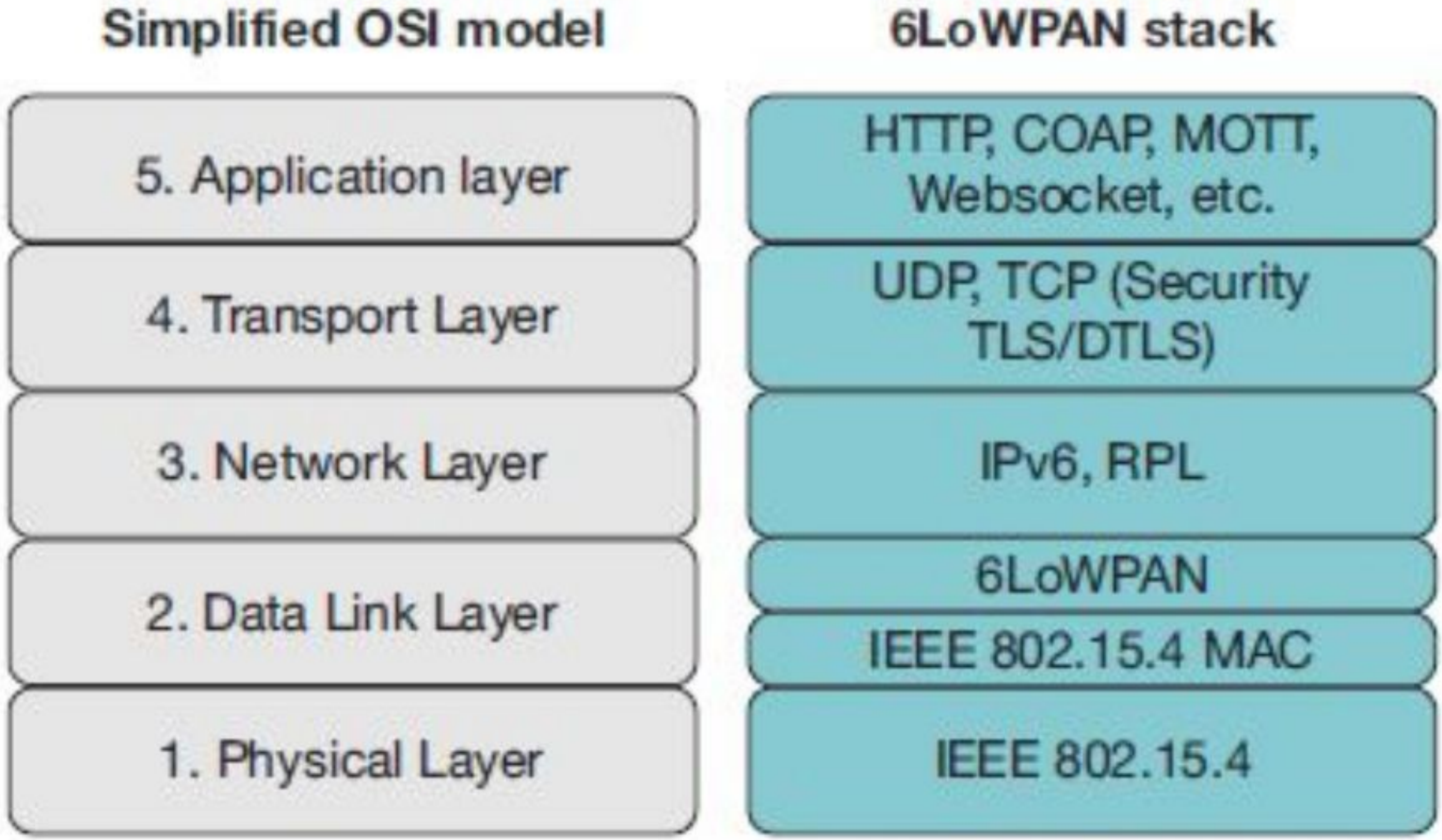
6LoWPAN(Continued…)

Recent Protocols for IoT

		Security	Management
Session	MQTT, SMQTT, CoRE, DDS, AMQP , XMPP, CoAP, IEC, IEEE 1888, …	IEEE 1888.3, TCG, Oath 2.0, SMACK, SASL, EDSA, ace, DTLS, Dice, …	IEEE 1905, IEEE 1451, IEEE 1377, IEEE P1828, IEEE P1856
Network	Encapsulation: **6LowPAN**, 6TiSCH, 6Lo, Thread…		
	Routing: **RPL**, CORPL, CARP		
Datalink	WiFi, Bluetooth Low Energy, Z-Wave, ZigBee Smart, DECT/ULE, 3G/LTE, NFC, Weightless, HomePlug GP, 802.11ah, 802.15.4e, G.9959, WirelessHART, DASH7, ANT+, LTE-A, LoRaWAN, ISA100.11a, DigiMesh, WiMAX, …		

Ref: Tara Salman, Raj Jain, "A Survey of Protocols and Standards for Internet of Things," Advanced Computing and Communications, Vol. 1, No. 1, March 2017, http://www.cse.wustl.edu/~jain/papers/iot_accs.htm


Simplified OSI model
6LoWPAN stack
5. Application layer
HTTP, COAP, MOTT, Websocket, etc.
4. Transport Layer
UDP, TCP (Security TLS/DTLS)
3. Network Layer
IPv6, RPL
2. Data Link Layer
6LoWPAN
IEEE 802.15.4 MAC
1. Physical Layer
IEEE 802.15.4

IPv6 over IEEE 802.15.4 CHALLENGES

- **Fragmentation**
  - IPv6: Minimum MTU(Maximum Transmission Unit) is 1,280 bytes
  - IEEE 802.15.4: Maximum 127 bytes
- **Head compression**
  - IPv6: 40 bytes compressed IP Header
  - 802.15.4: effective link payload is 81 bytes
- **Routing**
  - IPv6: A link is a single broadcast domain
  - 802.15.4: a mesh of short-range connections

- The header overhead is large
  - 802.15.4 maximum frame overhead of 25 bytes
  - Link-layer security can be as high as 21 bytes
  - This leaves 81 bytes left
  - 40-byte IP header
  - 8-byte UDP header
- **33 bytes remaining for actual data!**

Functions of Adaptation Layer:

There are various problems to be addressed:

- Links can be point-to-point or they can be multiple link
- Finding path for packets to proceed to the next IP node:

– Lowpan is not connection oriented.

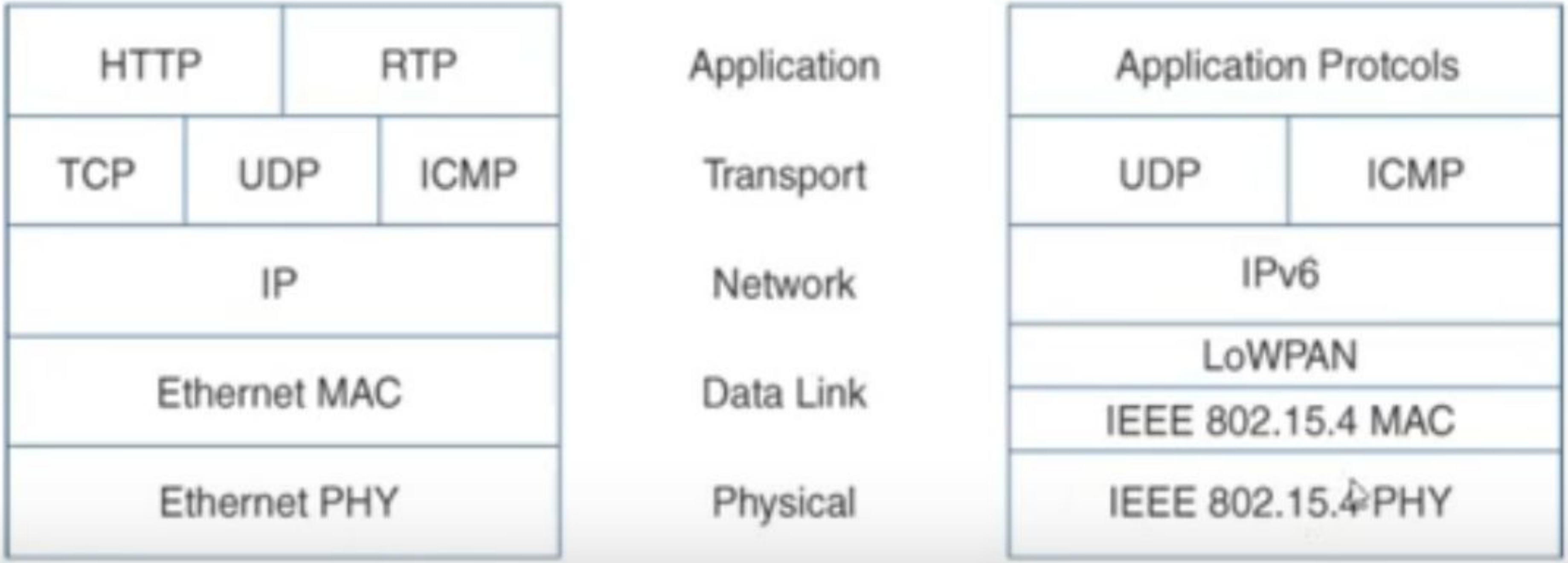
– Mesh-under routing, adaptation layer should provide L2 hop details and information for frame forwarding.

Contd…

- IP packets needs to be encapsulated in the subnetwork.
  - Some problems to be noted:
    - Different types of packets are carried by the links.
    - IP packets may not fit in L2 frame.
    - Lot of information in header.

IP Protocol Stack

IoT Protocol Stack with 6LoWPAN Adaptation Layer



```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version| Traffic Class |           Flow Label                  | IPv6
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+   |
|         Payload Length        |  Next Header  |   Hop Limit   |   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+   |
|                                                               |   |
+                                                               +   |
|                                                               |   |
+                         Source Address                        +   |
|                                                               |   |
+                                                               +   |
|                                                               |   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+   |
|                                                               |   |
+                                                               +   |
|                                                               |   |
+                      Destination Address                      +   |
|                                                               |   |
+                                                               +   |
|                                                               |   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Source Port          |       Destination Port        | UDP
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+   |
|            Length             |           Checksum            |   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 1.12 Standard IPv6/UDP headers (48 bytes).

Assumptions about link layer:

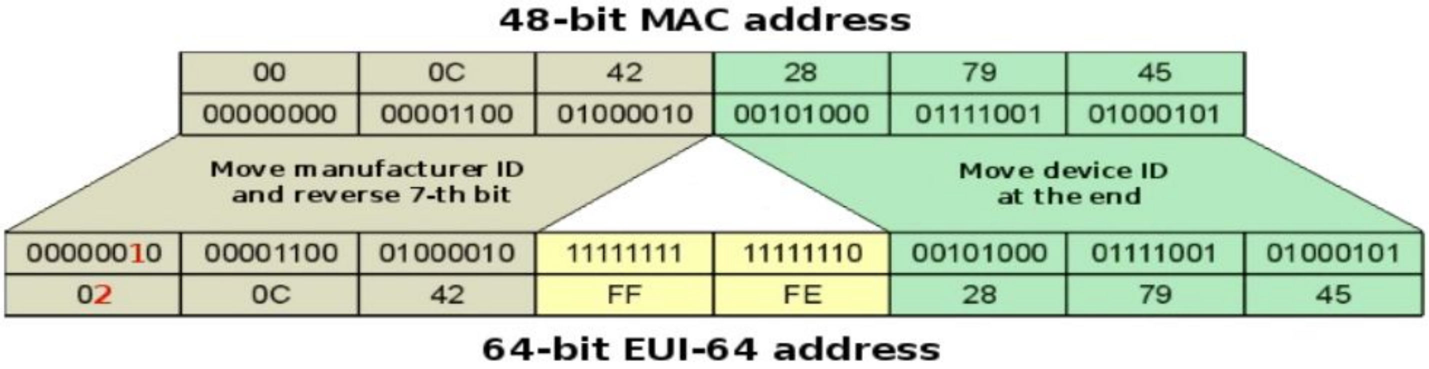
- **Link layer technologies beyond IEEE 802.15.4:**
  - 6LoWPAN is designed by keeping IEEE 802.15.4 in mind.
  - Goal is to make 6LoWPAN applicable to a much wider set of technologies.
- **Link layer service model:**
  - Basic service requirements of 6LoWPAN on link layer:
    - One node needs to be able to send packets of limited size to another node within radio range.
    - IP is unreliable. Even 6LoWPAN knows that low power wireless links cannot always offer a high reliability.
    - 6lowpan considers one hop neighborhood of a node.
    - IEEE 802.15.4 frame types: Data frame, Acknowledgement frames, MAC layer command frames (association, diassociation, synchronization..), Beacon frames.

- **Link Layer Addressing:**
  - Link Layer address is not routable.
  - Data frames carry source and destination addresses.
  - IEEE 802.15.4 defines
    - 64 bits address identified by EUI-64 (global/universal).
    - 16 bits short address assigned by PAN coordinator.
    - IEEE 802.15.4 identifies a node by PAN identifier and 16 bit short address.

How to derive 64 bit Interface Id from 48 bit MAC Address?

```
|0              7 8             5 6             3|
+----+----+----+----+----+----+
|cccc|ccug|cccc|cccc|cccc|cccc|
+----+----+----+----+----+----+
```

U/L bit

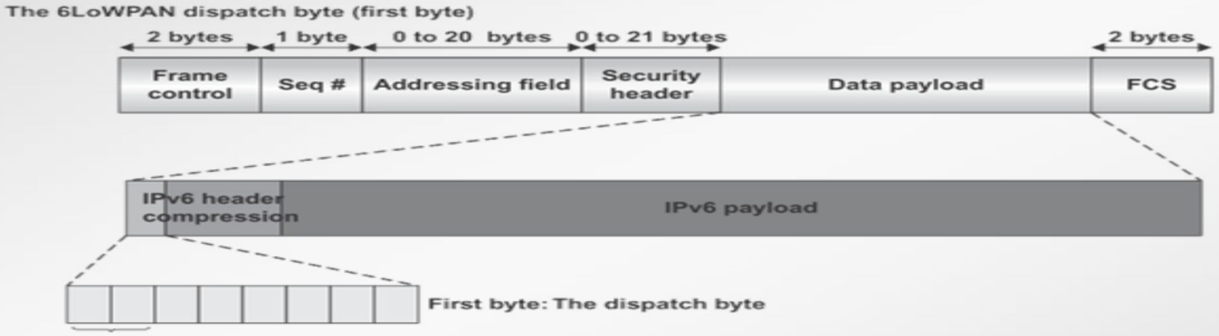


When IANA assigns an Organizationally Unique Identifier (OUI) to a NIC card vendor, the 7th bit will be 0, indicating the OUI was universally assigned. **Should a user manually change their MAC address, this 7th bit would be set to 1, indicating the Ethernet address was locally administered**.

6LoWPAN FORMAT

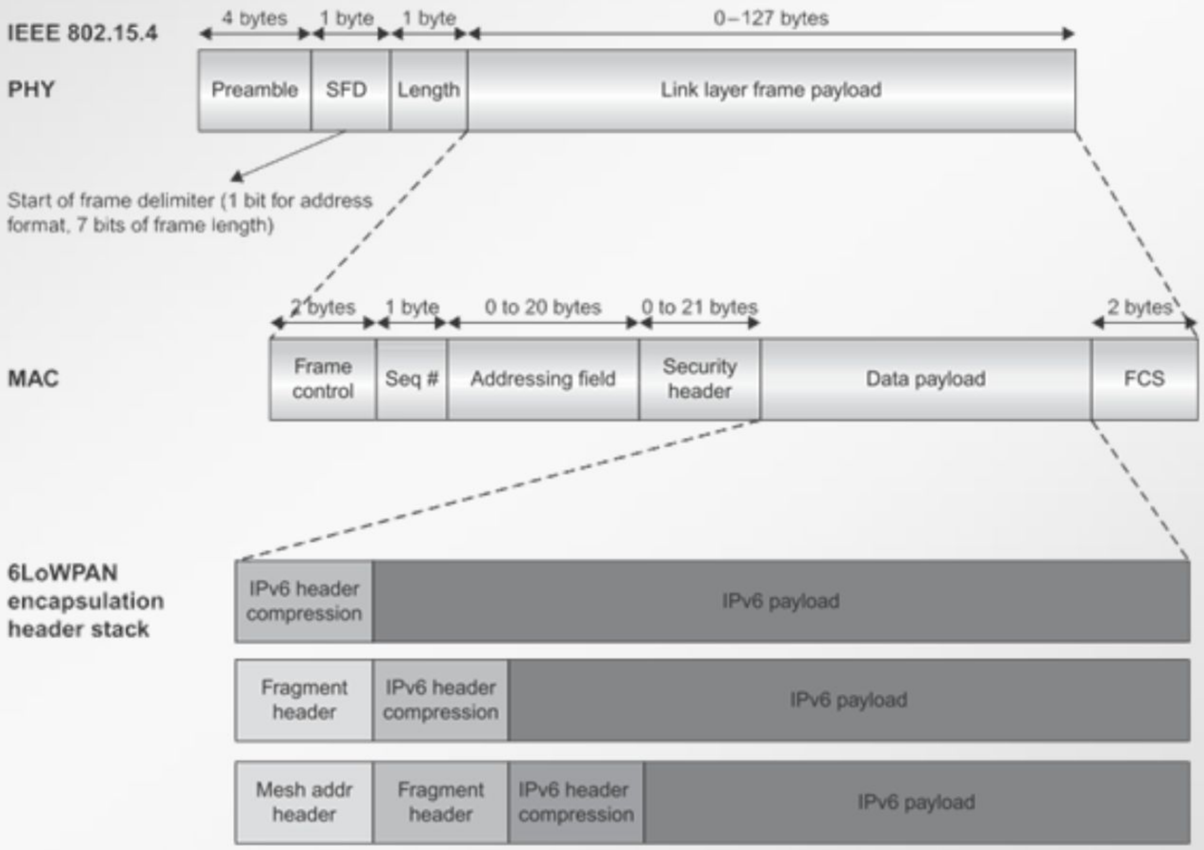
```
A LoWPAN encapsulated IPv6 datagram:

  +---------------+-------------+---------+
  | IPv6 Dispatch | IPv6 Header | Payload |
  +---------------+-------------+---------+
```

Header Dispatch Byte



00	Not a 6LoWPAN frame
01	IPv6 addressing header
10	Mesh header
11	Fragmentation header (6 lower bits are 100xxx)

6LowPAN Header Stack



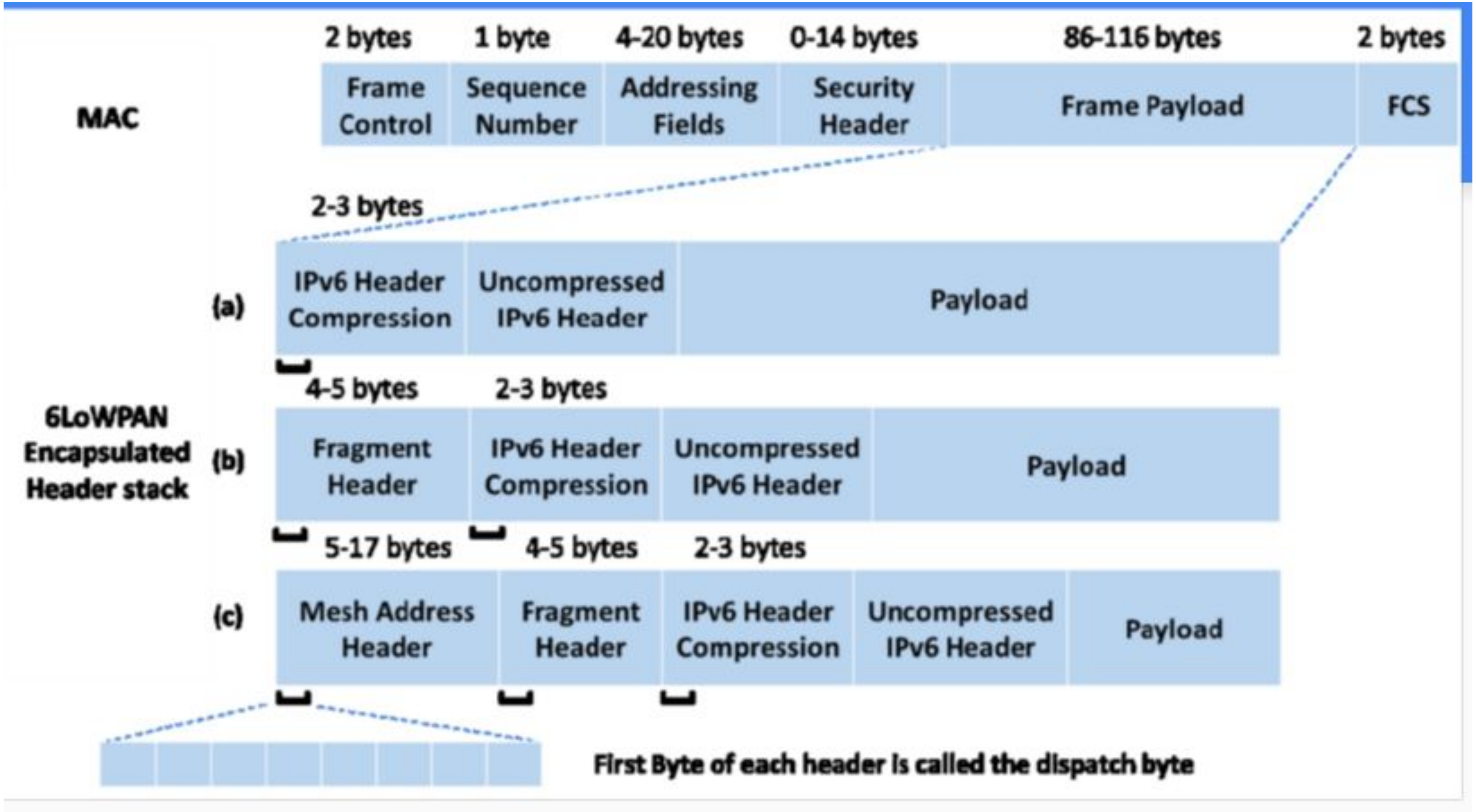

2 bytes
1 byte
4-20 bytes
0-14 bytes
86-116 bytes
2 bytes
MAC
Frame Control
Sequence Number
Addressing Fields
Security Header
Frame Payload
FCS
2-3 bytes
(a)
IPv6 Header Compression
Uncompressed IPv6 Header
Payload
4-5 bytes
2-3 bytes
6LoWPAN Encapsulated Header stack
(b)
Fragment Header
IPv6 Header Compression
Uncompressed IPv6 Header
Payload
5-17 bytes
4-5 bytes
2-3 bytes
(c)
Mesh Address Header
Fragment Header
IPv6 Header Compression
Uncompressed IPv6 Header
Payload
First Byte of each header is called the dispatch byte

Table 2.2 Current and proposed dispatch byte allocations.

From	To	Allocation
00 000000	00 111111	NALP – Not a LoWPAN frame (NALP)
01 000000		reserved for future use
01 000001		IPv6 – uncompressed IPv6 packets
01 000010		LOWPAN_HC1 – compressed IPv6, see Section 2.6.1
01 000011	01 001111	reserved for future use
01 010000		LOWPAN_BC0 – broadcast, see Section 2.8
01 010001	01 011111	reserved for future use
01 100000	01 111111	proposed for LOWPAN_IPHC, see Section 2.6.2
01 111111		ESC – Additional Dispatch byte follows (preempted by IPHC)
10 000000	10 111111	MESH – Mesh header, see Section 2.5
11 000000	11 000111	FRAG1 – Fragmentation Header (first), see Section 2.7
11 001000	11 011111	reserved for future use
11 100000	11 100111	FRAGN – Fragmentation Header (subsequent), see Section 2.7
11 101000	11 101011	proposed for fragment recovery [ID-thubert-sfr]
11 101100	11 111111	reserved for future use

When more than one LoWPAN header is used in the same packet, they MUST appear in the following order:

Mesh Addressing Header

Broadcast Header

Fragmentation Header

Addressing

- IP adaptation layer involves at least two kind of addresses.
  - IP (L3) address: 128 bit IPv6 address
  - Link layer (L2) address:
    - 64 bit IEEE EUI - 64 address
    - 16 bit short address assigned by PAN coordinator.

- **EUI-64 address**

– OUI: Organization Unique Identifier – 24 bits

– M: Muliticast address /Unicast address

– L: Locally assigned Address

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    OUI    |L|M|        OUI (cont.)            |               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+               +
|                    extension identifier                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2.2 Composition of an EUI-64.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                            Prefix                             +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    OUI    |U|M|           OUI (cont.)         |               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+               +
|                       extension identifier                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

2001:0DB8:0BAD:FADE::                       -- Prefix (/64)
                    ACDE:4812:3456:7890 -- EUI-64
2001:0DB8:0BAD:FADE:AEDE:4812:3456:7890 -- IPv6 Address
```

Figure 2.3 Composition of an IPv6 address from an EUI-64: U is the inverted L bit.

Short Address

- IPv6 Interface identifier for 16 bit short address 0X00FF and 0xFE00 are used. (reserved)

```
 0                                       1                                       2                                       3
 0   1   2   3   4   5   6   7   8   9   0   1   2   3   4   5   6   7   8   9   0   1   2   3   4   5   6   7   8   9   0   1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      PAN Id|0|entifier            |    0    |    0    |    F    |    F    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    F    |    E    |    0    |    0    |      16-bit short address      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2.4 Interface identifier for 16-bit short addresses.

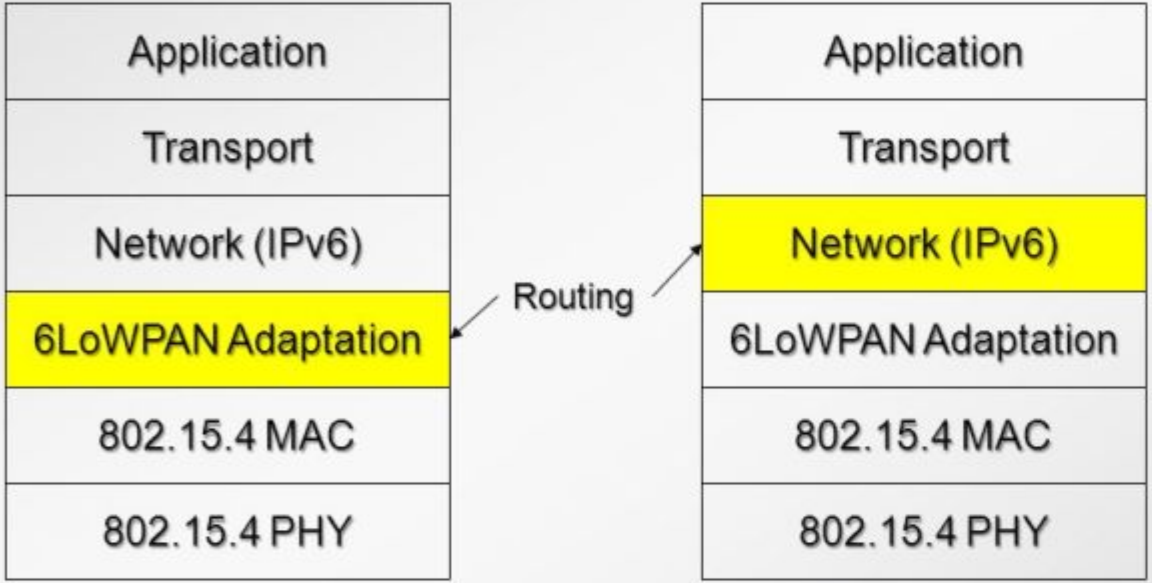
Table 2.3 Address ranges for 16-bit short addresses.

0xxxxxxxxxxxxxxx	Available for assignment as unicast address
100xxxxxxxxxxxxx	Multicast address (see Section 2.8)
1010000000000000 to	
1111111111111101	Reserved by 6LoWPAN
111111111111111x	0xFFFE and 0xFFFF are reserved by IEEE 802.15.4

Forwarding and Routing :

- Packets have to travel multiple hops on their way through the LoWPAN.
- This involves two processes: Routing and Forwarding.
- Both can be performed at Layer 2 or Layer 3.

Mesh-under vs. Route-over Routing



Mesh-under routing

Route-over routing

- The 6LoWPAN working group published several RFCs, but **RFC 4994** is foundational because it defines frame headers for the capabilities of header compression, fragmentation, and mesh addressing.

- These headers can be stacked in the adaptation layer to keep these concepts separate while enforcing a structured method for expressing each capability.

- Depending on the implementation, all, none, or any combination of these capabilities and their corresponding headers can be enabled.

- Figure shows examples of typical 6LoWPAN header stacks

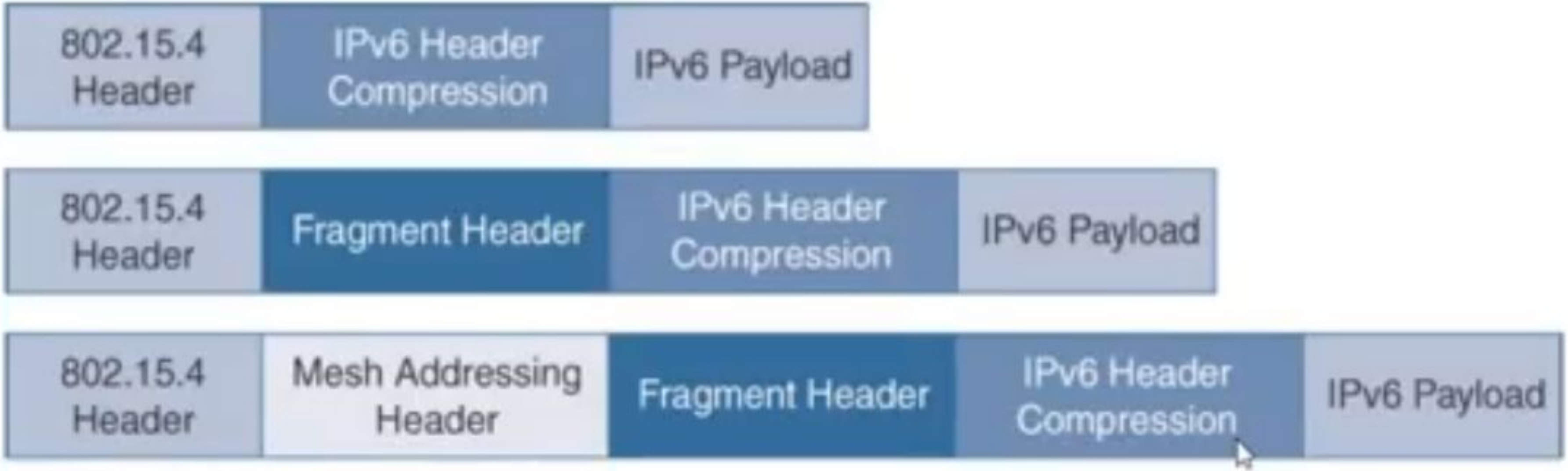


Figure 6LoWPAN Header Stacks

Header Compression

- IPv6 header compression for 6LoWPAN was defined initially in RFC 4944 and subsequently updated by RFC 6282.

- This capability shrinks the size of IPv6's 40-byte headers and User Datagram Protocol's (UDP's) 8-byte headers down as low as 6 bytes combined in some cases.

- The header compression for 6LoWPAN is only defined for an IPv6 header and not IPv4. The 6LoWPAN protocol does not support IPv4, and, in fact, there is no standardized IPv4 adaptation layer for IEEE 802.15.4.

- 6LoWPAN header compression is stateless, and conceptually it is not too complicated.

- However, a number of factors affect the amount of compression, such as implementation of RFC 4944 versus RFC 6922, whether UDP is included, and various IPv6 addressing scenarios.

- At a high level, 6LoWPAN works by taking advantage of shared information known by all nodes from their participation in the local network.

- In addition, it omits some standard header fields by assuming commonly used values.

- Figure 5.4 highlights an example that shows the amount of reduction that is possible with 6LoWPAN header compression.

- At the top of Figure 5.4, we see a 6LoWPAN frame without any header compression enabled:

    - ➢ The full 40-byte IPv6 header and 8-byte UDP header are visible. The 6LoWPAN header is only a single byte in this case.

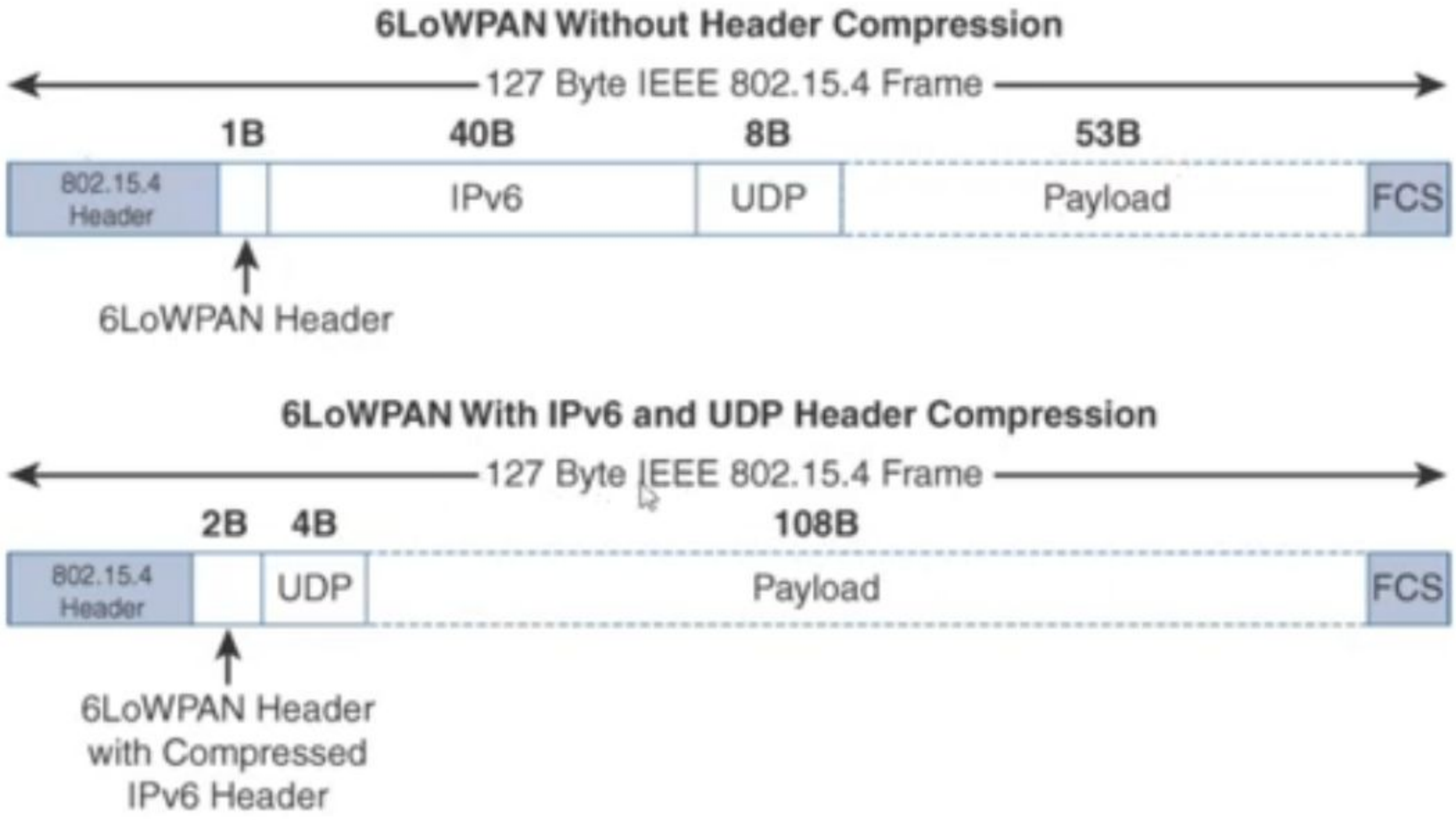


Figure 5.4: 6LoWPAN Header Compression

- Notice that uncompressed IPv6 and UDP headers leave only 53 bytes of data payload out of the 127-byte maximum frame size in the case of IEEE 802.15.4.

- The bottom half of Figure 5.4 shows a frame where header compression has been enabled for a best-case scenario.
- The 6LoWPAN header increases to 2 bytes to accommodate the compressed IPv6 header, and UDP has been reduced in half, to 4 bytes from 8.
- Most importantly, the header compression has allowed the payload to more than double, from 53 bytes to 108 bytes, which is obviously much more efficient.

Fragmentation

- The maximum transmission unit (MTU) for an IPv6 network must be at least 1280 bytes.
- The term MTU defines the size of the largest protocol data unit that can be passed. For IEEE 802.15.4, 127 bytes is the MTU.
- We can see that this is a problem because IPv6, with a much larger MTU, is carried inside the 802.15.4 frame with a much smaller one.
- To remedy this situation, large IPv6 packets must be fragmented across multiple 802.15.4 frames at Layer 2.
- The fragment header utilized by 6LoWPAN is composed of three primary fields:

i. Datagram Size
ii. Datagram Tag and
iii. Datagram offset

- The 1-byte Datagram Size field specifies the total size of the unfragmented payload.

- Datagram Tag identifies the set of fragments for a payload. Finally, the Datagram Offset field delineates how far into a payload a particular fragment occurs.

- Figure 5.5 provides an overview of a 6LoWPAN fragmentation header. The 6LoWPAN fragmentation header field itself uses a unique bit value to identify that the subsequent fields behind it are fragment fields as opposed to another capability, such as header compression.

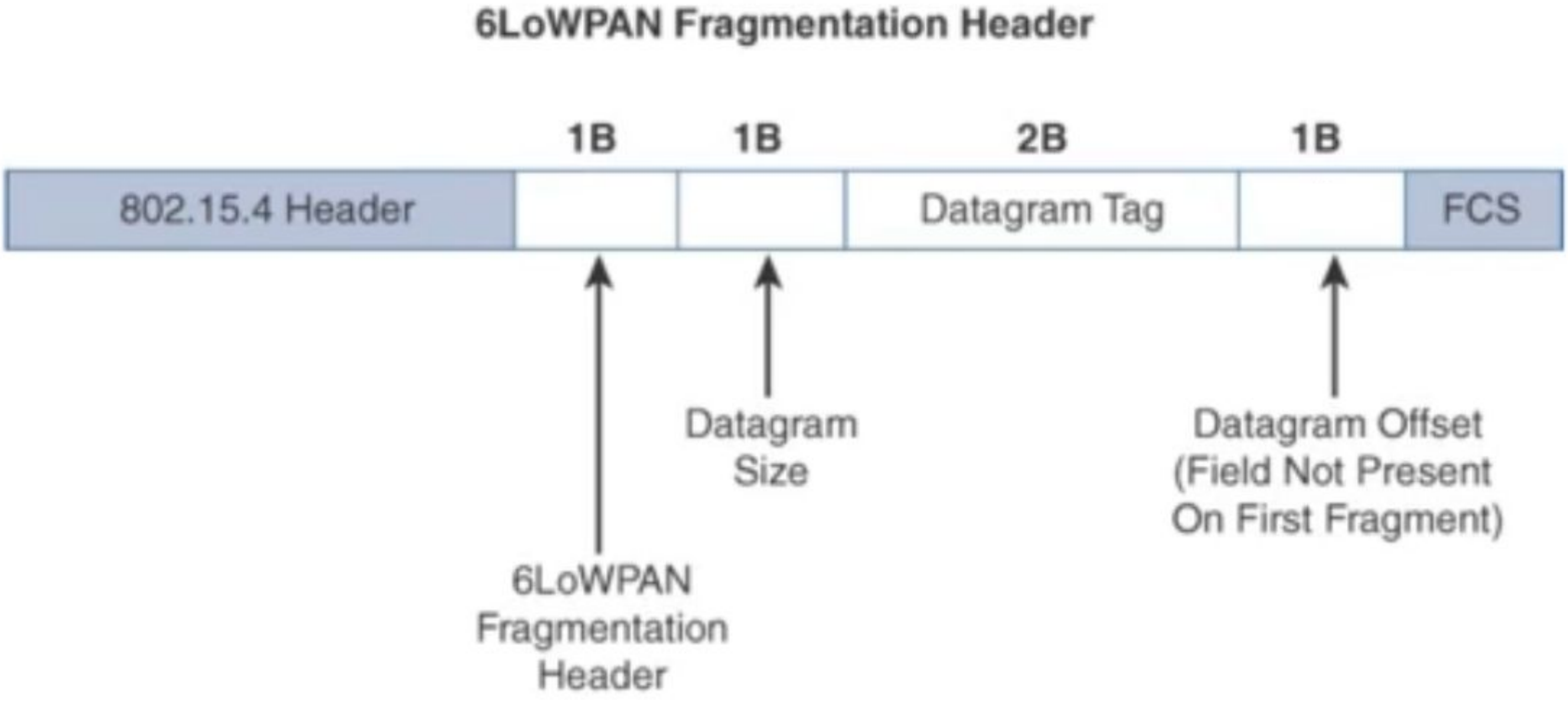


Figure 5.5: 6LoWPAN Fragmentation Header

- Also, in the first fragment, the Datagram Offset field is not present because it would simply be set to 0.

- This results in the first fragmentation header for an IPv6 payload being only 4 bytes long. The remainder of the fragments have a 5-byte header field so that the appropriate offset can be specified.

Mesh Addressing

- The purpose of the 6LoWPAN mesh addressing function is to forward packets over multiple hops.

- Three fields are defined for this header: Hop Limit, Source Address, and Destination Address.

- Analogous to the IPv6 hop limit field, the hop limit for mesh addressing also provides an upper limit on how many times the frame can be forwarded.

- Each hop decrements this value by 1 as it is forwarded. Once the value hits 0, it is dropped and no longer forwarded.

- The Source Address and Destination Address fields for mesh addressing are IEEE 802.15.4 addresses indicating the endpoints of an IP hop.

- Figure 5.6 details the 6LoWPAN mesh addressing header fields.

- Note that the mesh addressing header is used in a single IP subnet and is a Layer 2 type of routing known as mesh-under.

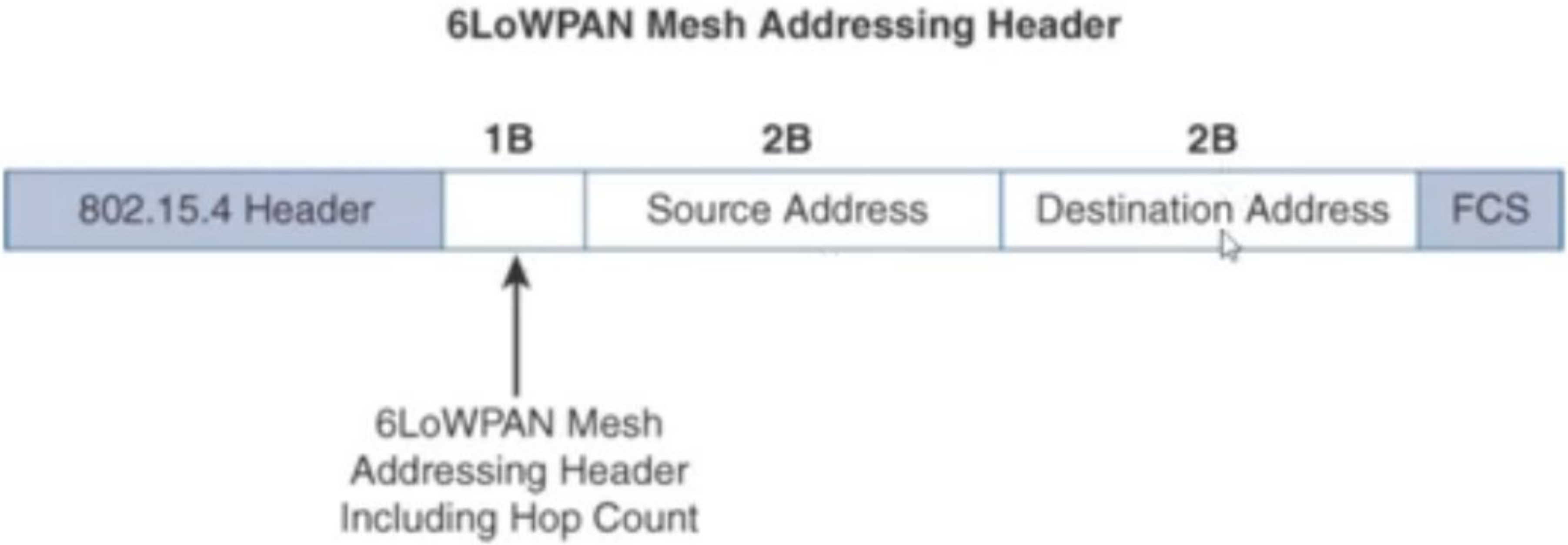


Figure 5.6 : 6LoWPAN Mesh Addressing Header

Mesh-Under Versus Mesh-Over Routing

- For network technologies such as IEEE 802.15.4, IEEE 802.15.4g, and IEEE 1901.2a that support mesh topologies and operate at the physical and data link layers, two main options exist for establishing reachability and forwarding packets.

- With the first option, mesh-under, the routing of packets is handled at the 6LoWPAN adaptation layer.

- The other option, known as **“mesh-over”** or **“route-over,”** utilizes IP routing for getting packets to their destination.

- With mesh-under routing, the routing of IP packets leverages the 6LoWPAN mesh addressing header to route and forward packets at the link layer.

- The term ***mesh-under*** is used because multiple link layer hops can be used to complete a single IP hop.

- Nodes have a Layer 2 forwarding table that they consult to route the packets to their final destination within the mesh.

- An edge gateway terminates the mesh-under domain. The edge gateway must also implement a mechanism to translate between the configured Layer 2 protocol and any IP routing mechanism implemented on other Layer 3 IP interfaces.

- In mesh-over or route-over scenarios, IP Layer 3 routing is utilized for computing reachability and then getting packets forwarded to their destination, either inside or outside the mesh domain.

Stateless Header Compression

- HC1 and HC2 Compression
- HC1: Compression of IPv6 header
- HC2: Compression of UDP header
- HC1: dispatch value: 01000010

Table 2.2 Current and proposed dispatch byte allocations.

From	To	Allocation
00 000000	00 111111	NALP – Not a LoWPAN frame (NALP)
01 000000		reserved for future use
01 000001		IPv6 – uncompressed IPv6 packets
01 000010		LOWPAN_HC1 – compressed IPv6, see Section 2.6.1
01 000011	01 001111	reserved for future use
01 010000		LOWPAN_BC0 – broadcast, see Section 2.8
01 010001	01 011111	reserved for future use
01 100000	01 111111	proposed for LOWPAN_IPHC, see Section 2.6.2
01 111111		ESC – Additional Dispatch byte follows (preempted by IPHC)
10 000000	10 111111	MESH – Mesh header, see Section 2.5
11 000000	11 000111	FRAG1 – Fragmentation Header (first), see Section 2.7
11 001000	11 011111	reserved for future use
11 100000	11 100111	FRAGN – Fragmentation Header (subsequent), see Section 2.7
11 101000	11 101011	proposed for fragment recovery [ID-thubert-sfr]
11 101100	11 111111	reserved for future use

I. The version number is obviously always 6 and therefore never needs to be sent.

II. Two fields that often are zero in IPv6 headers are the traffic class and the flow label. The C bit in the HC1 header, if set, indicates that these bits indeed are zero and are not sent. If the C bit is clear, they are included among the non-compressed fields.

III. The payload length can be inferred from the remaining length of the 6LoWPAN PDU (which in turn can be found out from the link-layer frame or from the fragmentation mechanism) and therefore is never sent in a compressed header.

IV. The next header field is one full byte, but has a number of values that are much more likely than others. The NH bits in the HC1 header, if non-zero, indicate that the next header field is implied by their value.

V. Finally, the Hop Limit was considered to be too difficult to compress and therefore is always sent in-line in the non-compressed fields.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version| Traffic Class |           Flow Label                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Payload Length        |  Next Header  |   Hop Limit   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                        ... addresses...                       :
```

Figure 2.12 IPv6 header: non-address fields.

1 Byte

1 Byte

HC1 Compression

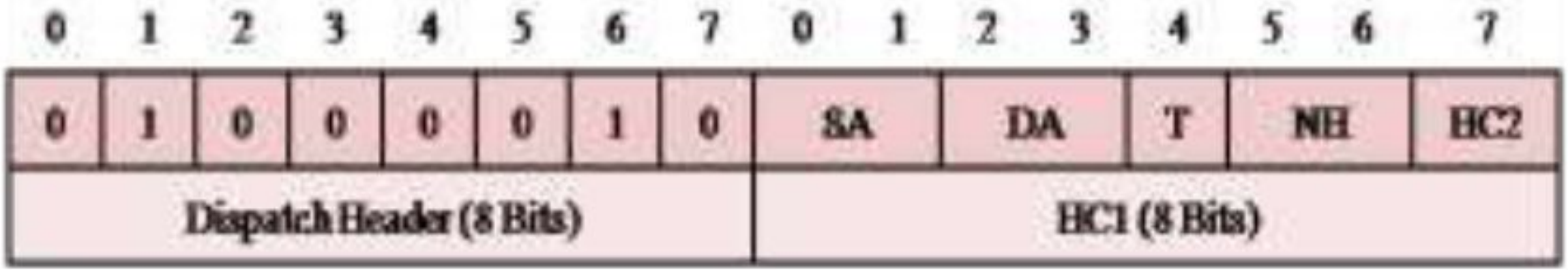
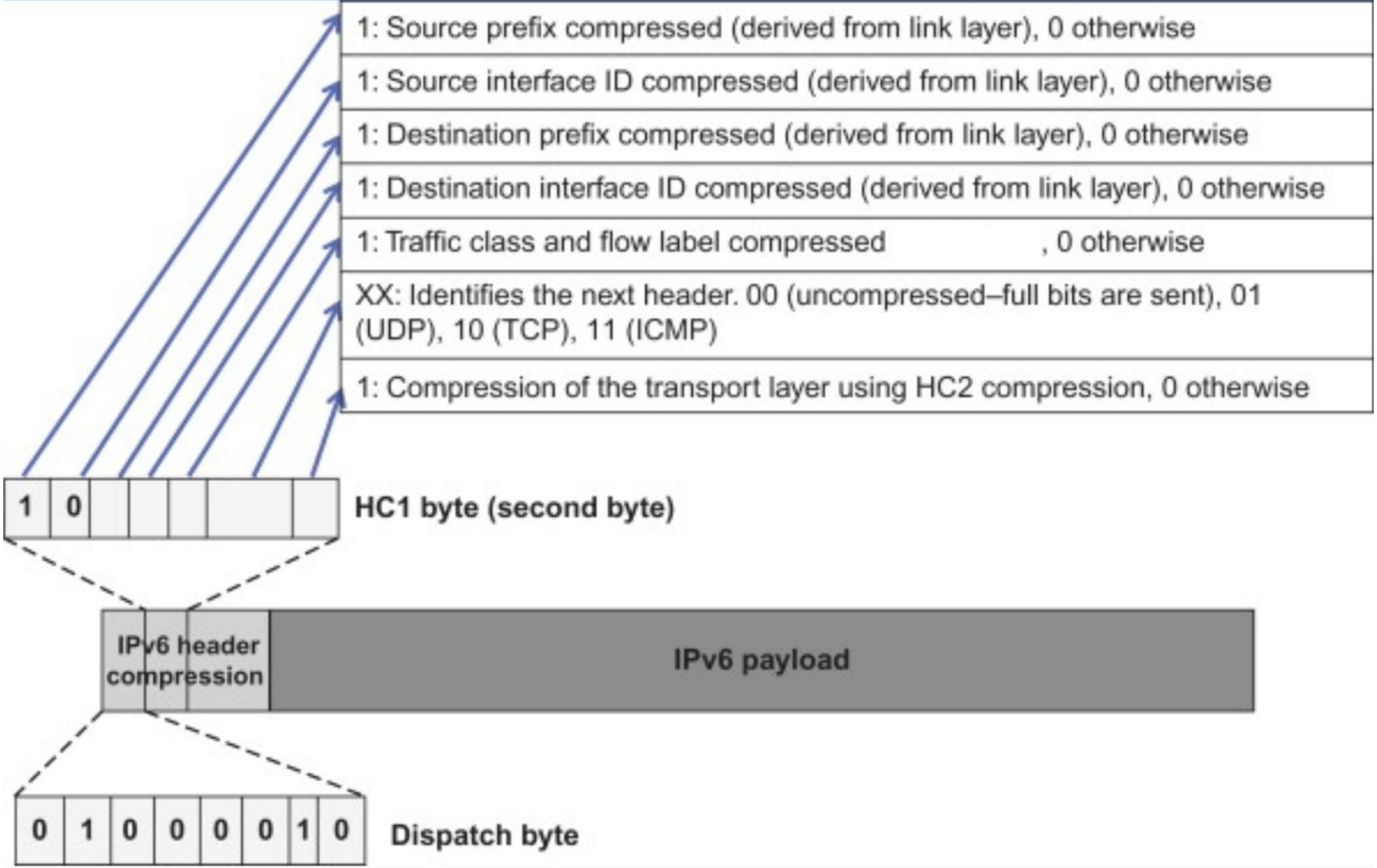


Figure 4. 6LoWPAN_HC1 Encoding

2 Bytes

Table 2.5 HC1 NH values.

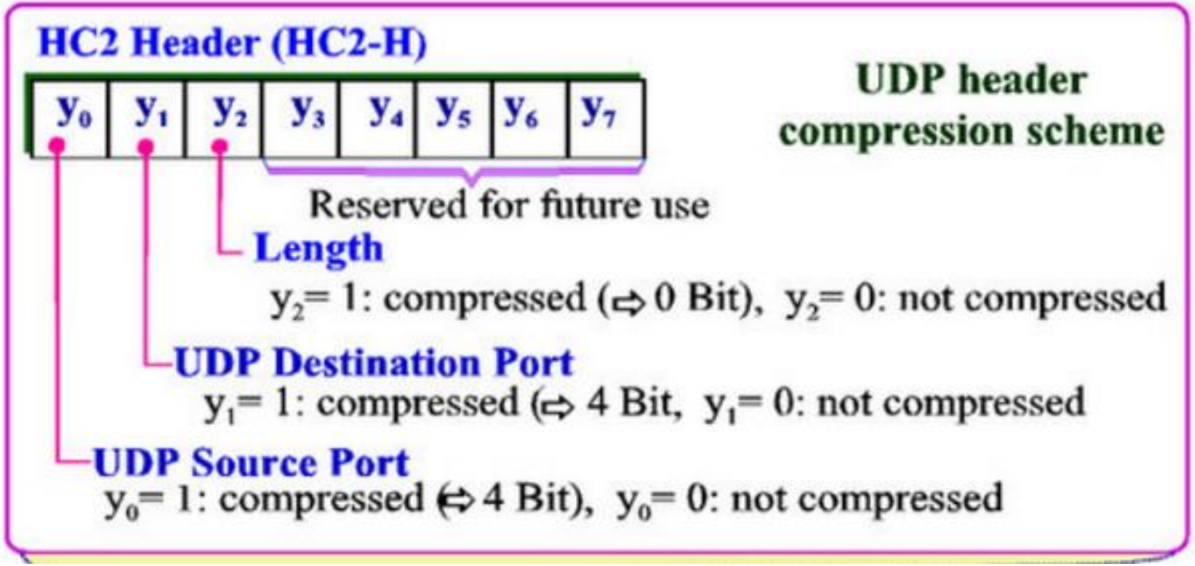
00	Next header sent in-line
01	Next header = 17 (UDP)
10	Next header = 1 (ICMP)
11	Next header = 6 (TCP)



1: Source prefix compressed (derived from link layer), 0 otherwise
1: Source interface ID compressed (derived from link layer), 0 otherwise
1: Destination prefix compressed (derived from link layer), 0 otherwise
1: Destination interface ID compressed (derived from link layer), 0 otherwise
1: Traffic class and flow label compressed , 0 otherwise
XX: Identifies the next header. 00 (uncompressed–full bits are sent), 01 (UDP), 10 (TCP), 11 (ICMP)
1: Compression of the transport layer using HC2 compression, 0 otherwise
1 0
HC1 byte (second byte)
IPv6 header compression
IPv6 payload
0 1 0 0 0 0 1 0
Dispatch byte

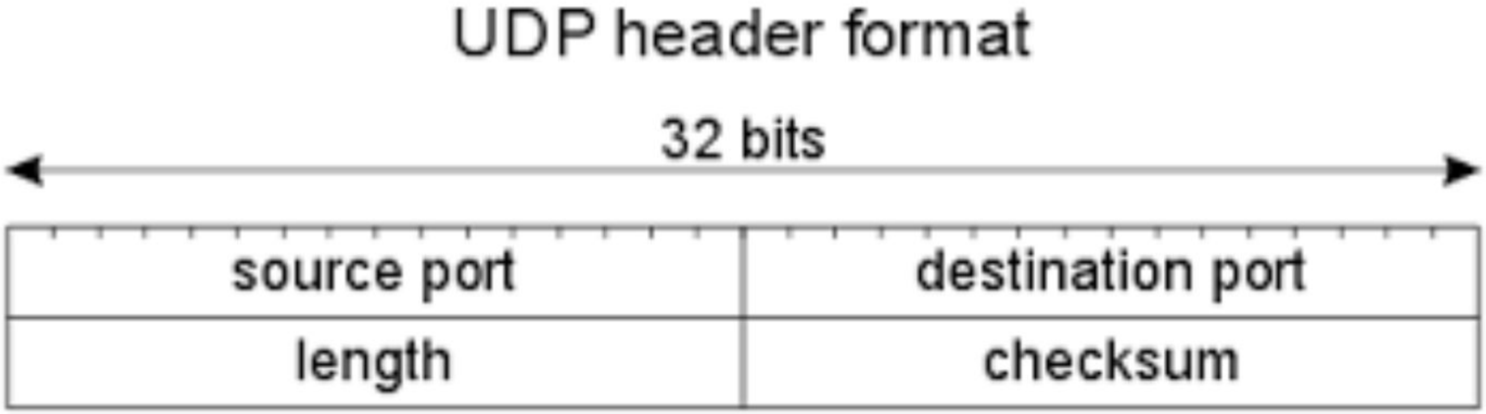
HC2 Compression

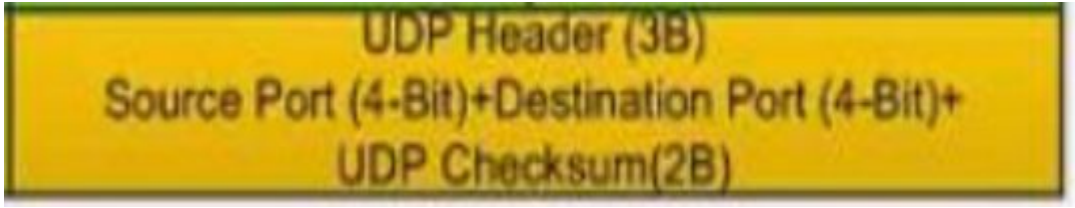
- Compress UDP header
- Length field can be inferred from frame length
- Source and destination ports are shortened into 4 bits each
  - Given that ports fall in the well-known range of 61616 – 61631


HC2 Header (HC2-H)
y0 y1 y2 y3 y4 y5 y6 y7
UDP header compression scheme
Reserved for future use
Length
y2= 1: compressed (⇨ 0 Bit), y2= 0: not compressed
UDP Destination Port
y1= 1: compressed (⇨ 4 Bit, y1= 0: not compressed
UDP Source Port
y0= 1: compressed (⇔ 4 Bit), y0= 0: not compressed

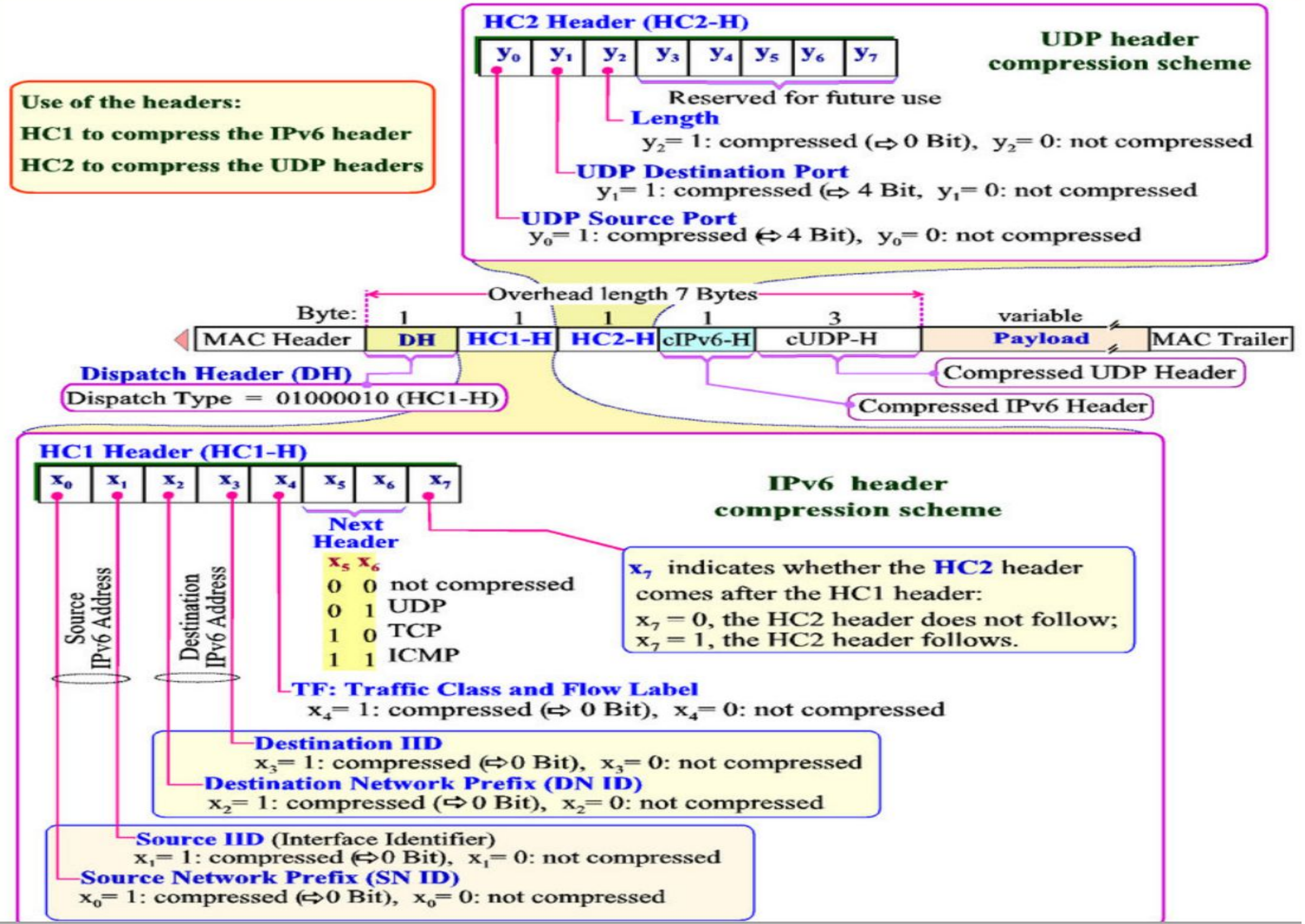
1 Byte

UDP Header

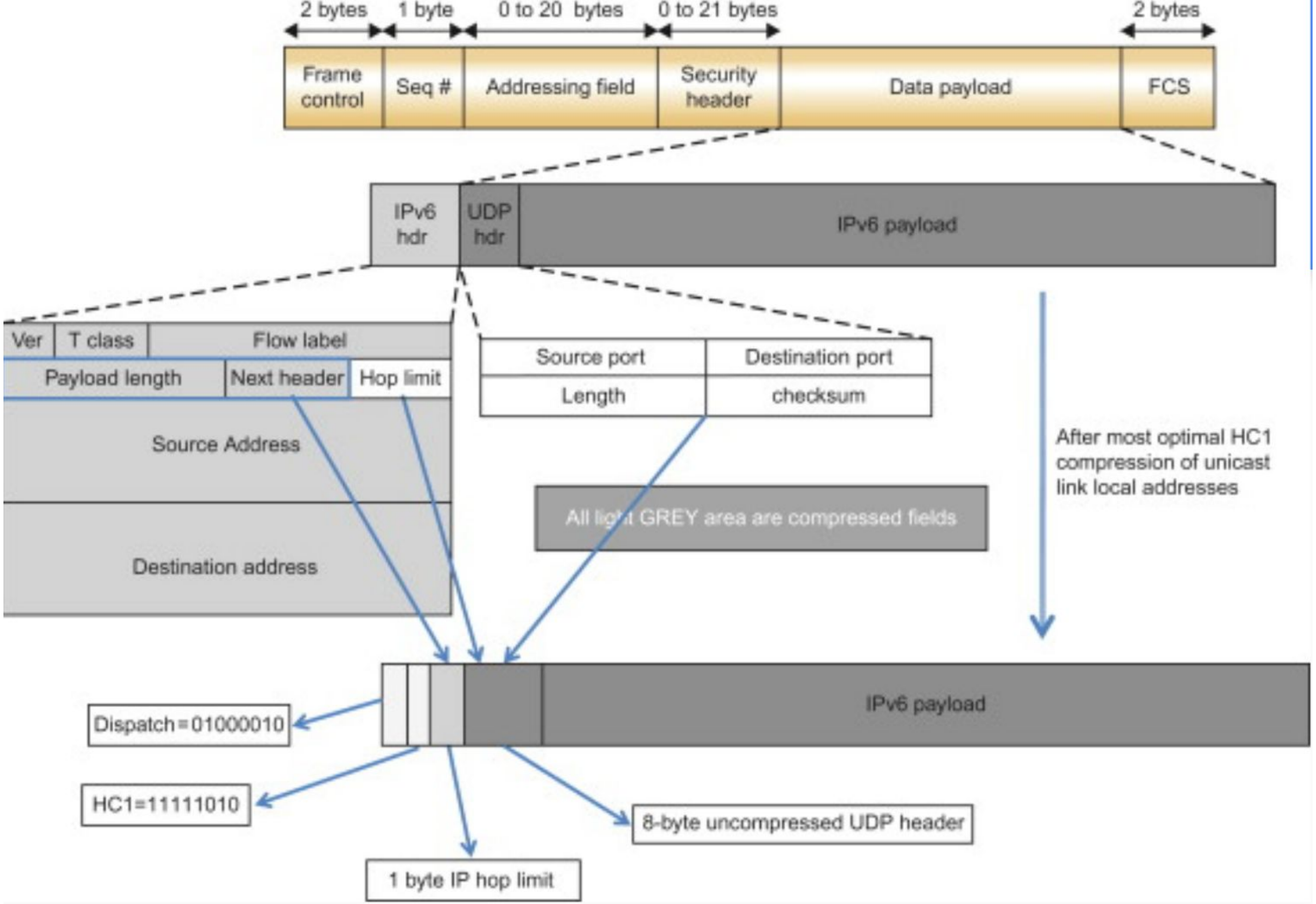


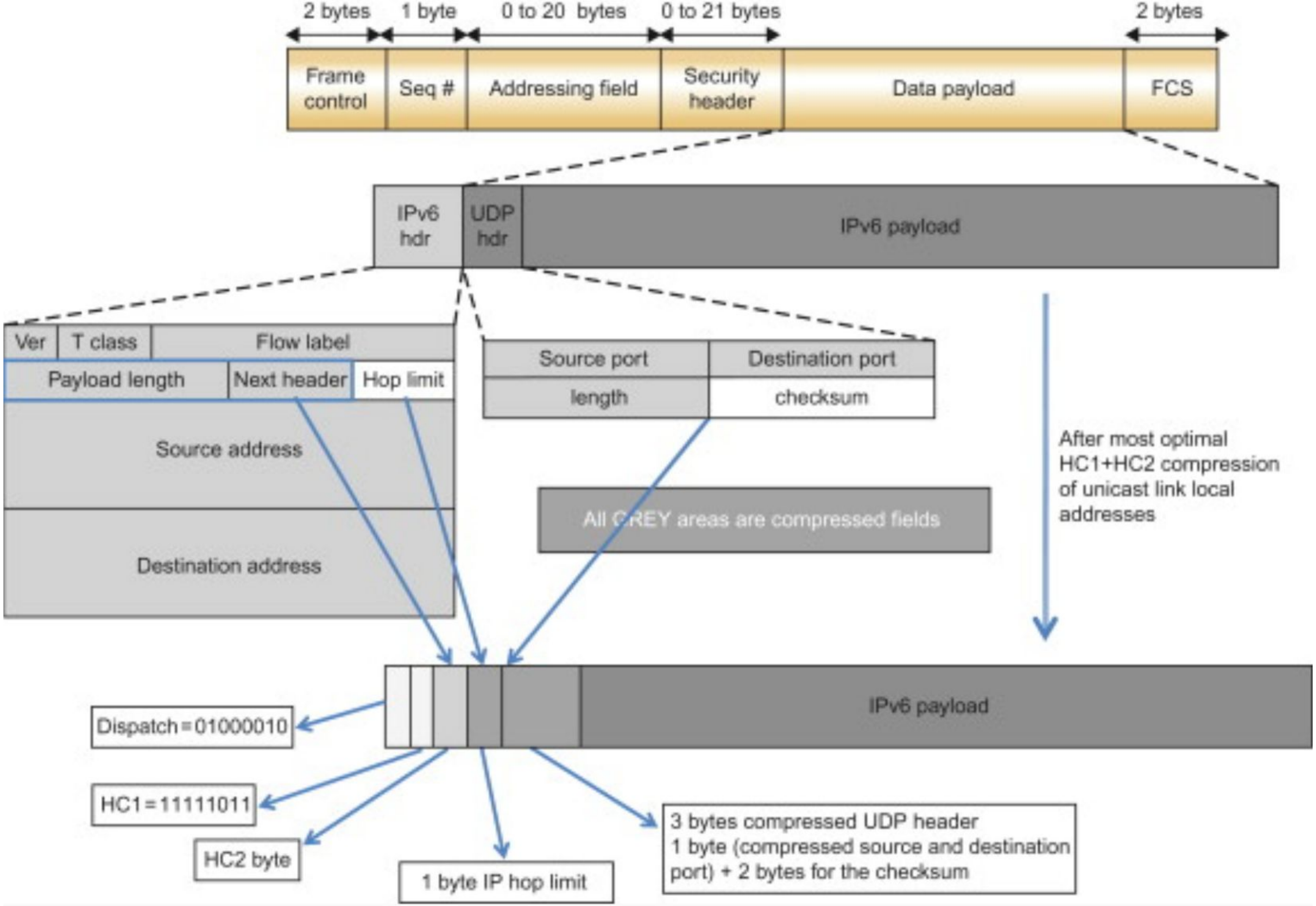


3 Bytes



Use of the headers:
HC1 to compress the IPv6 header
HC2 to compress the UDP headers
HC2 Header (HC2-H)
y0 y1 y2 y3 y4 y5 y6 y7
UDP header compression scheme
Reserved for future use
Length
y2= 1: compressed (⇨ 0 Bit), y2= 0: not compressed
UDP Destination Port
y1= 1: compressed (⇨ 4 Bit, y1= 0: not compressed
UDP Source Port
y0= 1: compressed (⇔ 4 Bit), y0= 0: not compressed
Overhead length 7 Bytes
Byte: 1 1 1 1 3 variable
MAC Header
DH
HC1-H
HC2-H
cIPv6-H
cUDP-H
Payload
MAC Trailer
Dispatch Header (DH)
Dispatch Type = 01000010 (HC1-H)
Compressed UDP Header
Compressed IPv6 Header
HC1 Header (HC1-H)
x0 x1 x2 x3 x4 x5 x6 x7
IPv6 header compression scheme
Next Header
x5 x6
0 0 not compressed
0 1 UDP
1 0 TCP
1 1 ICMP
x7 indicates whether the HC2 header comes after the HC1 header:
x7 = 0, the HC2 header does not follow;
x7 = 1, the HC2 header follows.
Source IPv6 Address
Destination IPv6 Address
TF: Traffic Class and Flow Label
x4= 1: compressed (⇔ 0 Bit), x4= 0: not compressed
Destination IID
x3= 1: compressed (⇔0 Bit), x3= 0: not compressed
Destination Network Prefix (DN ID)
x2= 1: compressed (⇔0 Bit), x2= 0: not compressed
Source IID (Interface Identifier)
x1= 1: compressed (⇔0 Bit), x1= 0: not compressed
Source Network Prefix (SN ID)
x0= 1: compressed (⇔0 Bit), x0= 0: not compressed


2 bytes
1 byte
0 to 20 bytes
0 to 21 bytes
2 bytes
Frame control
Seq #
Addressing field
Security header
Data payload
FCS
IPv6 hdr
UDP hdr
IPv6 payload
Ver
T class
Flow label
Payload length
Next header
Hop limit
Source Address
Destination address
Source port
Destination port
Length
checksum
All light GREY area are compressed fields
After most optimal HC1 compression of unicast link local addresses
IPv6 payload
Dispatch=01000010
HC1=11111010
1 byte IP hop limit
8-byte uncompressed UDP header


2 bytes
1 byte
0 to 20 bytes
0 to 21 bytes
2 bytes
Frame control
Seq #
Addressing field
Security header
Data payload
FCS
IPv6 hdr
UDP hdr
IPv6 payload
Ver
T class
Flow label
Payload length
Next header
Hop limit
Source address
Destination address
Source port
Destination port
length
checksum
All GREY areas are compressed fields
After most optimal HC1+HC2 compression of unicast link local addresses
IPv6 payload
Dispatch=01000010
HC1=11111011
HC2 byte
1 byte IP hop limit
3 bytes compressed UDP header
1 byte (compressed source and destination port) + 2 bytes for the checksum

6Lo- Adaptation Layer

6Lo Working Group:

- The charter of the 6Lo working group, now called the IPv6 over Networks of Resource-Constrained Nodes, is to facilitate the IPv6 connectivity over constrained-node networks.
- In particular, this working group is focused on the following:
- IPv6-over-foo adaptation layer specifications using 6LoWPAN technologies (RFC4944, RFC6282, RFC6775) for link layer technologies:

- For example, this includes:

1. IPv6 over Bluetooth Low Energy
2. Transmission of IPv6 packets over near-field communication
3. IPv6 over 802.11ah
4. Transmission of IPv6 packets over DECT Ultra Low Energy
5. Transmission of IPv6 packets on WIA-PA (Wireless Networks for Industrial Automation–Process Automation)

   Transmission of IPv6 over Master Slave/Token Passing (MS/TP)

- Optimizations that are applicable to more than one adaptation layer specification:
  - For example, this includes RFC 7400, "6LoWPAN-GHC: Generic Header Compression for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs)."

	ZigBee	6LoWPAN	WiFi	Bluetooth
IEEE Specification	802.15.4	802.15.4	802.11a/b/g	802.15.1
Maximum Signal rate	250Kb/s	200Kb/s	54Mb/s	1Mb/s
Range	10-100meters	~200m	50-100m	1-10m
Networking Topology	Ad-hoc, peer-to-peer,star, mesh	Star,mesh,P2P	Star,tree,point to hub,P2P	Ad-hoc, star, very small networks
Security	128 AES	128 AES	RC4 Stream and AES block cipher	64 & 128 bit encryption AES block cipher
Operating Frequency	868MHz, 915MHz,2.4GHz	2.4GHz	2.4GHz & 5 GHz	2.4GHz
Power Consumption	Very low	low	high	medium
Maximum nodes per network	65,536	~100	30	8
Data Protection	16 bit CRC	16 bit CRC	32 bit CRC	16 bit CRC

Key Characteristics	Stability,low power consumption,low	Stability,low, power consumption	Very high speed, large network	Low price,easy use, high data rate
Applications	Industrial Control and monitoring, sensor networks,building automation	Industrial Control and monitoring, sensor networks,building automation	Broadband internet access, wireless LAN connectivity	Cable replacemnt, wireless connectivity between devices such as PDA,phones,laptops,headsets
Main Applications	Monitoring & control	Monitoring & control	Data Transmission	Dat and Voice Transmission
Access Control	CSMA/CA	CSMA/CA	CSMA/CA	OFDMA,MC-CDMA
Packet Length	127 bytes	127 bytes	Upto 10,48,575 bytes	10-265 bytes
Power consumption	<10MW	<10MW	>100MW	<10MW