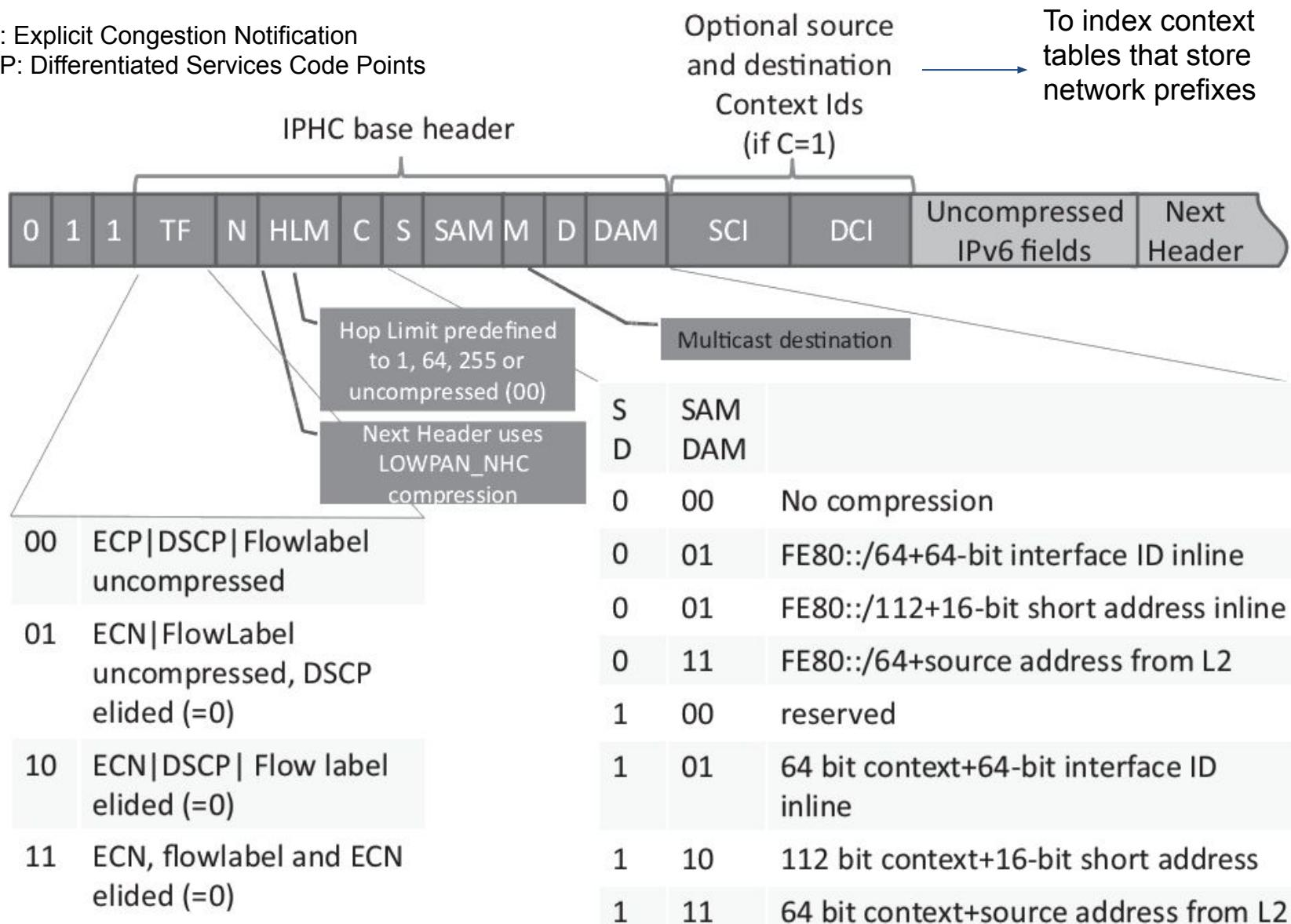


- Low effectiveness for Global Unicast addresses

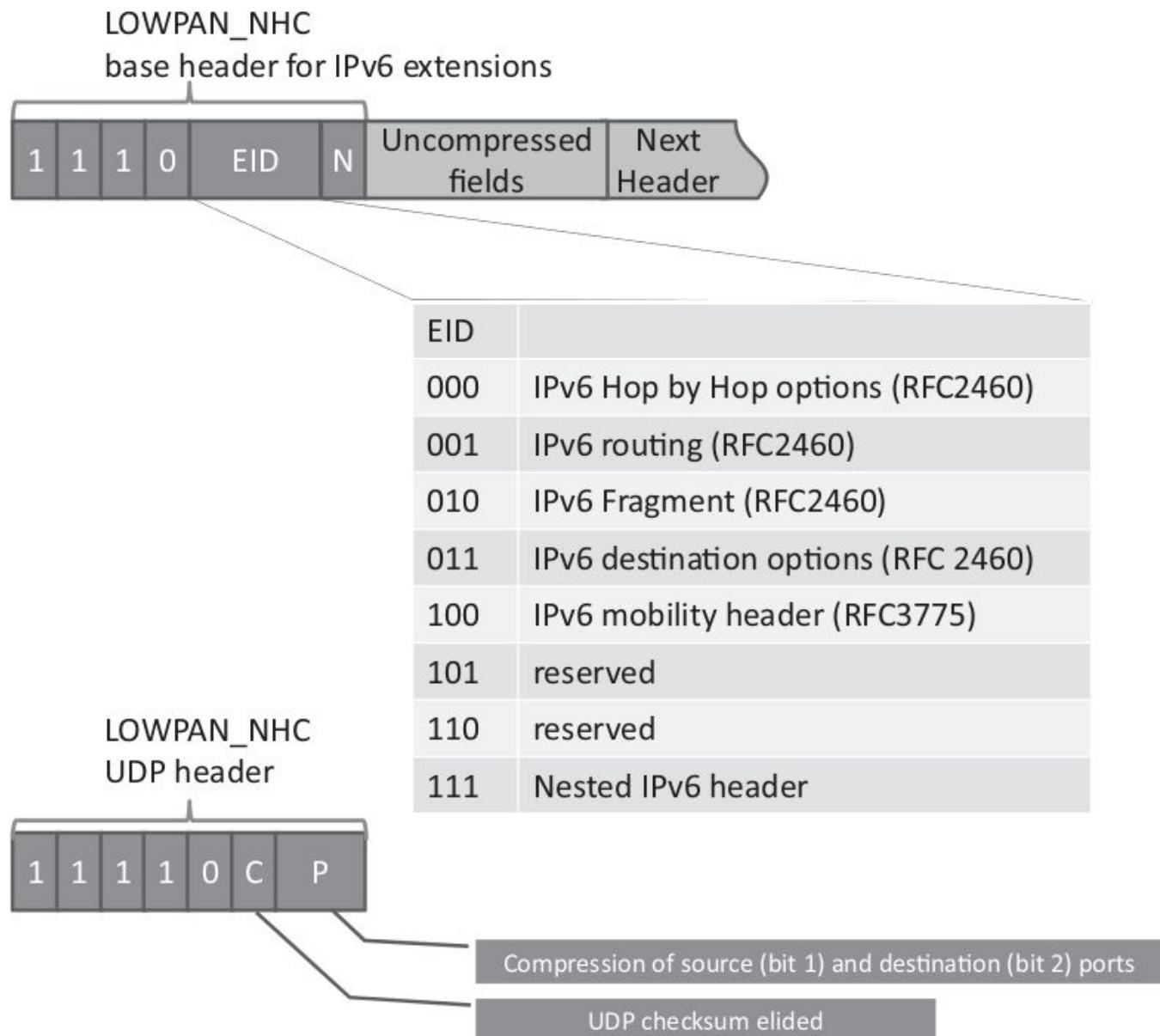
Context based IPHC compressed header

ECN: Explicit Congestion Notification

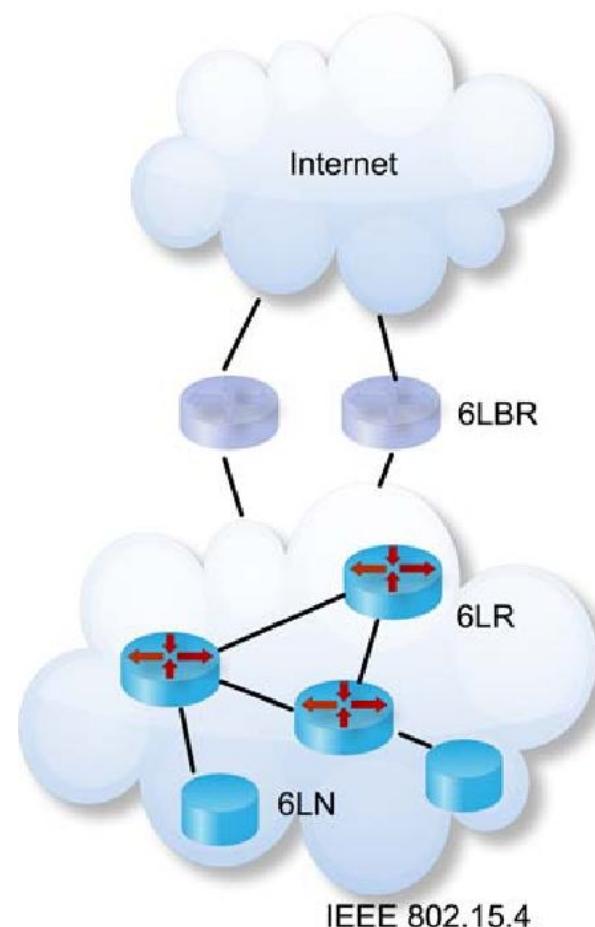
DSCP: Differentiated Services Code Points



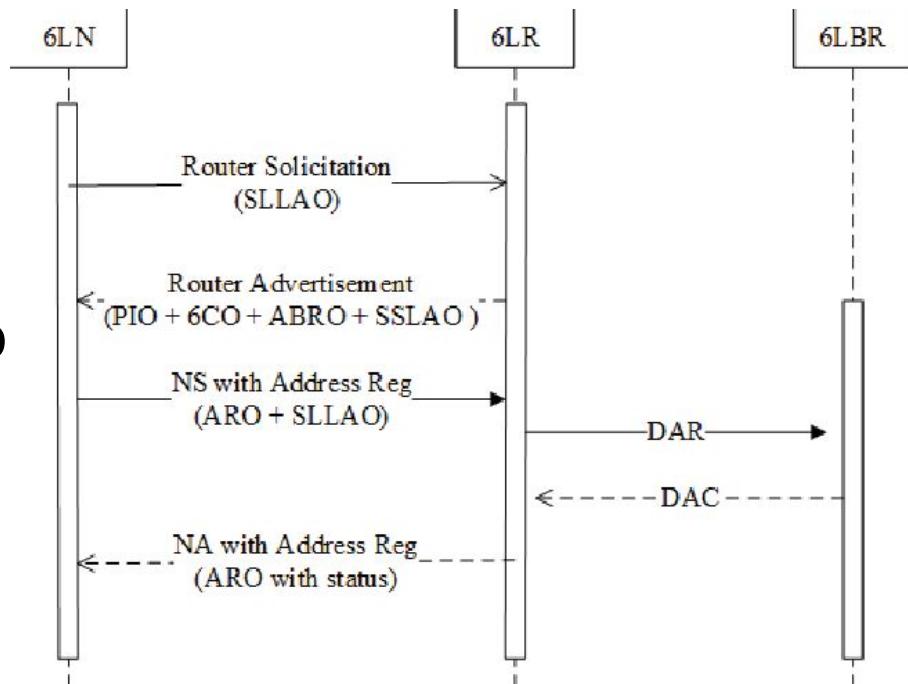
LOWPAN_NHC compressed options



- 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



- 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

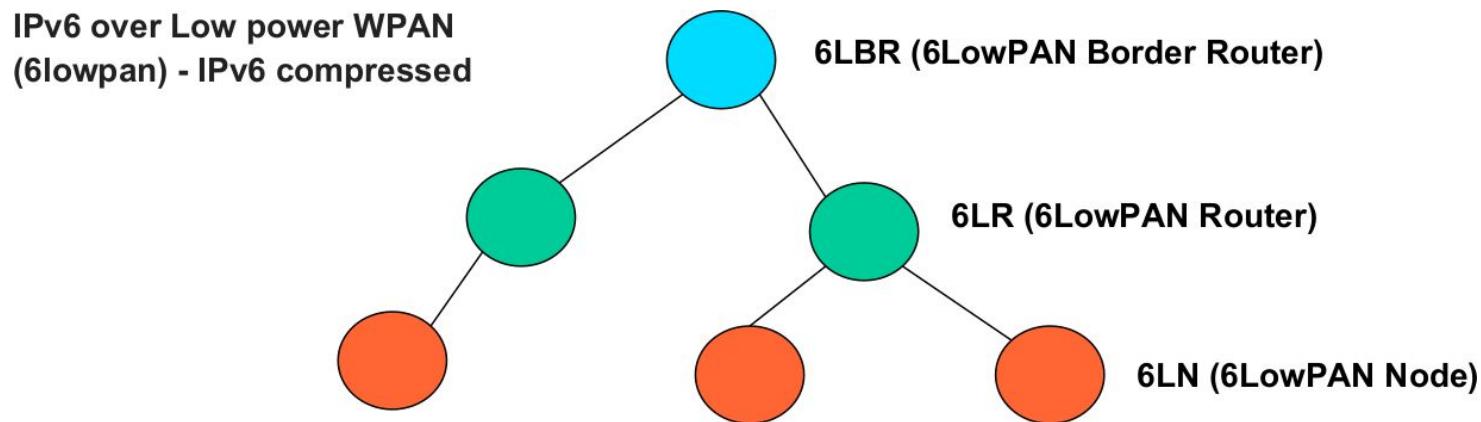
ABRO: Authoritative Border Router Option

6CO: 6LoWPAN context options

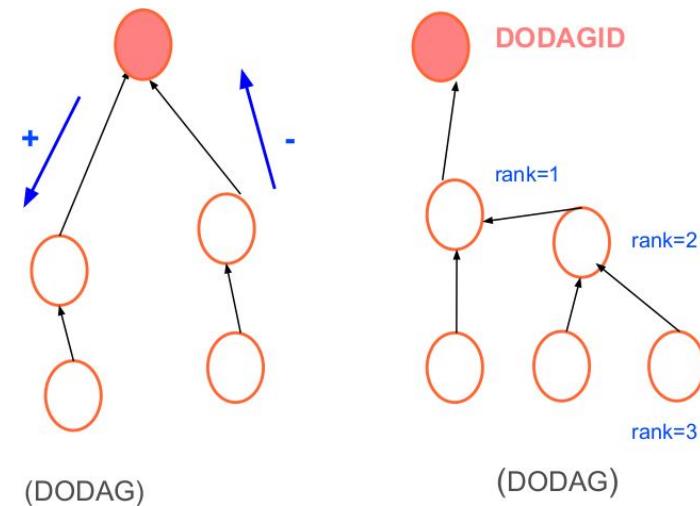
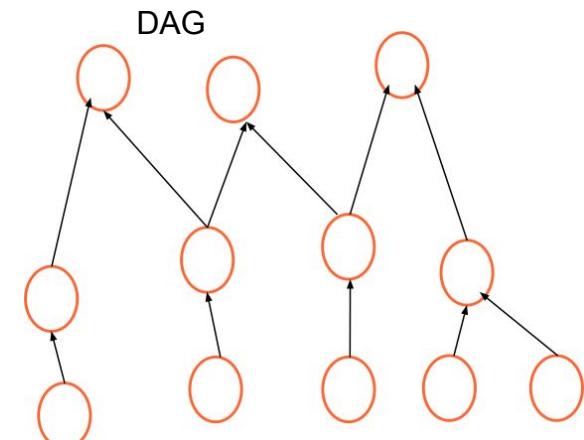
PIO: Prefix information options

ARO: Address Registration Option

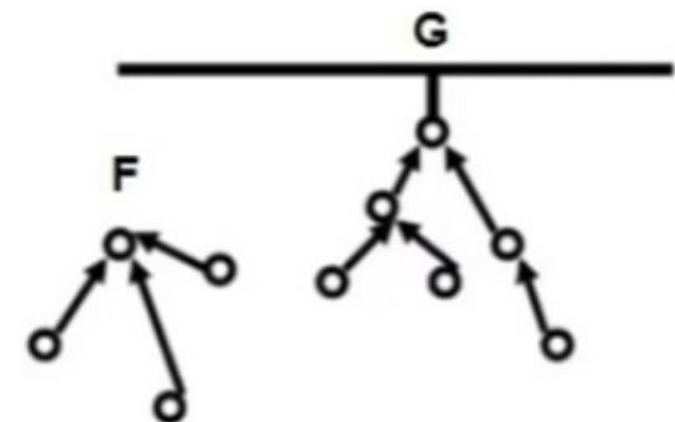
- IPv6 Routing Protocol for Low Power Lossy Networks
 - Specified by the IETF, [RFC6550](#)
- Distance Vector Routing Protocol
 - Each node maintains a table of distances to all the other nodes of the network
 - address of next hop
 - distance/cost
 - Simpler and less overhead than link state algorithms
- Intra domain routing
- Topological changes are notified to neighbors



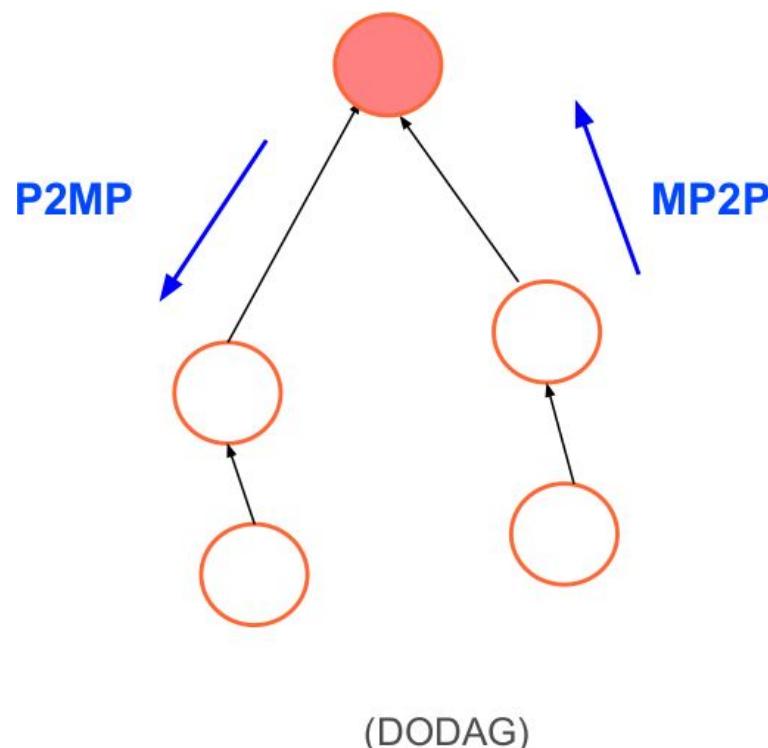
- DAG: Acyclic Directed Graph
 - Oriented edges
 - No cycles
 - A node can have more than one edge
- DAG Root:
 - A node with no output edges
- DODAG: Destination Oriented DAG
 - A DAG with only one root
- DODAG Root:
 - The root of the DODAG
 - Act as a border/edge router
 - Has a DODAGID
- Up: upstream flow
- Down: downstream flow
- Rank: distance to the root



- Objective function:
 - How to compute the rank
- RPLInstanceID: unique id for the RPL network
- RPL Instance:
 - A set of one or more DODAGs with the same RPLInstanceID and objective function
 - A node may belong to more than one DODAGs
- Storing Nodes:
 - store the complete routing table
- Non Storing Nodes:
 - Only store the parents
- Grounded DODAG:
 - Can reach the GOAL
- Floating DODAG:
 - Cannot reach the GOAL



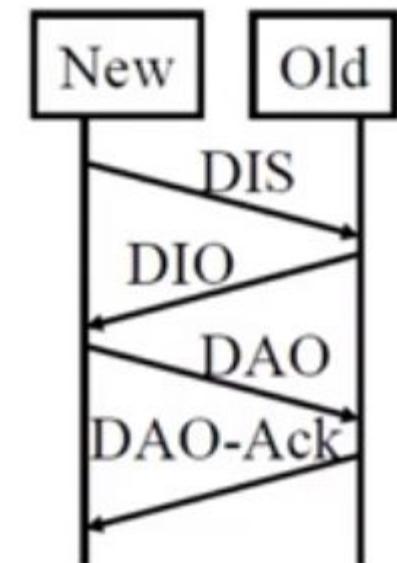
- Three flows
 - Multi Point to Point (MP2P)
 - Point to Multi Point (P2MP)
 - Point to Point (P2P)
- RPL is optimised for MP2P

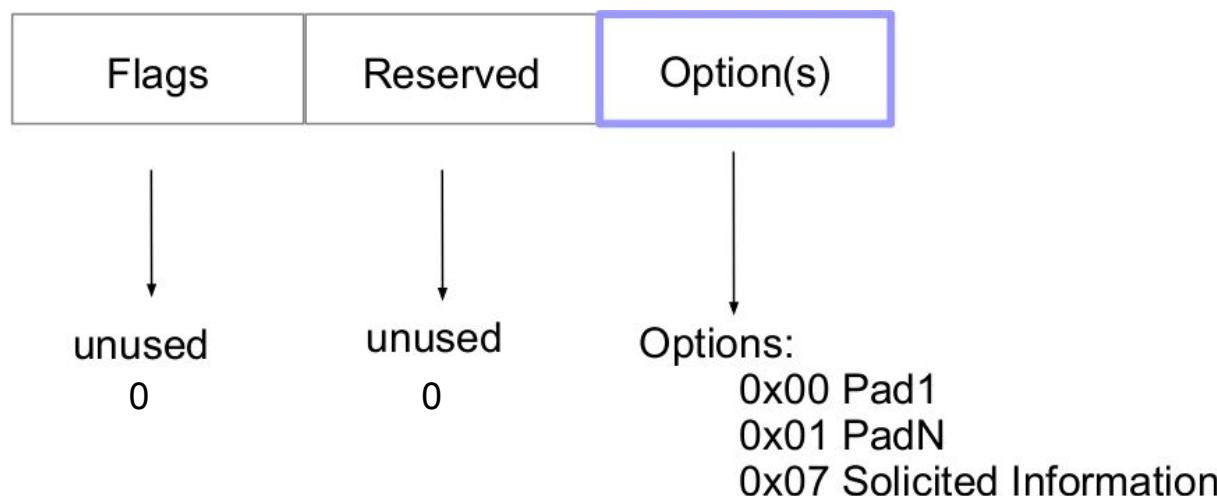


- New ICMPv6 control packets

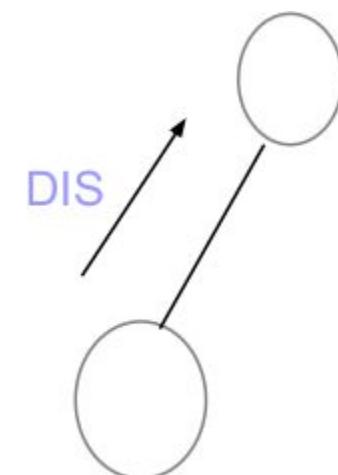


- Code identifies the type of message
 - 0x00: DODAG Information Solicitation (DIS)
 - 0x01: DODAG Information Object (DIO)
 - 0x02: Destination Advertisement Object (DAO)
 - 0x03: DAO-Ack





- Equivalent to the RS in IPv6 NDP
- Sent upstream to request a DODAG Information Object (DIO)



DODAG Information Object (DIO)

RPLInstanceID				Version Number	Rank	
G	0	MOP	Prf	DTSN	Flags	Reserved
DODAGID						
IPv6 address of the DODAG root						
Option(s)						

Field	Interpretation
G	1 - Grounded, 0 - Floating
Prf	DAGPreference 0-7, 0 lower preference
DTSN	Destination Advertisement Trigger Sequence Number, to maintain downward routes
Flags	no usado, deben ser 0
Reserved	no usado, deben ser 0

MOP	Operation Mode
0	Not maintain downward routes
1	Non Storing Mode
2	Storing Mode without multicast
3	Storing Mode with multicast
4-7	reservado

Type	Options
0x00	PAD1
0x01	PADN
0x02	DAG Metric Container
0x03	Routing Information
0x04	DODAG Configuration
0x08	Prefix Information

Sent periodically by routers or as a response to a DIS

Sends downstream the DODAG Information

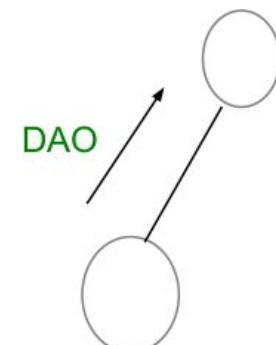
DODAG Advertisement Object (DAO)

RPLInstanceID	K	D	Flags	Reserved	DAOSequence
DODAGID					
IPv6 address of the DODAG root					
Option(s)					

Field	Interpretation
K	Requiere DAO-ACK
D	DODAGID present
Flags	not used, 0
Reserved	not used, 0
DAOSequence	Sequence number copied on the DAO-ACK

Type	Options
0x00	PAD1
0x01	PADN
0x05	RPL Target
0x06	Transit Information
0x09	RPL Target Descriptor

- Used to send information upwards



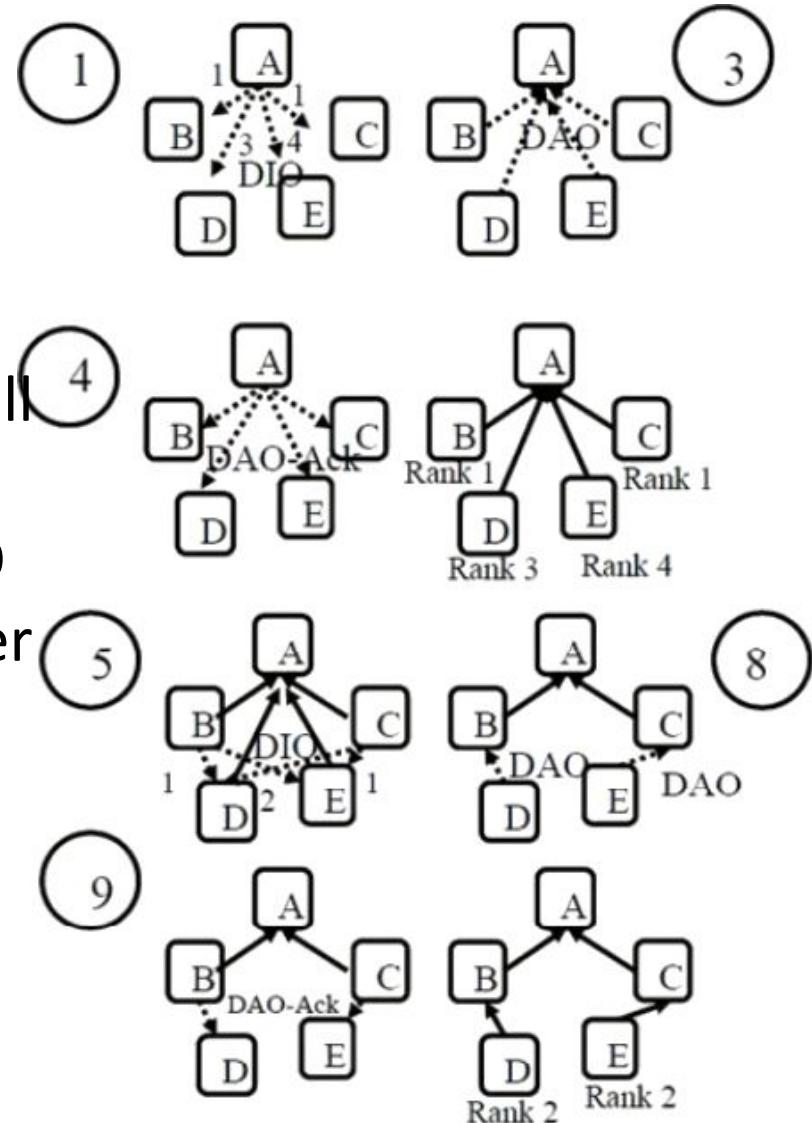
RPLInstanceID	D	Reserved	DAOSequence	Status
			DODAGID	
			IPv6 address of the DODAG root	
			Option(s)	

Status	Interpretation
0	Aceptado sin condiciones
1-127	Aceptado, pero se sugiere buscar un padre distinto
128-255	Rechazado, el nodo que envía el DAO-ACK rechaza actuar como padre

Sent as response to a DAO message

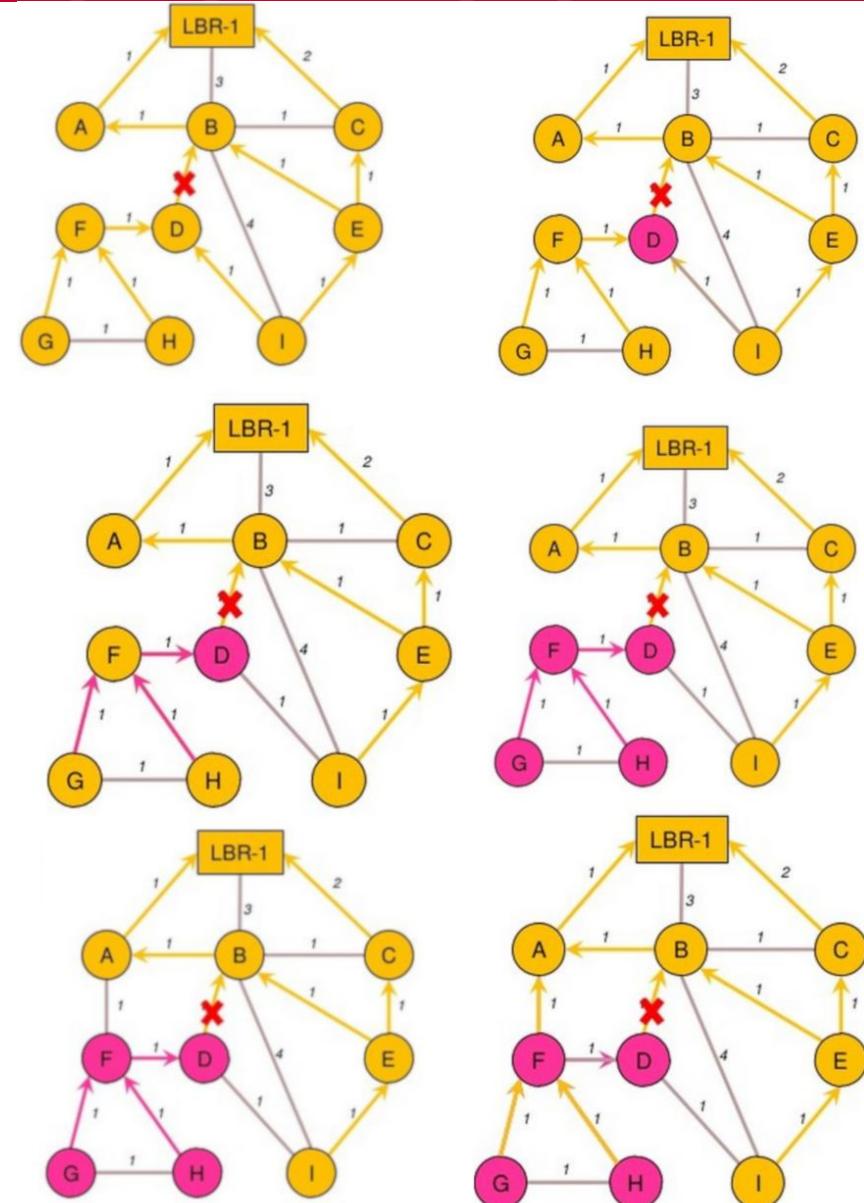
DODAG formation

1. The DODAG Root (A) sends DIO
2. On reception the nodes compute the rank to A
3. The nodes send a DAO
4. El DODAG Root accepts confirms all with DAO-ACK (accepts)
5. Nodes start sending their own DIO
6. D observes that it will have a better rank through B
7. E observes the same with C
8. D and E send DAO messages to B and C
9. B and C confirm with a DAO-ACK (accept)



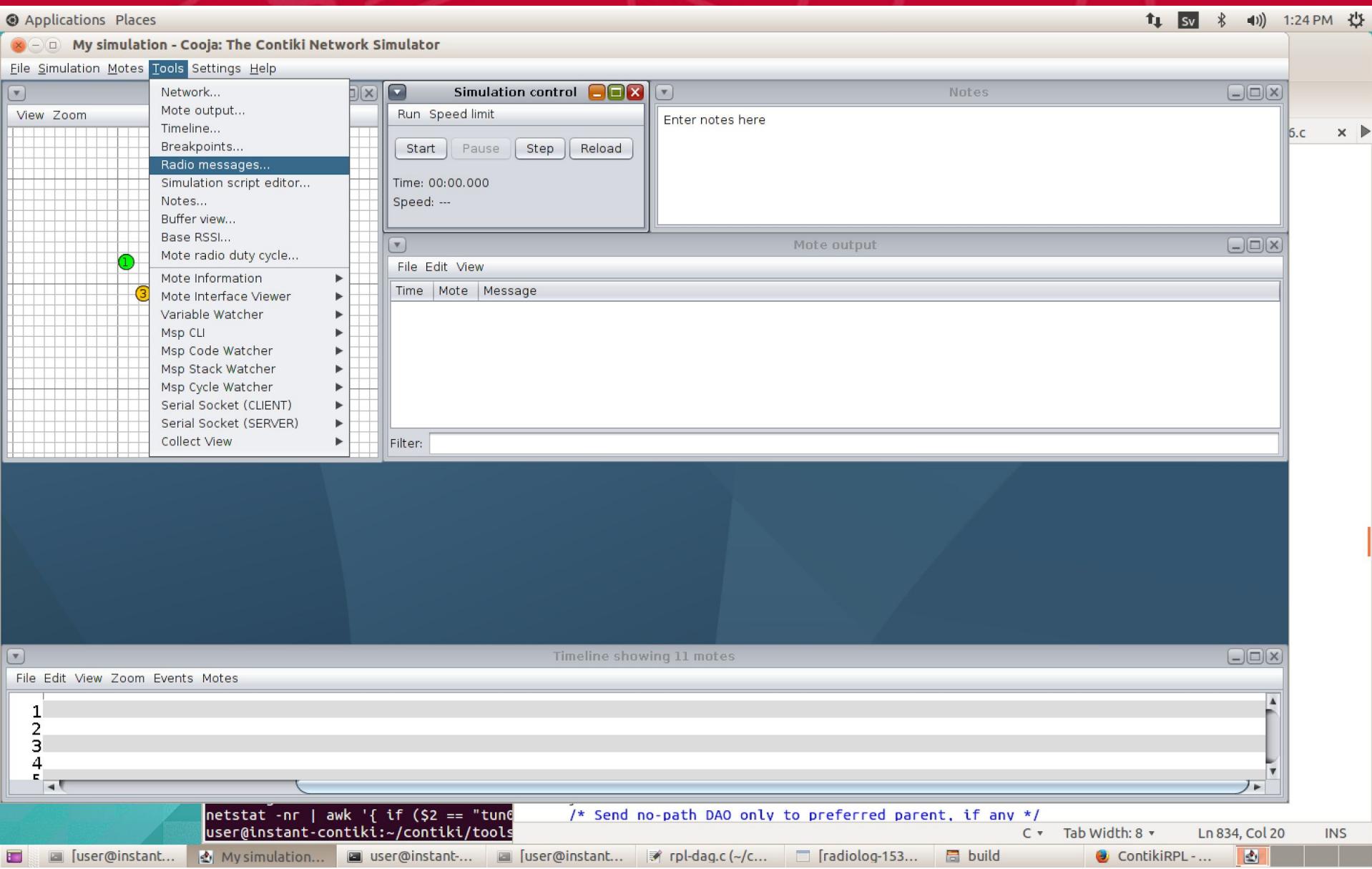
Broken Link

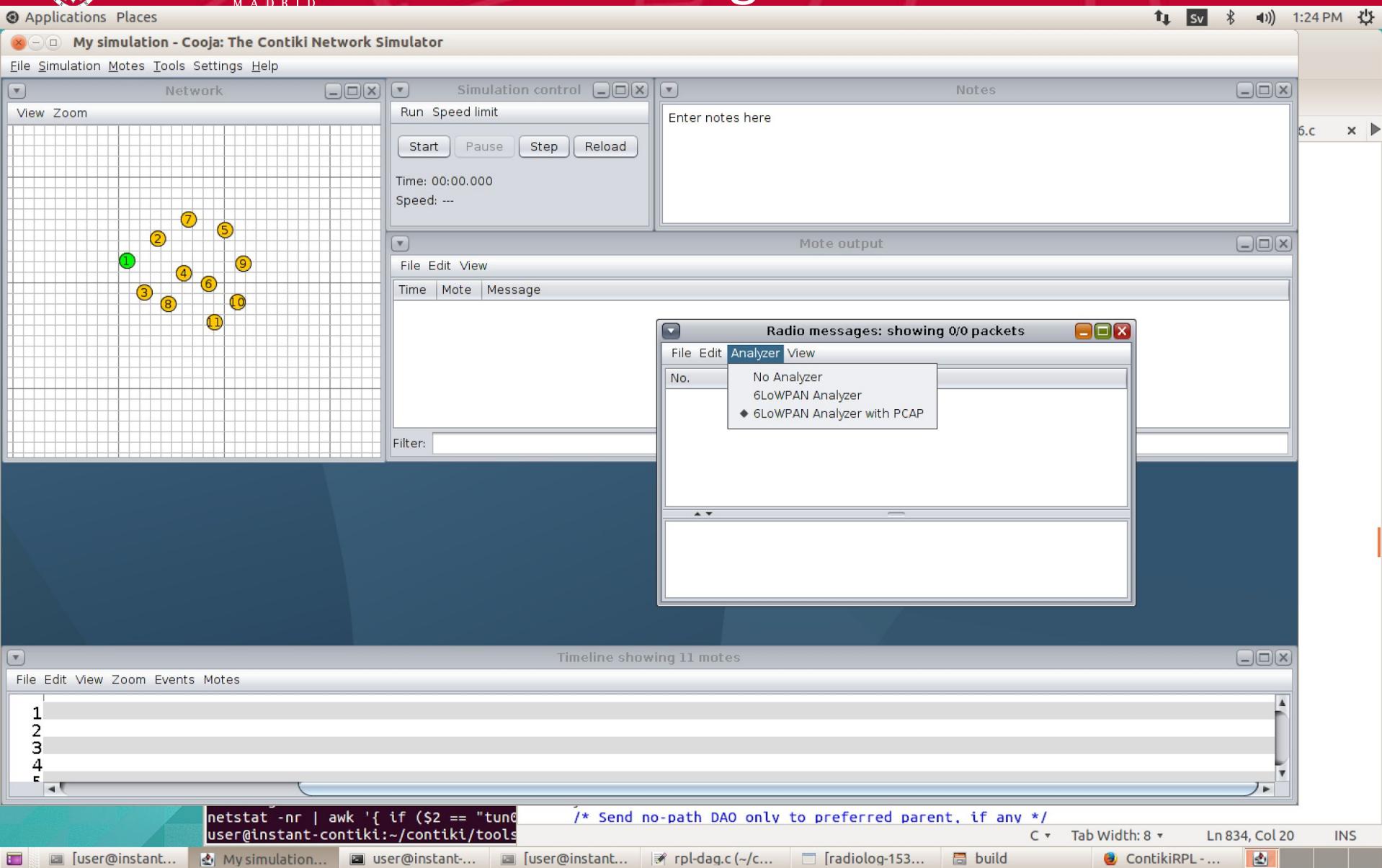
1. Link between D and B breaks
2. D sends a DIO to notify the changes in its sub-DAG
 - I remains in the DODAG through E
 - I removes D from the list of parents
3. F sends DIO to G and H
4. G and H join the floating DODAG
5. F receives a DIO from A
6. F sends DAO to A and joins again the DODAG LBR-1
 - Removes D from the list of parents



- You will use Cooja to simulate a 6LoWPAN network that uses RPL
 - <https://sourceforge.net/projects/contiki/files/Instant%20Contiki/>
 - # cd ~/contiki/tools/cooja/
 - # ant run
- You can analyze the network traffic with wireshark by exporting PCAP files of the simulated traffic
 - You can eliminate duplicate packets with the editcap tool:
`# editcap -d original_file.cap filtered-output.cap`
- To infer the DODAG topology you can
 - Filter the DIO and DAO messages
 - Activate the debug information in ~/contiki/core/net/rpl/rpl-dag.c and call `rpl_print_neighbor_list()` from the `rpl_process_dio()` function
 - Filter udp messages and analyse the 802.15.4 addresses to see the preferred routes for the UDP packets
 - Move/eliminate/add nodes and see how the RPL network converges

Open radio messages window





Applications Places

radiolog-1539180843814.pcap [Wireshark 1.7.2 (SVN Rev 42506 from /trunk)]

File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help

Filter: icmpv6.type == 155

No. Time Source

29592	255.084000	fe80::
29593	255.084000	fe80::
29594	255.085000	fe80::
29595	255.085000	fe80::
29596	255.085000	fe80::
29597	255.085000	fe80::
29598	255.086000	fe80::
29599	255.119000	fe80::
29600	255.119000	fe80::
29601	255.120000	fe80::
29602	255.120000	fe80::
29603	255.120000	fe80::
29604	255.120000	fe80::
29605	255.121000	fe80::
29607	255.160000	fe80::
29699	448.808000	fe80::
29700	448.833000	fe80::
29701	448.833000	fe80::

DAG Sequence: 252
DODAGID: aaaa::c30c:0:
ICMPv6 RPL Option (RPL)
Type: RPL Target (5)
Length: 18
Reserved
Target Length: 128
Target: aaaa::c30c:0:

Frame (76 bytes) 6LoWPAN
Frame (frame), 76 bytes

Wireshark: Open Capture File

Places

Search

Recently Used

user

root

File System

floppy0

Name

Size

Modified

Name	Size	Modified
external_tools_linux_04.config	98 bytes	10/01/2018
external_tools_macosx.config	2.2 kB	10/01/2018
external_tools_win32.config	1.2 kB	10/01/2018
log4j_config.xml	864 bytes	10/01/2018
quickhelp.txt	469 bytes	10/01/2018
radiolog-1538649111216.pcap	327.9 kB	10/04/2018
radiolog-1538657159714.pcap	199.2 kB	10/04/2018
radiolog-1538667350956.pcap	325.1 kB	10/04/2018
radiolog-1538759361083.pcap	542.8 kB	Saturday
radiolog-1538845172332.pcap	233.3 kB	Saturday
radiolog-1538846541178.pcap	2.0 MB	Saturday
radiolog-1539176005500.pcap	85.8 kB	Yesterday at 14:54
radiolog-1539176621614.pcap	517.7 kB	Yesterday at 15:04
radiolog-1539177130204.pcap	1.5 MB	Yesterday at 15:13
radiolog-1539180672554.pcap	545.5 kB	Yesterday at 16:11
radiolog-1539180843814.pcap	5.0 MB	Yesterday at 16:41
radiolog-1539182563304.pcap	1.5 MB	Yesterday at 16:45
radiolog-1539257068192.pcap	972.1 kB	13:26
radiolog-1539257670717.pcap	817.5 kB	13:35
radiolog-1539258387027.pcap	854.9 kB	13:47
test_template.c	3.4 kB	10/01/2018

Filter: radiolog-1539258387027.pcap

Format: Wireshark/tcpdump/... -libpcap

Enable MAC name resolution

Enable network name resolution

Enable transport name resolution

Size: 854866 bytes

Packets: 9371

First Packet: 2018-10-11 13:46:27

Elapsed time: 00:01:04

Cancel Open

user@instant-con... user@instant-con... [user@instant-co... rpl-daq.c (~/conti... radiolog-1539180... [ContikiRPL - Moz... Z1-simpleRPL - Co...