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6LoWPAN Adaptation Layer:
The Compression Operation

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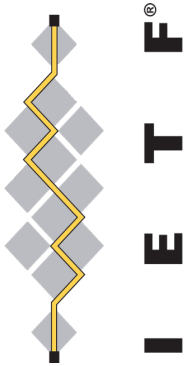
6TiSCH Protocol Stack



I E T F

IEEE

Applications	CoJP	
CoAP / OSCORE	6LoWPAN ND	RPL
UDP	ICMPv6	
IPv6		
6LoWPAN HC / 6LoRH HC	Scheduling Function (MSF)	
6top inc. 6top Protocol (6p)		
IEEE Std 802.15.4 TSCH		
IEEE Std 802.15.4 PHY		

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IPv6 Addressing

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IPv6 Addressing

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  - There are multiple mechanism to form the Interface ID
- There are different kinds of IPv6 addresses :
  - Loopback (::1), and Unspecified (::)
  - Unicast Link-local (fe80::/10)
  - Unique Local Unicast
  - Global unicast (2000::/3)
  - Multicast (ff00::/8)
  - Anycast

Address Types and Scopes [RFC 4291]

- There are different types and scopes of IPv6 address:
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- For *unicast* addresses, two defined scopes:
  - **Link-local scope**: are the *link-local* and the *loopback* addresses that can only be used on a single direct network (link).
  - **Global scope**: all other addresses, which means they are (or could be) globally routable, anywhere on the Internet.

IPv6 Addressing in 6LoWPAN

2001:660:3003:1:34ca:3b73:6543:210f / 64

Prefix *Interface ID*

- IPv6 addresses are compressed in 6LoWPAN
- Prefix
  - Addresses within **6LoWPAN** typically contain common prefix.
  - Supports up to 16 contexts (states).
  - Nodes typically target one or few central nodes, i.e., root node(s).
- Interface ID
  - Typically derived from L2 MAC addresses → autoconfiguration.
  - Elided when Interface ID can be derived from L2 header.

IPv6 Header Format

Check the relevant video
"*Introduction to IPv6 Header Format*"
on YouTube!

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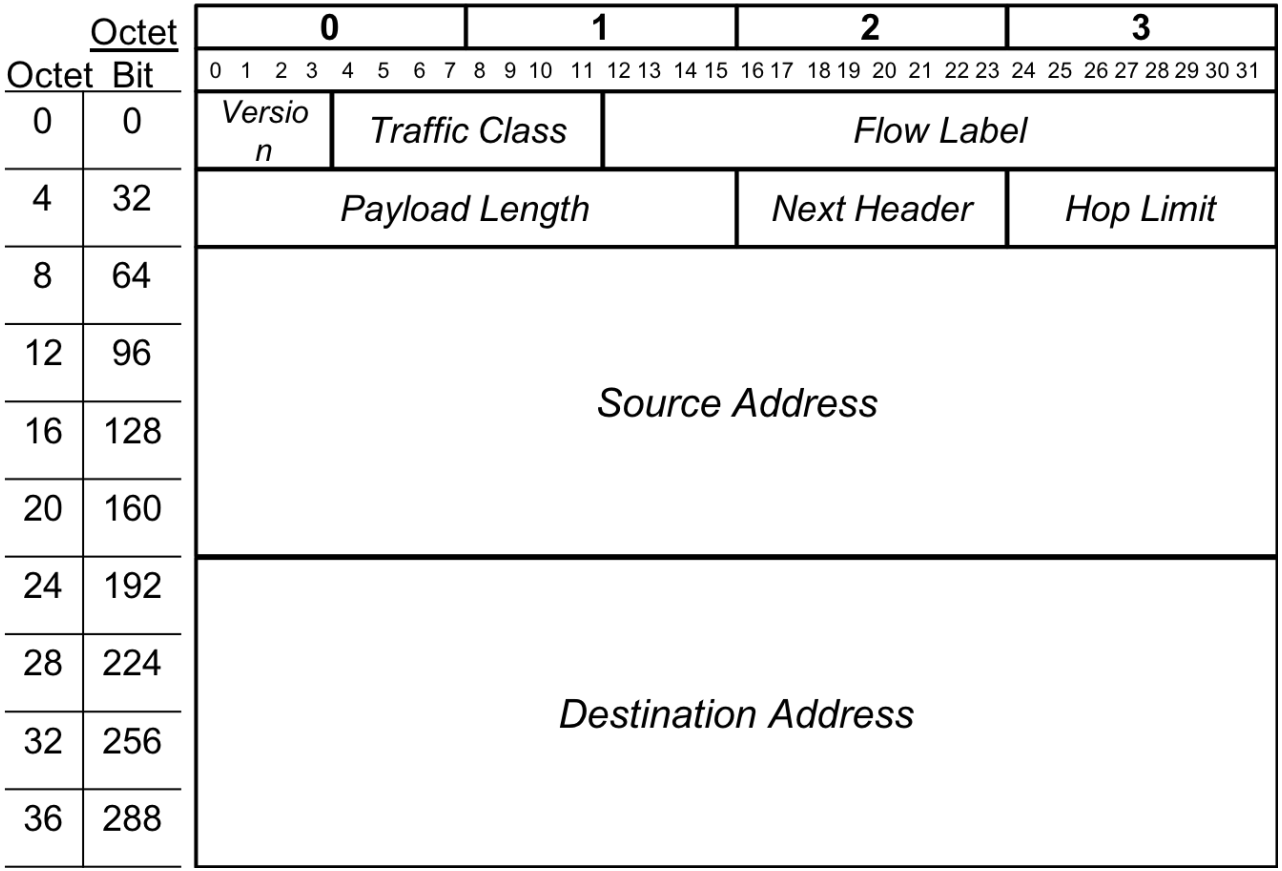
IPv6 Header Format



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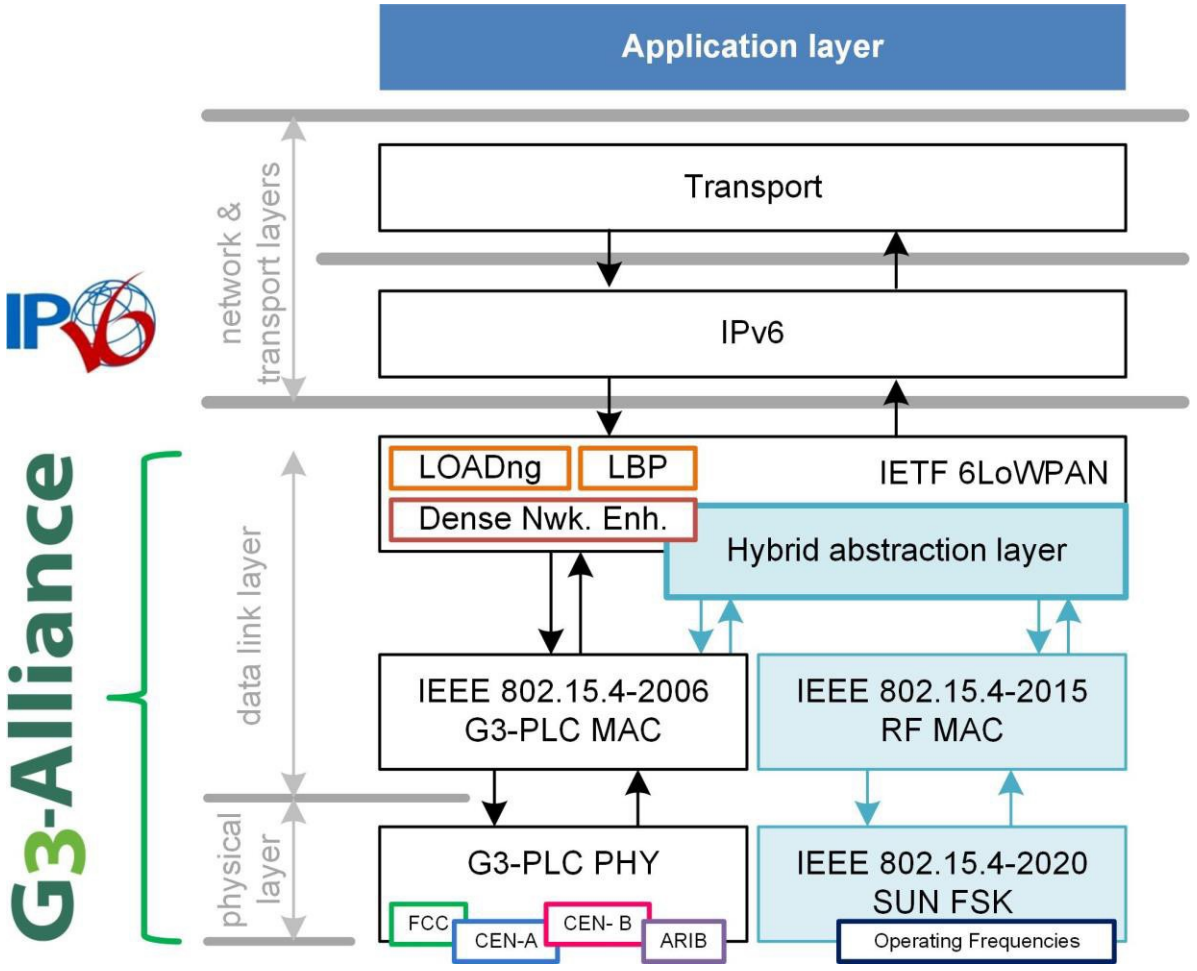
- Destination Address (128 bits):
  - The IPv6 unicast or multicast address of the destination node(s).

OUTLINE

1. IPv6
   - 1.1 IPv6 Addressing
   - 1.2 IPv6 Header Format
2. **6LoWPAN Adaptation Layer**
3. IPv6 Header Compression
4. Examples
   - 4.1 Link-local Multicast
   - 4.2 Global Unicast
5. UDP Header Compression

Check the relevant video
"*Tutorial on 6LoWPAN IPv6 and UDP Header Compression*"
on YouTube!

G3-PLC Protocol Stack



6LoWPAN Overview: RFC 4944, 6282, 8930, 8931

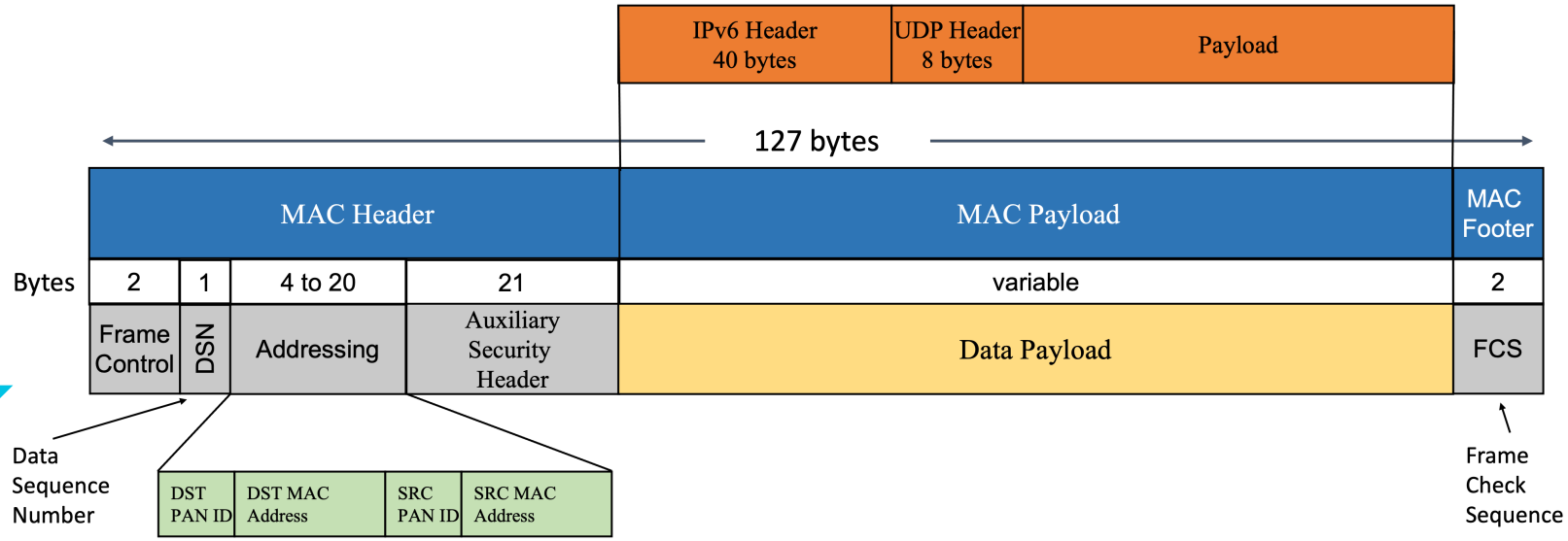
- The **6LoWPAN** is an adaptation layer allowing to transport IPv6 packets over IEEE Std 802.15.4 links.
  - Compression: reduces the size of 40-byte IPv6 header and higher protocols, i.e., UDP headers, RFC 6282.
  - Fragmentation: split (and reassembles) the IPv6 datagrams into smaller fragments, RFC 4944.
  - Fragment Delivery (Mesh-Under & Route-Over): RFC 4944.
  - 6LoWPAN Fragment Forwarding (6LFF): RFC 8930.
  - 6LoWPAN Selective Fragment Recovery mechanism: RFC 8931.

IEEE Std 802.15.4 vs IPv6 MTU: Problem Statement

- IEEE Std 802.15.4 has small MTU (i.e., 127 bytes).
- Header Size Calculation:
  - IPv6 header is 40 octets, UDP header is 8 octets.
  - IEEE Std 802.15.4 MAC header can be up to 25 octets (null security), **or** 25+21=46 octets (AES-CCM-128).
  - With the IEEE Std 802.15.4 frame size of 127 octets:

    127-25-40-8 = **54** octets (null security)

    127-46-40-8 = **33** octets (AES-CCM-128)



Encapsulation Header Format

- *encapsulated **IPv6 datagram***

- *encapsulated LOWPAN_IPHC **compressed IPv6 datagram***

- *encapsulated LOWPAN_IPHC compressed IPv6 datagram that requires **mesh addressing***

- *encapsulated LOWPAN_IPHC compressed IPv6 datagram that requires **fragmentation***

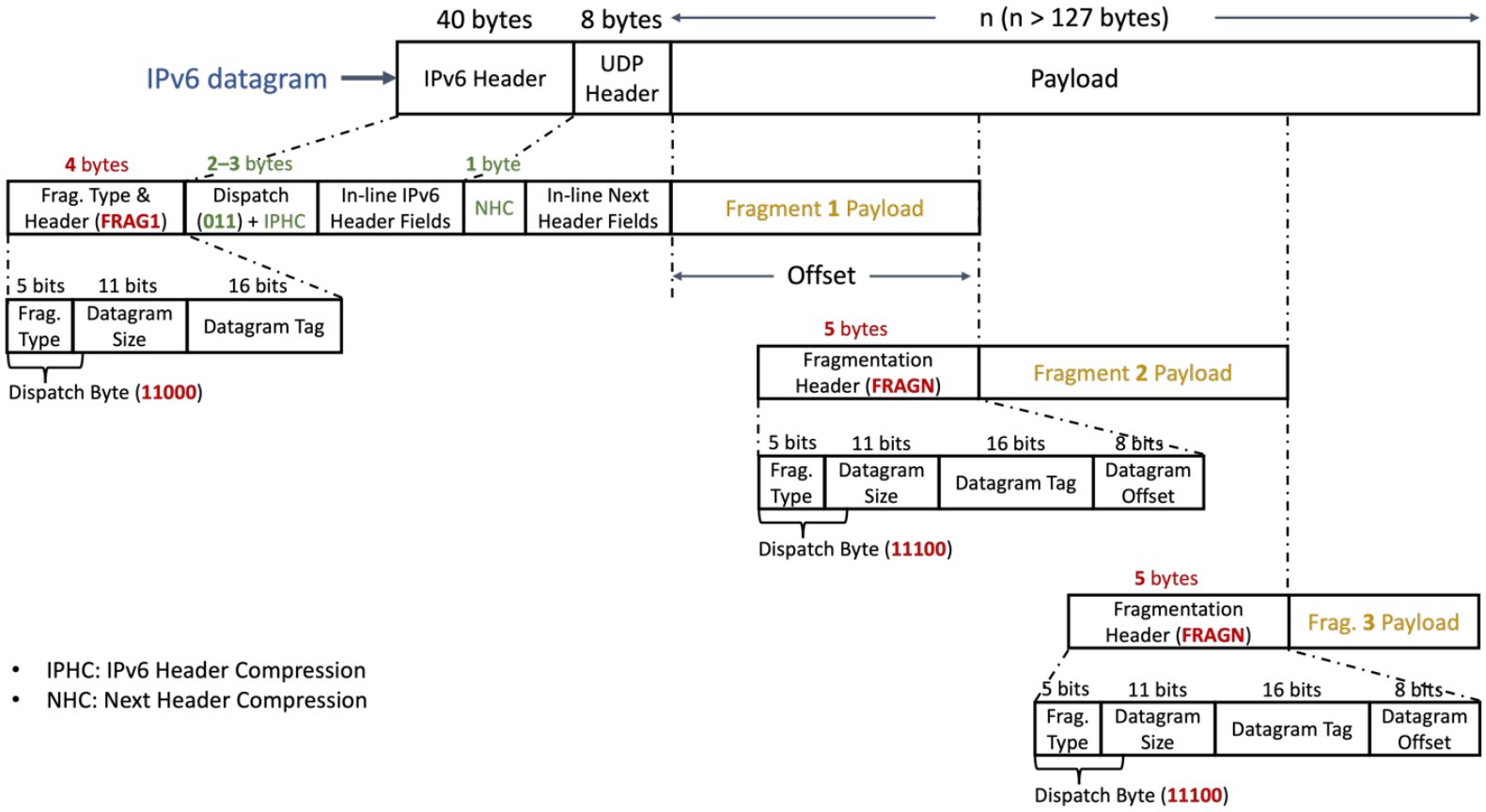
- *encapsulated LOWPAN_IPHC compressed IPv6 datagram that requires both **mesh addressing** and **fragmentation***

- *encapsulated LOWPAN_IPHC compressed IPv6 datagram that requires both **mesh addressing** and a **broadcast header** to support mesh broadcast/multicast*

6LoWPAN Dispatch Codes

Bit Pattern	Short Code	Description
00 xxxxxx	NALP	Not A 6LoWPAN Packet
01 000001	IPv6	Uncompressed IPv6 address
~~01 000010~~	~~LOWPAN_HC1~~	~~HC1 Compressed IPv6 header~~ (***obsolete***)
01 010000	LOWPAN_BC0	BC0 Broadcast header
01 1	LOWPAN_IPHC	IPHC Compressed IPv6 header (***new version, RFC 6282***)
10 xxxxxx	MESH	Mesh routing header
11 000xxx	FRAG1	Fragmentation header (first fragment)
11 100xxx	FRAGN	Fragmentation header (subsequent fragment)

Compression and Fragmentation Overview



- IPHC: IPv6 Header Compression
- NHC: Next Header Compression

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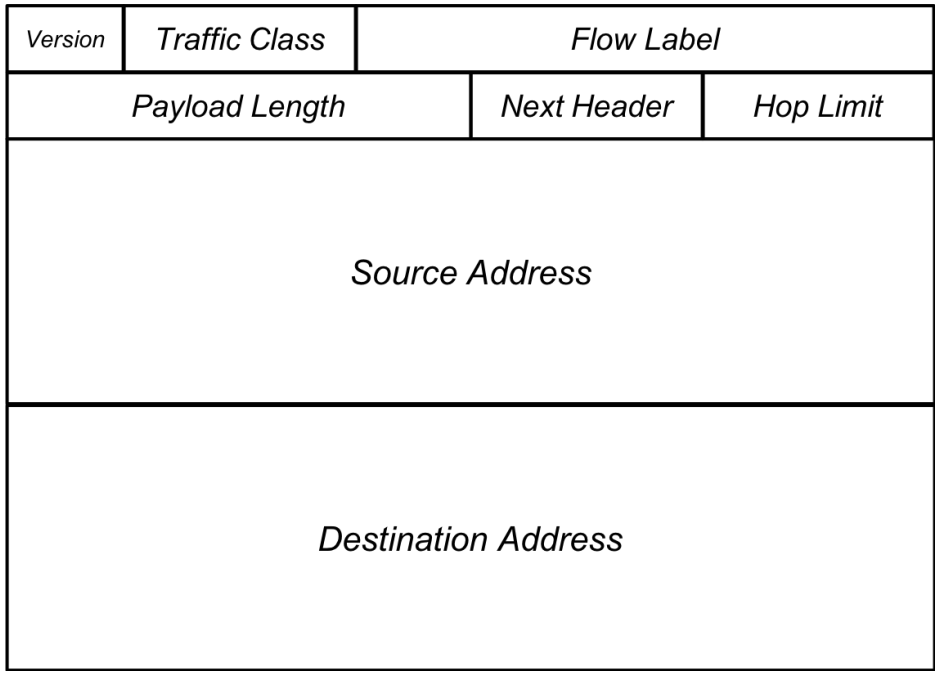
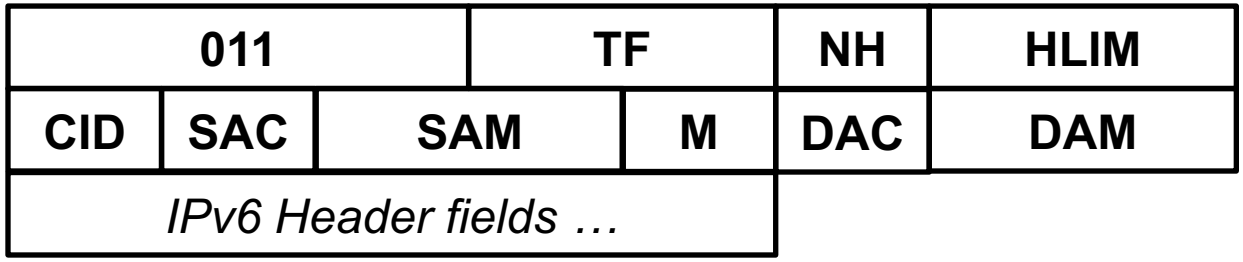
IPv6 Header Compression (IPHC)



Original IPv6 Header

Compressed Header (IPHC)



- Objective: transform the IPv6 Header to Compressed Header.
- By adding few extra bits which indicate how the packet is compressed.

IPHC: Overview

- Stateless compression
  - It **does not require** the IoT node that process the compression and decompression of an IPv6 packet **to store any configuration information locally**, which is used to decide how that packet needs to be compressed or decompressed.

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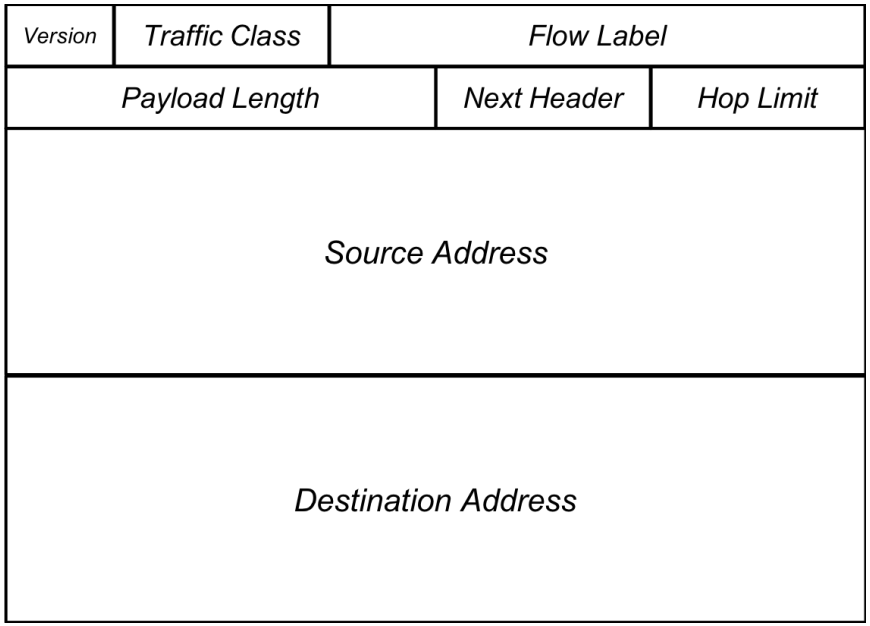
- 6LoWPAN is Layer 2 (L2) independent protocol.

The Default Elided IPv6 Header Fields



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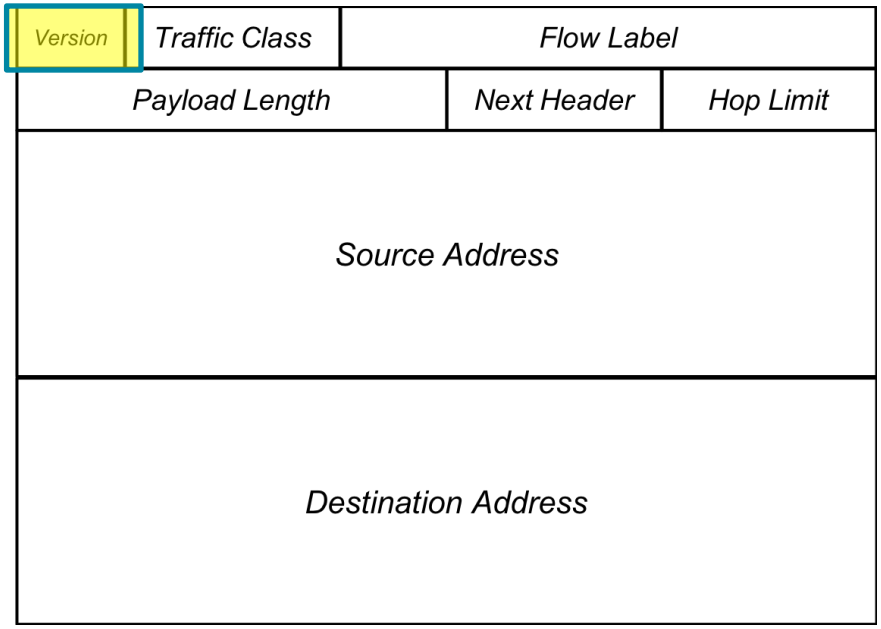

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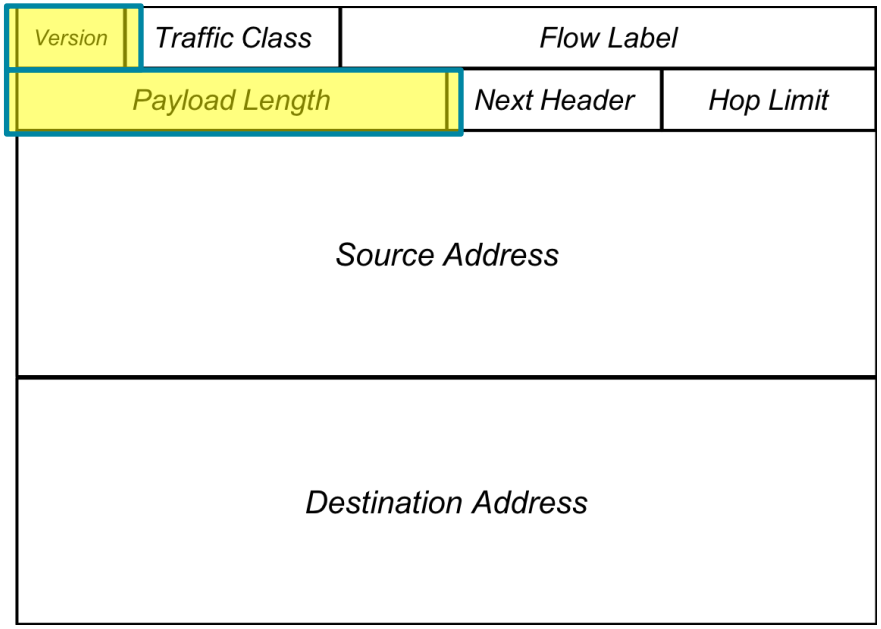
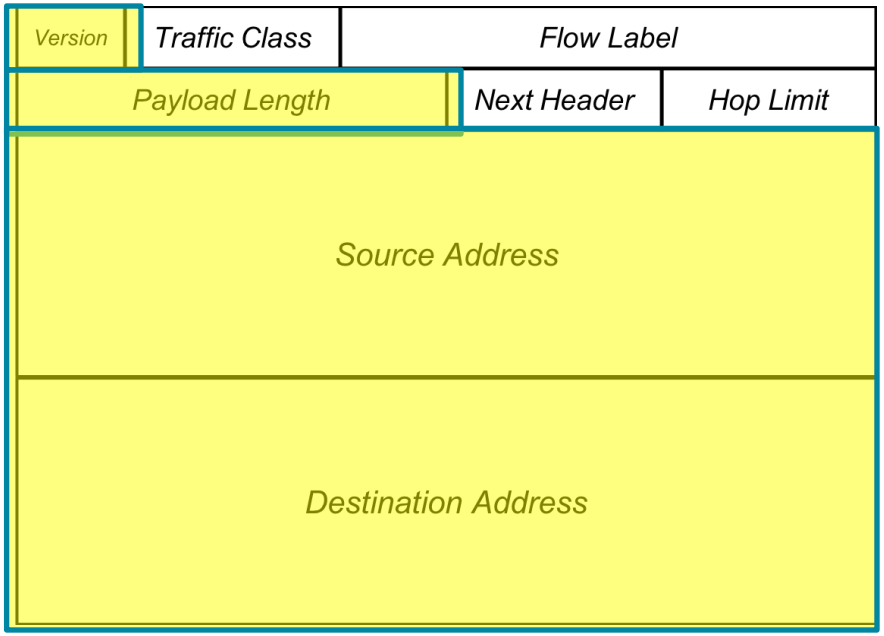


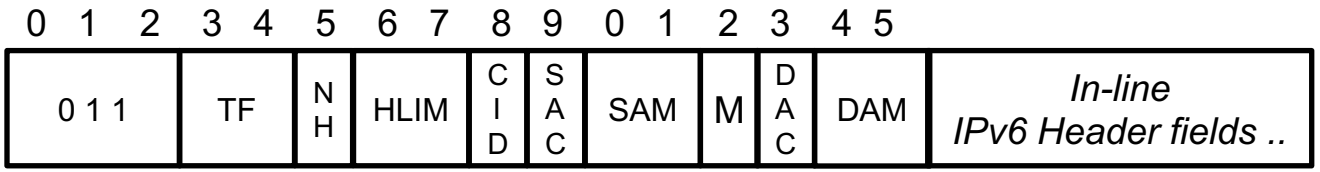
The Default Elided IPv6 Header Fields

- The version is almost always 6.
- The Payload length can be derived from L2 header.
- Source and Destination Addresses can be elided (link-local) and/or compressed depending on the “context” of the transmitted packet.

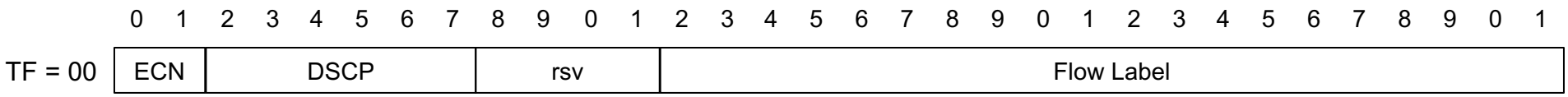


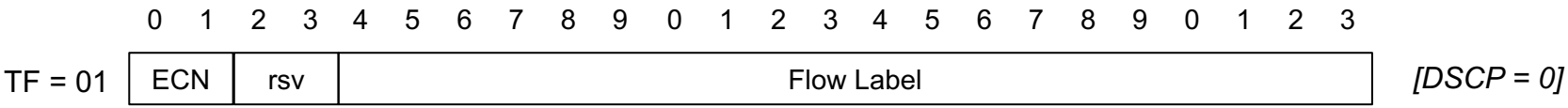
IPHC base Encoding

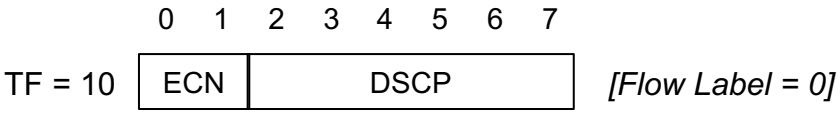
- TF : Traffic Class and Flow Label
  - 0: Carried Inline (ECN+DSCP+Flow), 1: ECN+Flow, 2: ECN+DSCP, 3: All zero
- NH (Next Header compression)
  - 0: Carried Inline, 1: Next Header is compressed (allows L4 compression)
- HLIM (Hop Limit = Inline, 1, 64, 255) : well known values
  - 0: Carried Inline, 1: 1, 2: 64, 3: 255
- CID (Context Identifier Extension)
  - 0: No 1-byte CID identifier, 1: 1-byte identifier follows
  - An additional 8-bit CID field immediately follows the (DAM) field.
  - Add a context to allow 16 source and destination prefixes
- SAC/DAC (Source/Destination Address Compression)
  - 0: Stateless, 1: Stateful, i.e., Context-based
- SAM/DAM (Source/Destination Address Mode)
  - 0: 16 bytes inline, 1: 8 bytes inline, 2: 2 bytes inline, 3: elided
- M (Multicast Destination)
  - 0: Destination is not multicast, 1: Destination is multicast



Traffic Class and Flow Label Compression

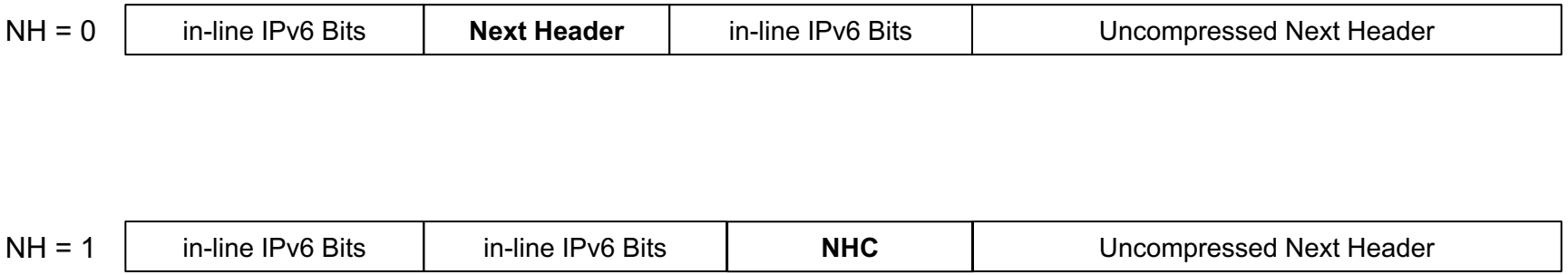




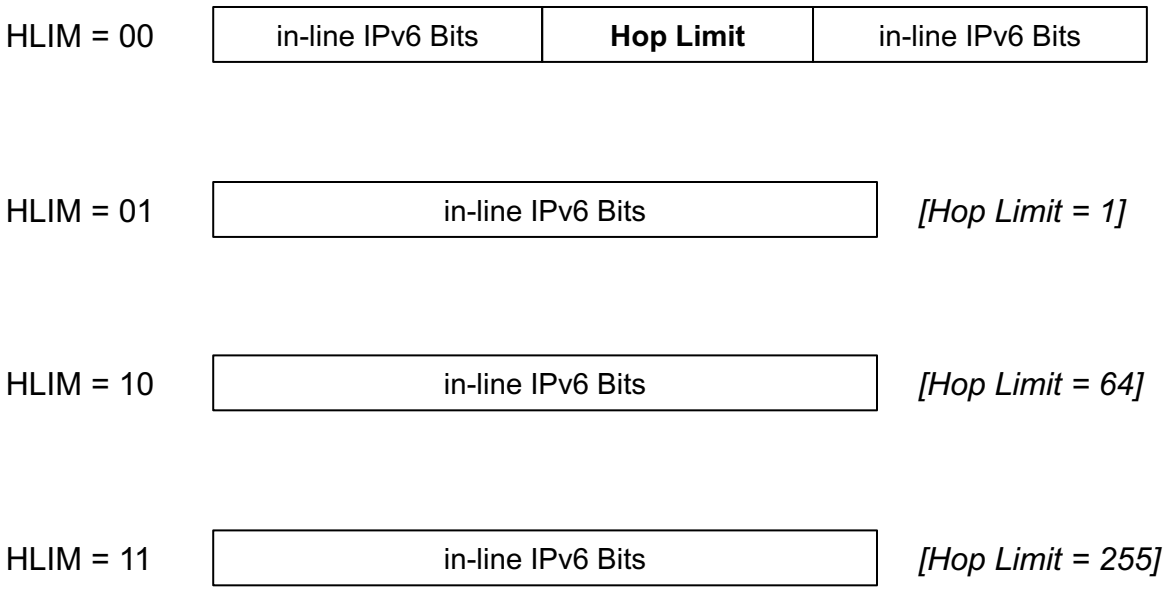


TF = 11 *[ECN = 0, DSCP = 0, Flow Label = 0]*

Next Header Compression



Hop Limit Compression



Source Address Compression (SAC) and SAM

SAC \ SAM	00	01	10	11
IID		64 first prefix bits are elided. IID is fully sent.	112 first prefix bits are elided. Last 16 IID bits are sent.	All 128 bits are elided.
0 : Stateless / Link Local	The full address (128 bits) is carried in-line.	The prefix is link-local i.e., fe80::/64	The prefix is link-local i.e., fe80::0:ff:fe00:/112	The prefix is link-local i.e., fe80::/64. IID is taken from L2 source address.
1 : Stateful / Global	The full address (128 bits) is carried in-line.	The prefix is given by the context, and 64 bits are carried in-line.	The prefix is given by the context. IID starts with 0000:00ff:fe00: and 16 bits are carried in-line.	The prefix is given by the context. IID is taken from L2 source address.

Destin. Address Compression (DAC) and DAM

DAM / M, DAC	00	01	10	11
00 : Stateless / Link Local	The full address (128 bits) is carried in-line.	The first 64 bits (prefix is fe80::/64) are elided. IID (64 bits) is sent.	The first 112 bits (prefix is fe80::0:ff:fe00:/112) are elided. IID (16 bits) is sent.	The address is fully elided. Prefix is fe80::/64. IID is taken from L2 source address.
01 : Stateful / Global	Reserved	The prefix (64 bits) is given by the context. IID (64 bits) is sent.	The prefix (112 bits) is given by the context. IID starts with 0000:00ff:fe00: and 16 bits sent.	The address is fully elided. The prefix is given by the context. IID is taken from L2 source address
10 : Stateless / Link Local Multicast	The full address is carried in-line.	48 bits are sent. The multicast address takes the form: ffXX::00XX:XXXX:XXXX	32 bits are carried in-line. The multicast address takes the form: ffXX::00XX:XXXX	8 bits are carried in-line. The multicast address takes the form: ff02::00XX
11 : Stateful / Global **Multicast**	48 bits are sent. The format follows Unicast-Prefix-based IPv6 Multicast Addresses [RFC 3956]. Context value contains the Rendezvous Point address.	Reserved	Reserved	Reserved

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Example 1: Link-local Multicast

Check the relevant video
"*6LoWPAN Examples of the IPv6 Header Compression*"
on YouTube!

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6LoWPAN: Compression Example

```
6e 00 00 00   00 40 3a ff
fe 80 00 00   00 00 00 00
02 01 64 ff   fe 2f fc 0a
ff 02 00 00   00 00 00 00
00 00 00 00   00 00 00 01
86 00 8b a3   40 00 07 08
00 00 00 00   00 00 00 00
01 01 00 01   64 2f fc 0a
05 01 00 00   00 00 05 dc
03 04 40 c0   00 27 8d 00
00 09 3a 80   00 00 00 00
20 01 06 60   73 01 37 28
00 00 00 00   00 00 00 00
```

Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

6LoWPAN: Compression Example

Version (4 bits)

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6e 00 00 00   00 40 3a ff
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ff 02 00 00   00 00 00 00
00 00 00 00   00 00 00 01
86 00 8b a3   40 00 07 08
00 00 00 00   00 00 00 00
01 01 00 01   64 2f fc 0a
05 01 00 00   00 00 05 dc
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```

Compressed Header

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011			TF		NH	HLIM	
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IPv6 Header fields …							

6LoWPAN: Compression Example

TC (DSCP + ECN)
(8 bits)

Version
(4 bits)

```
6e 00 00 00   00 40 3a ff
fe 80 00 00   00 00 00 00
02 01 64 ff   fe 2f fc 0a
ff 02 00 00   00 00 00 00
00 00 00 00   00 00 00 01
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00 00 00 00   00 00 00 00
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00 00 00 00   00 00 00 00
```

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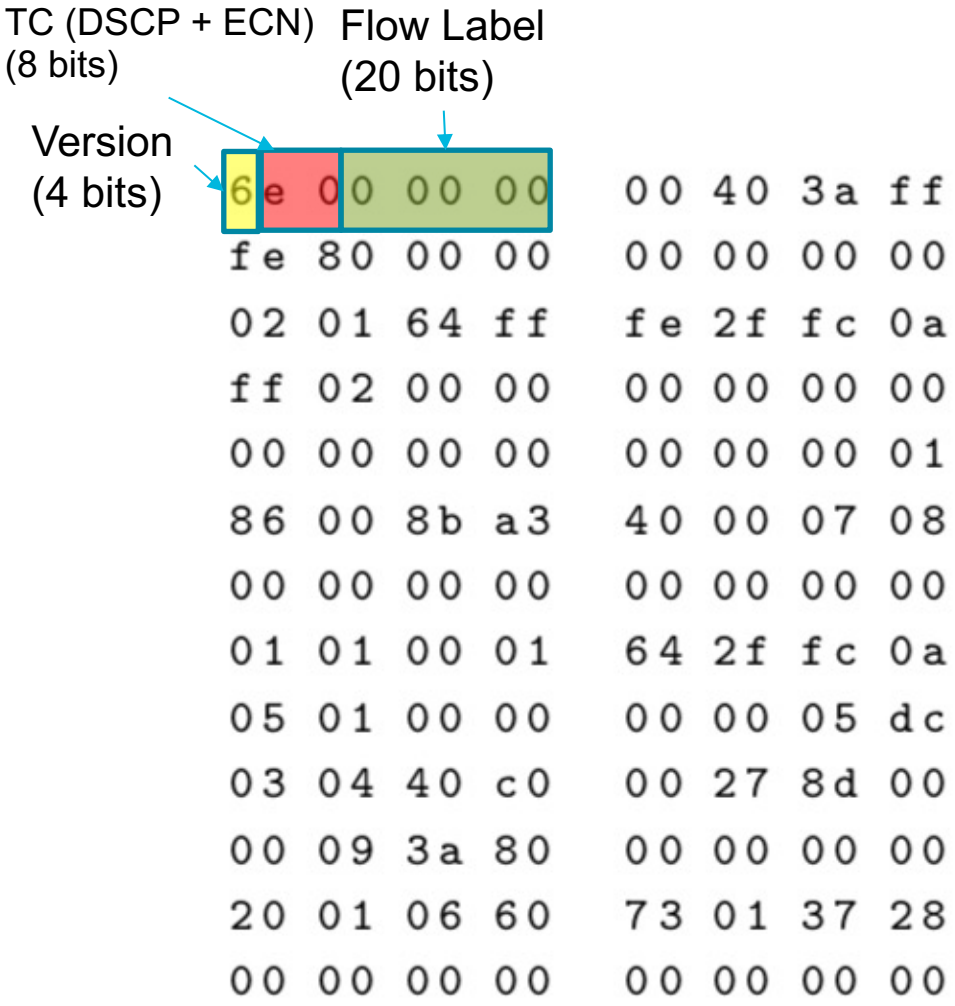

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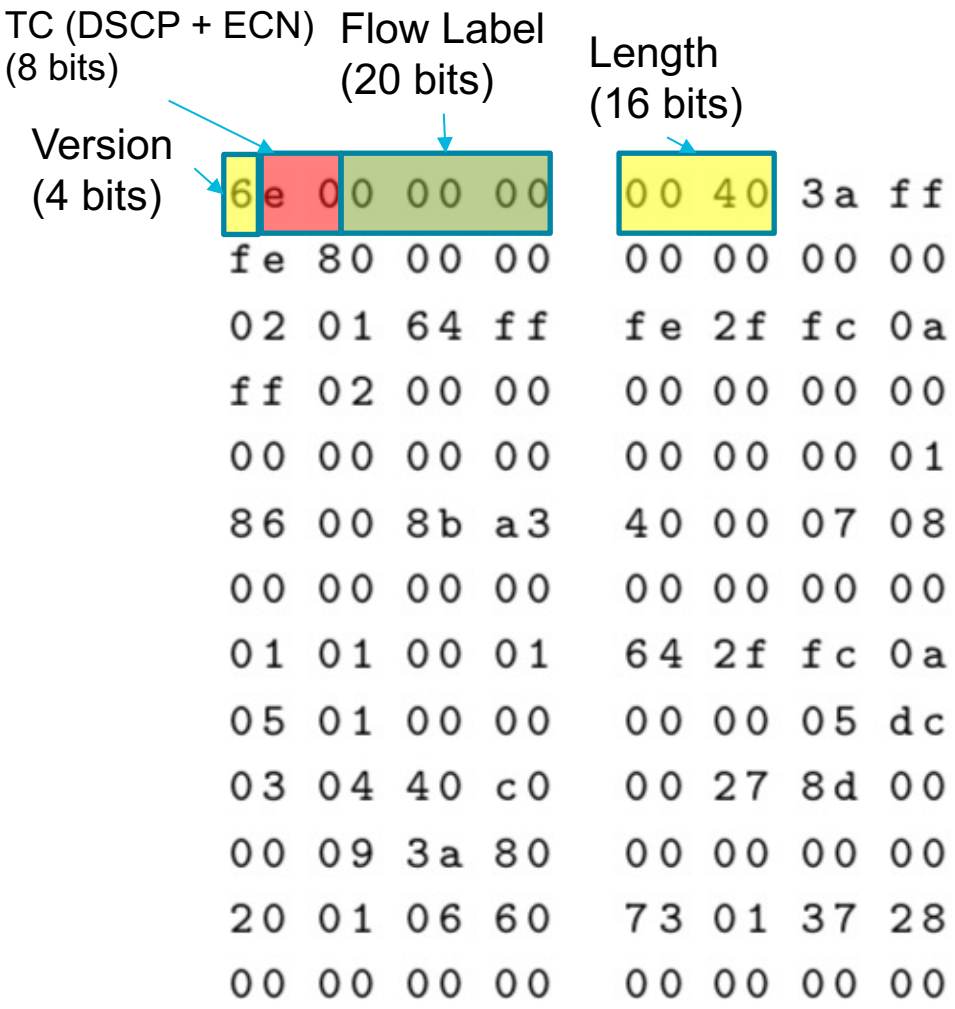
IPv6 Header fields …							

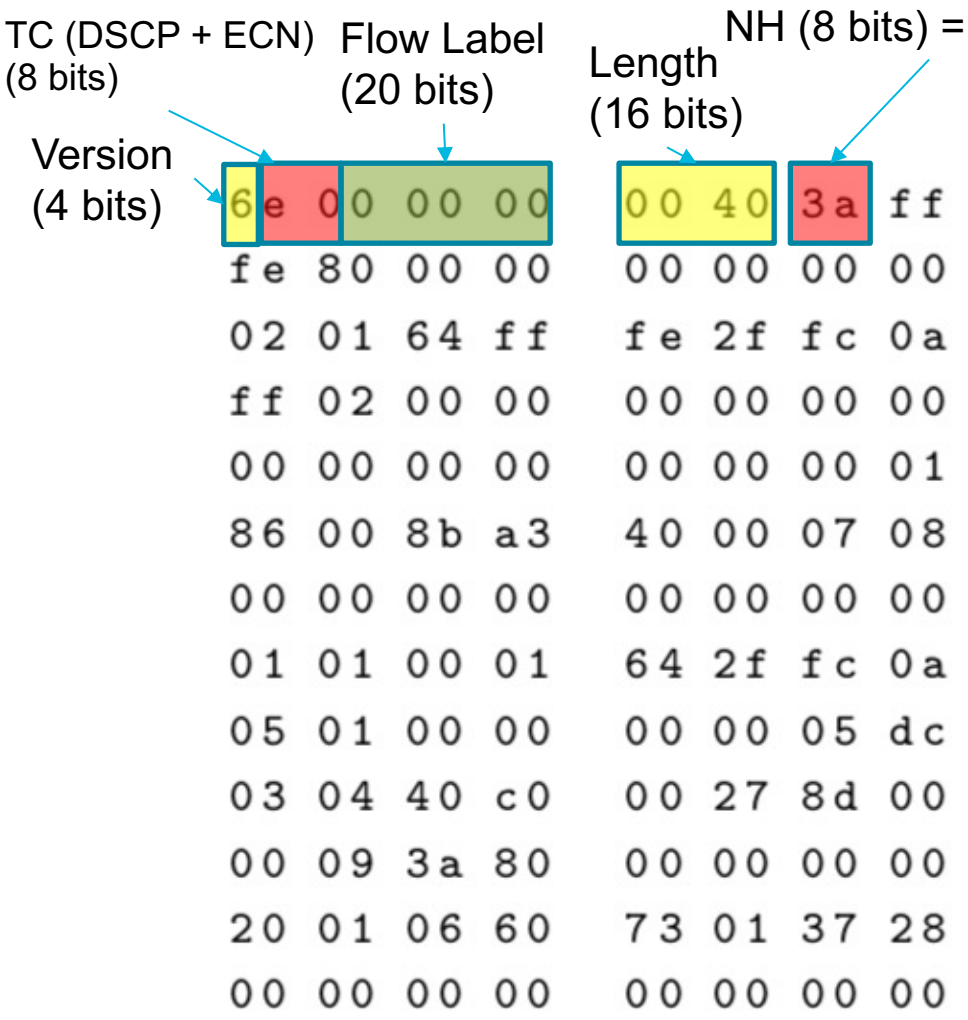
6LoWPAN: Compression Example



Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

6LoWPAN: Compression Example

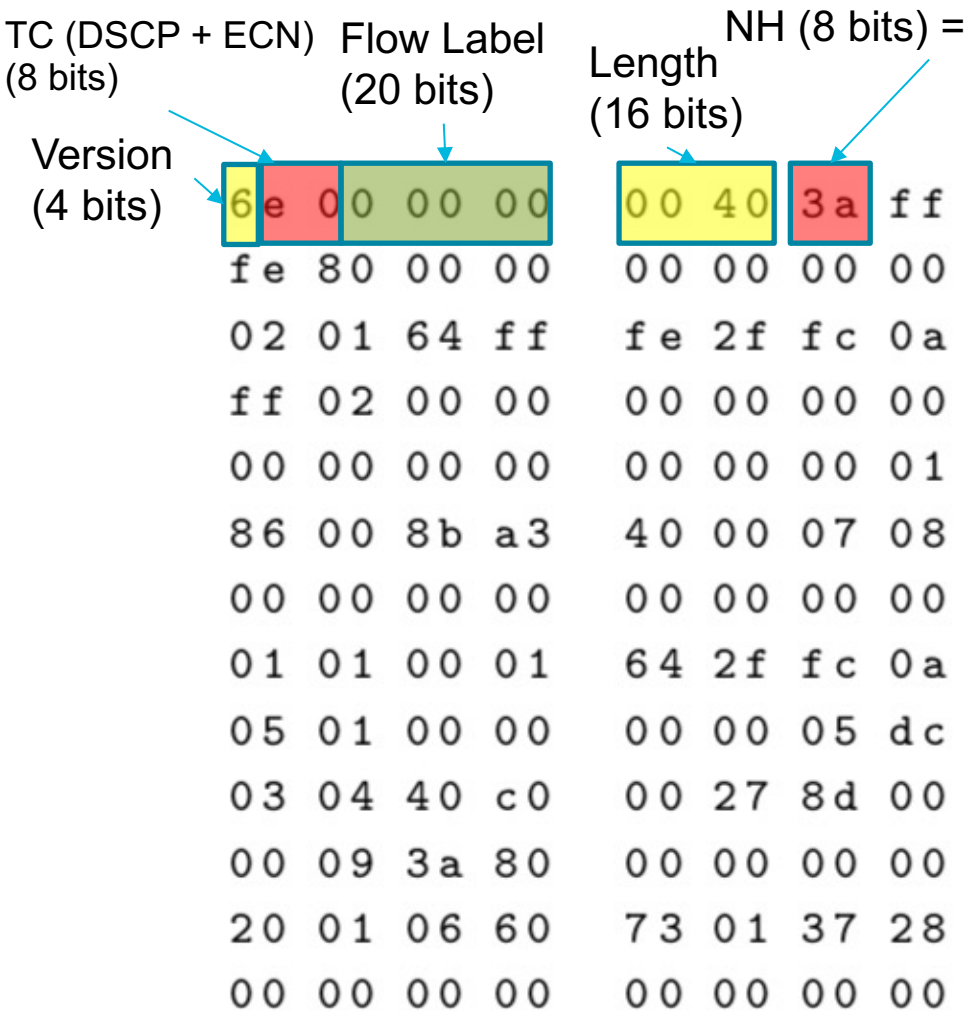


Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

What is the value of the NH field here?

6LoWPAN: Compression Example

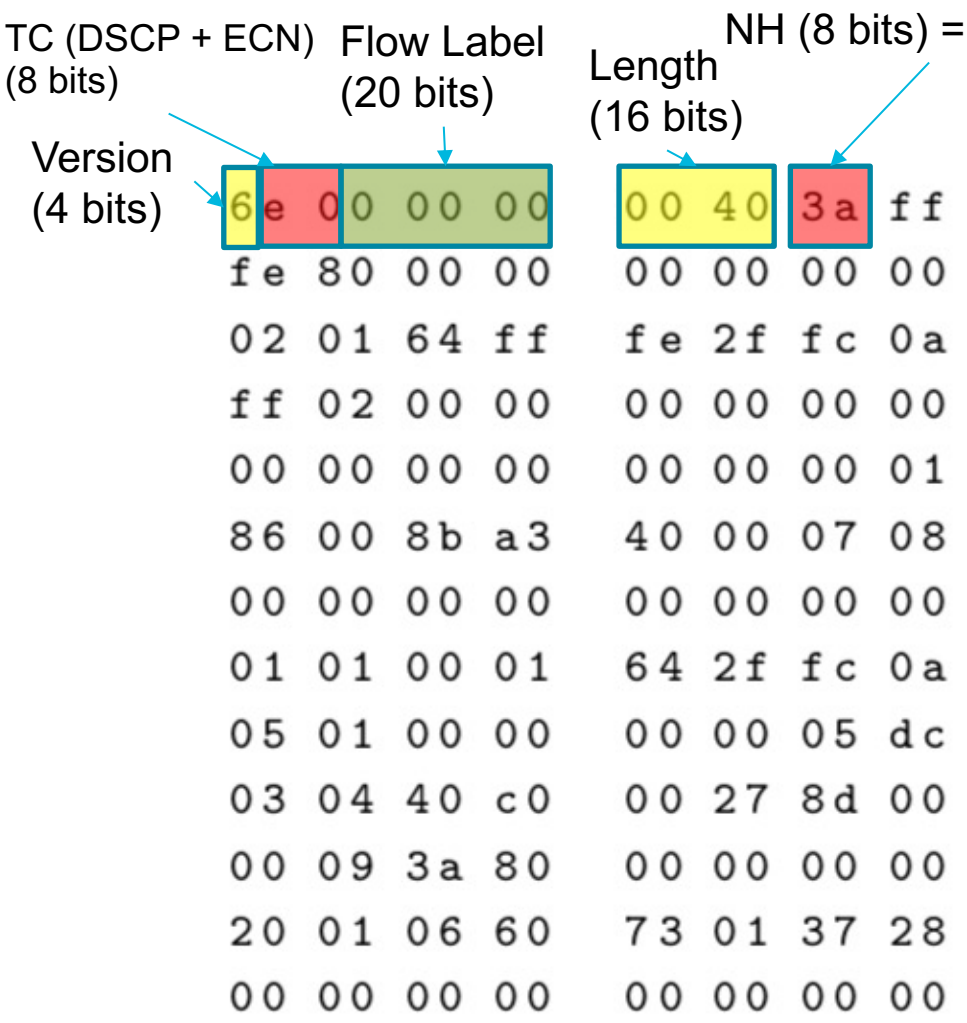


Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

Google or IANA: https://www.iana.org/assignments/protocol-numbers/protocol-numbers.xhtml

6LoWPAN: Compression Example

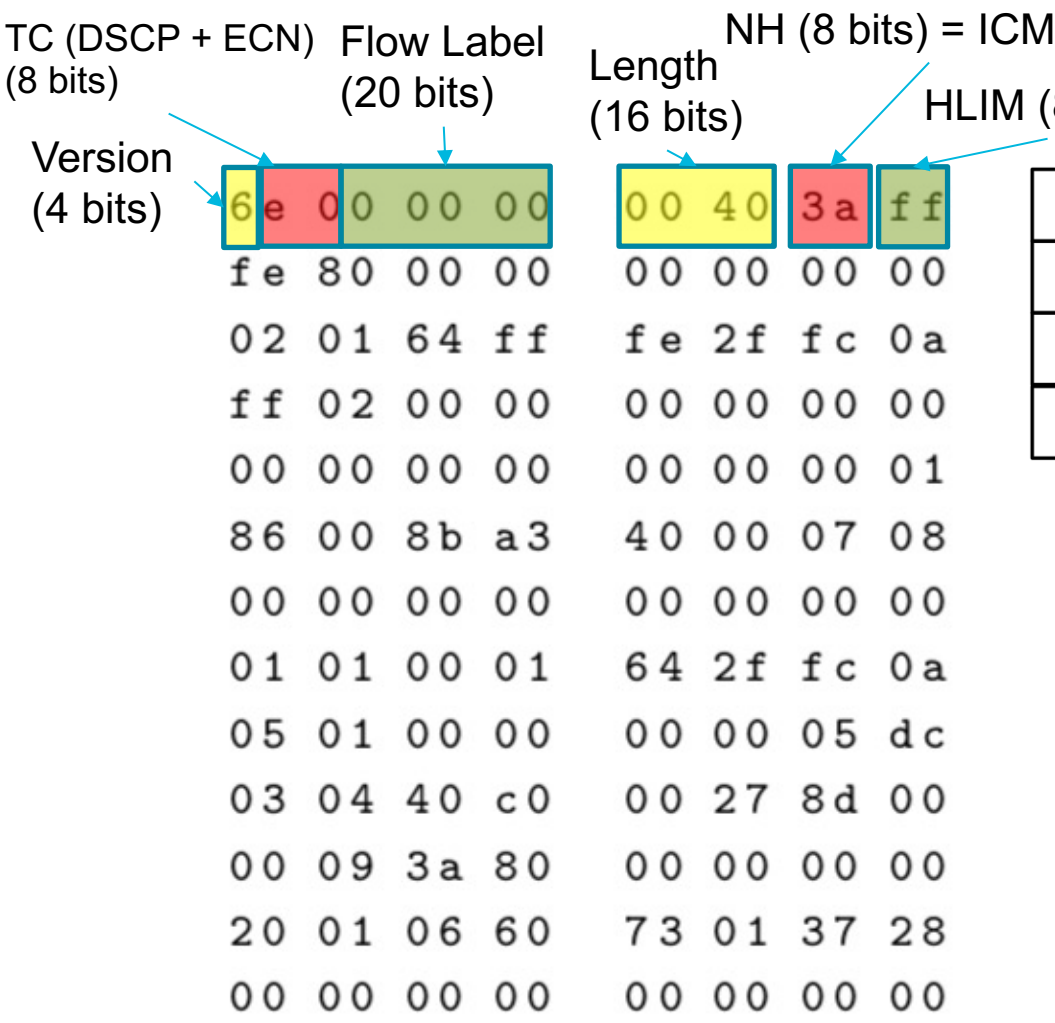


Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

3a hexadecimal is 58 in decimal → ICMPv6

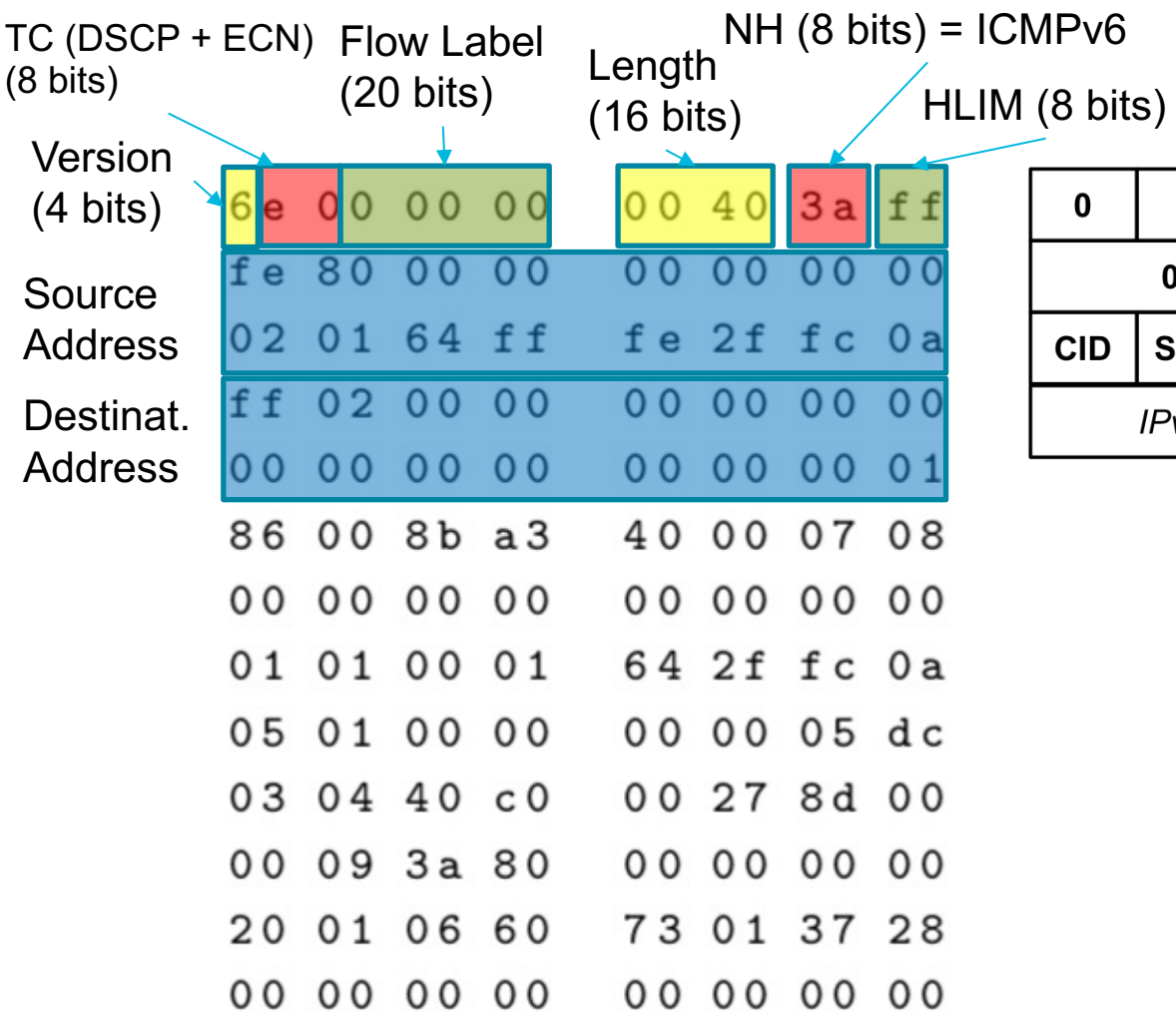
6LoWPAN: Compression Example



Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

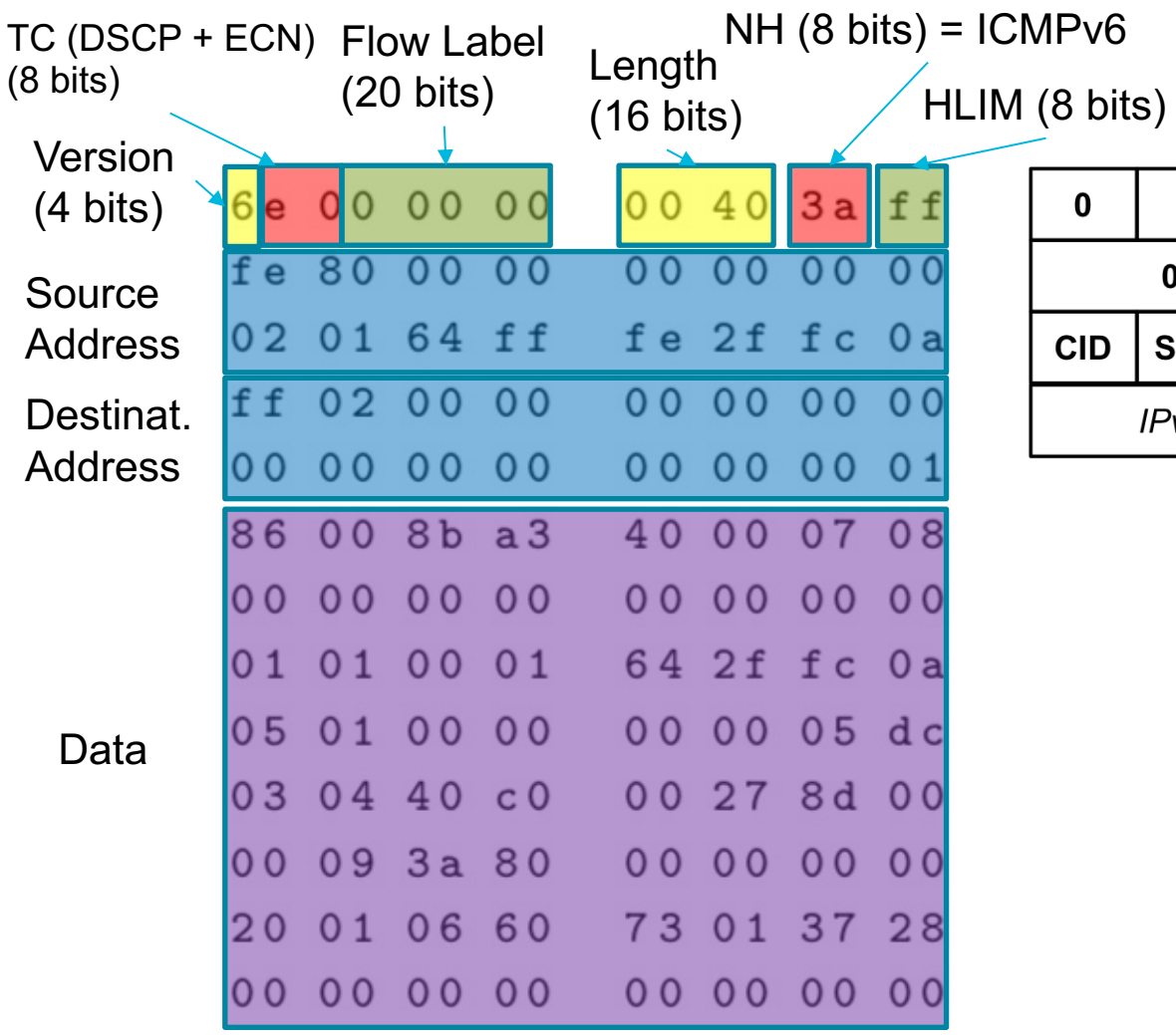
6LoWPAN: Compression Example



Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

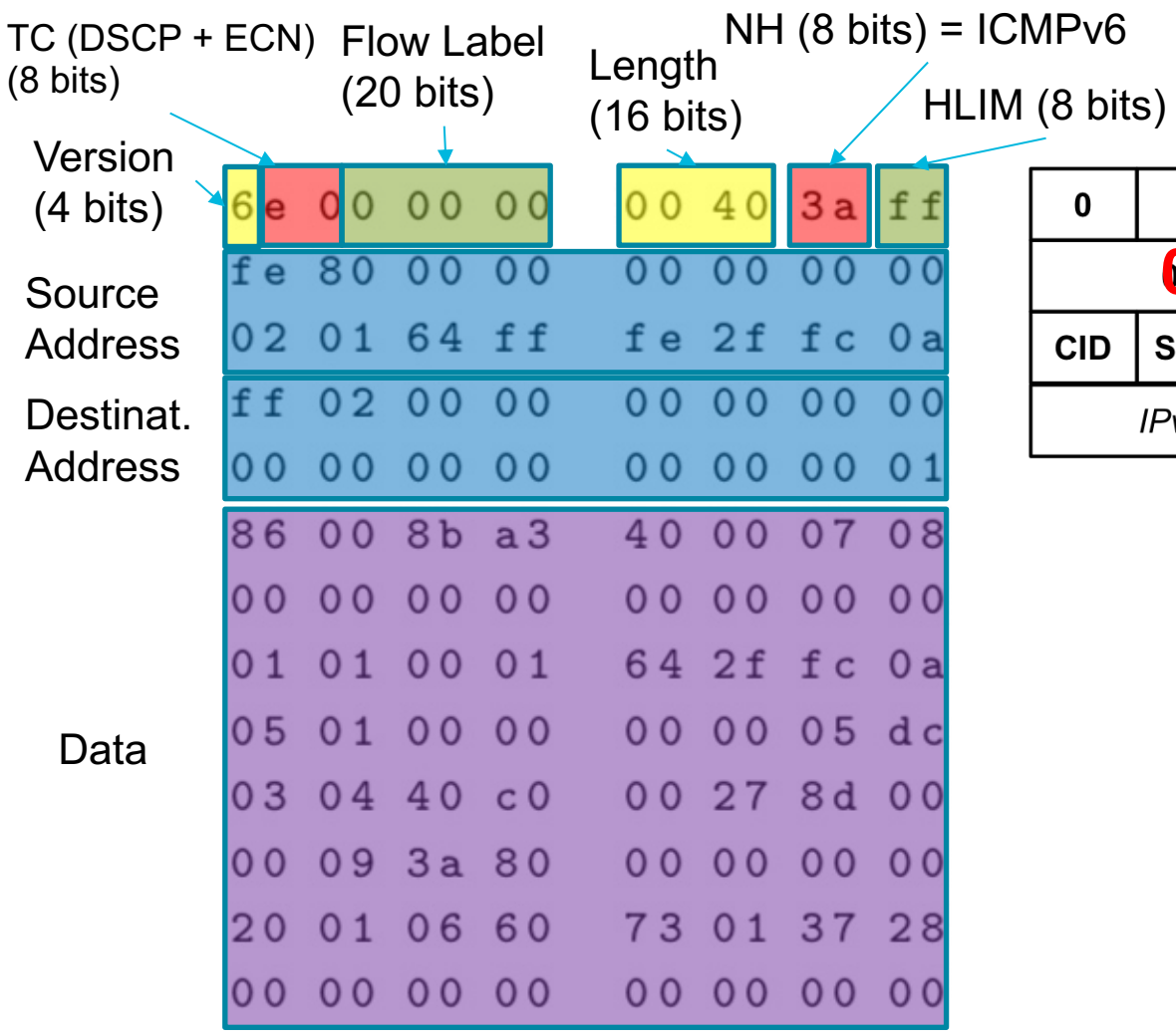
6LoWPAN : Compression Example



Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

6LoWPAN : Compression Example



Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

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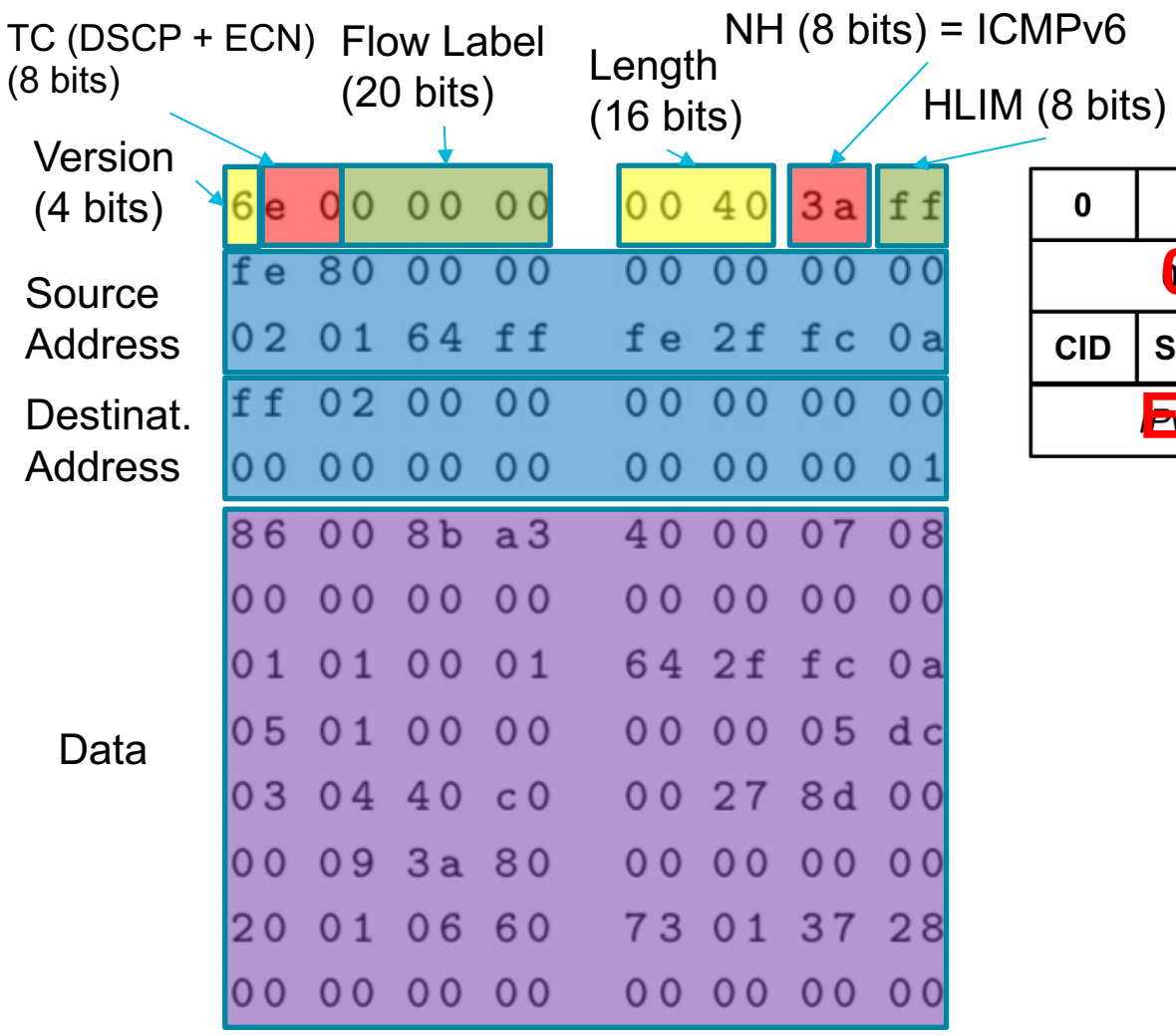
6LoWPAN : Compression Example



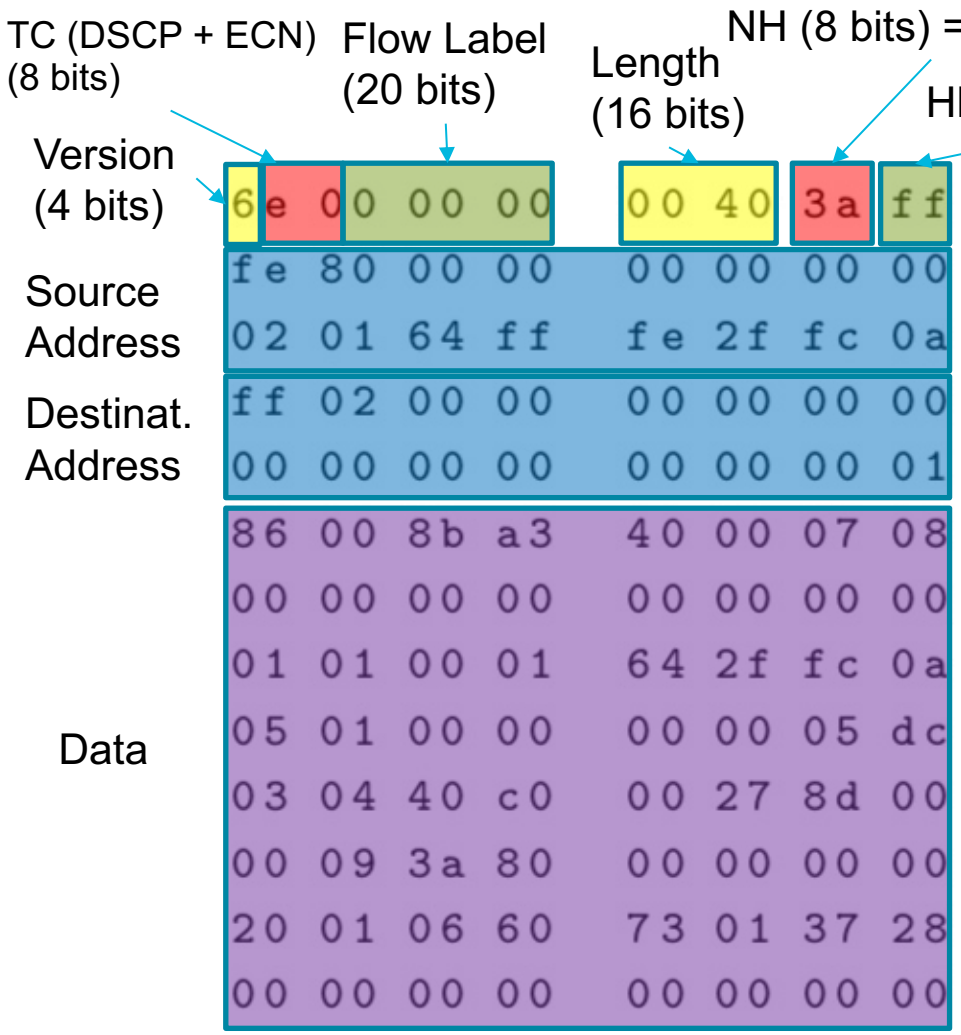
Compressed Header

0	1	2	3	4	5	6	7
011		TF			NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

10

E0

6LoWPAN : Compression Example



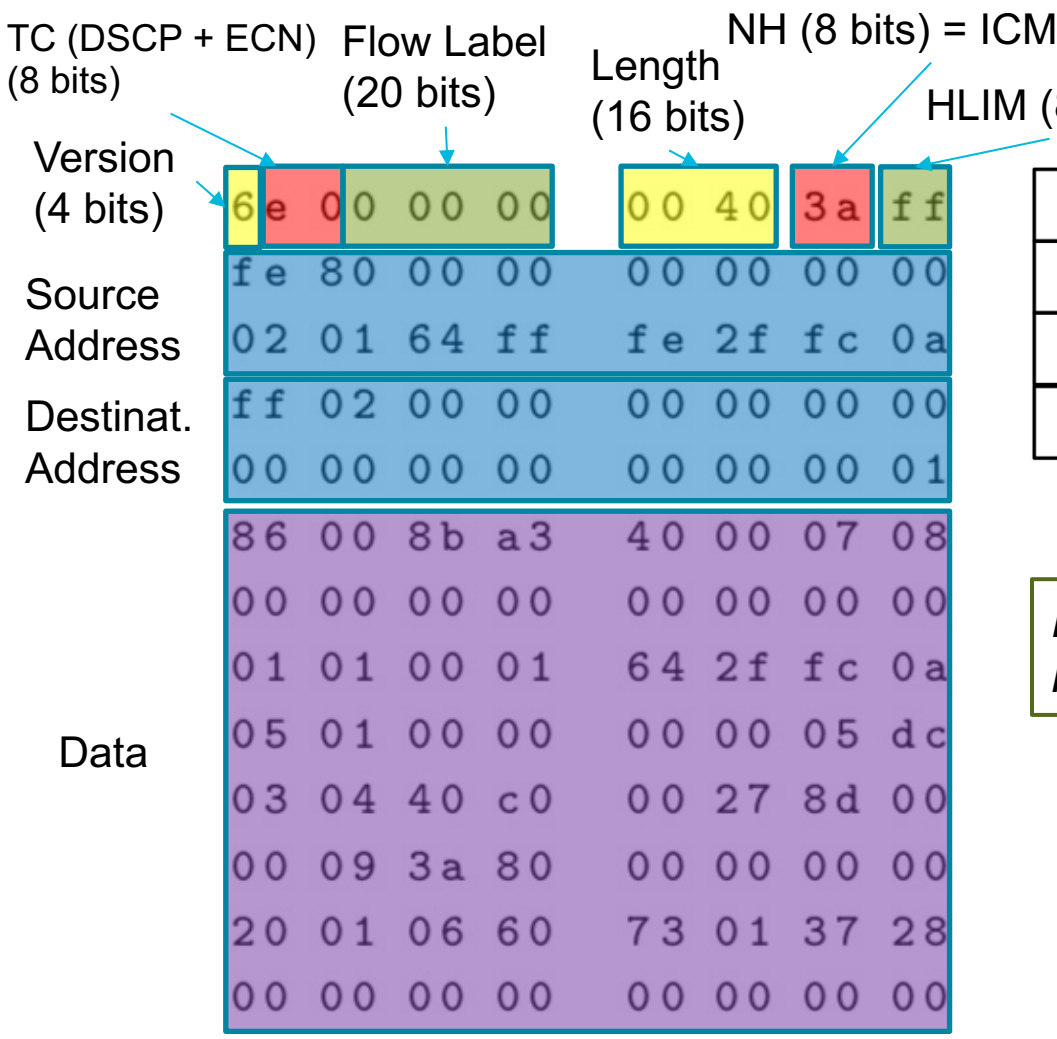
Compressed Header

0	1	2	3	4	5	6	7
011		TF			NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

E0 3A

3a (58 in decimal) in NH is ICMPv6 → there is not a compression mechanism (yet) for ICMPv6 protocol.

6LoWPAN : Compression Example



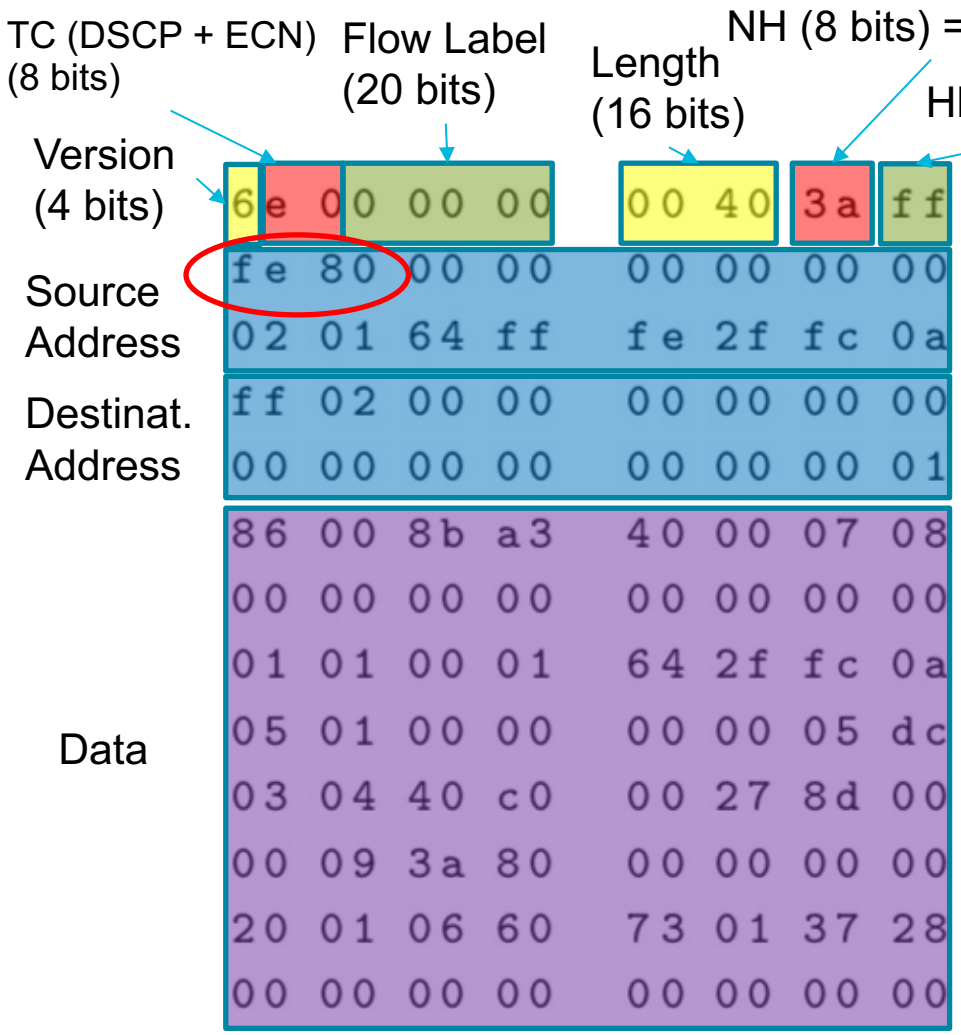
Compressed Header

0	1	2	3	4	5	6	7
011		TF			NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

E0 3A

HLIM value is ff in hexadecimal is 255 in decimal.

6LoWPAN : Compression Example



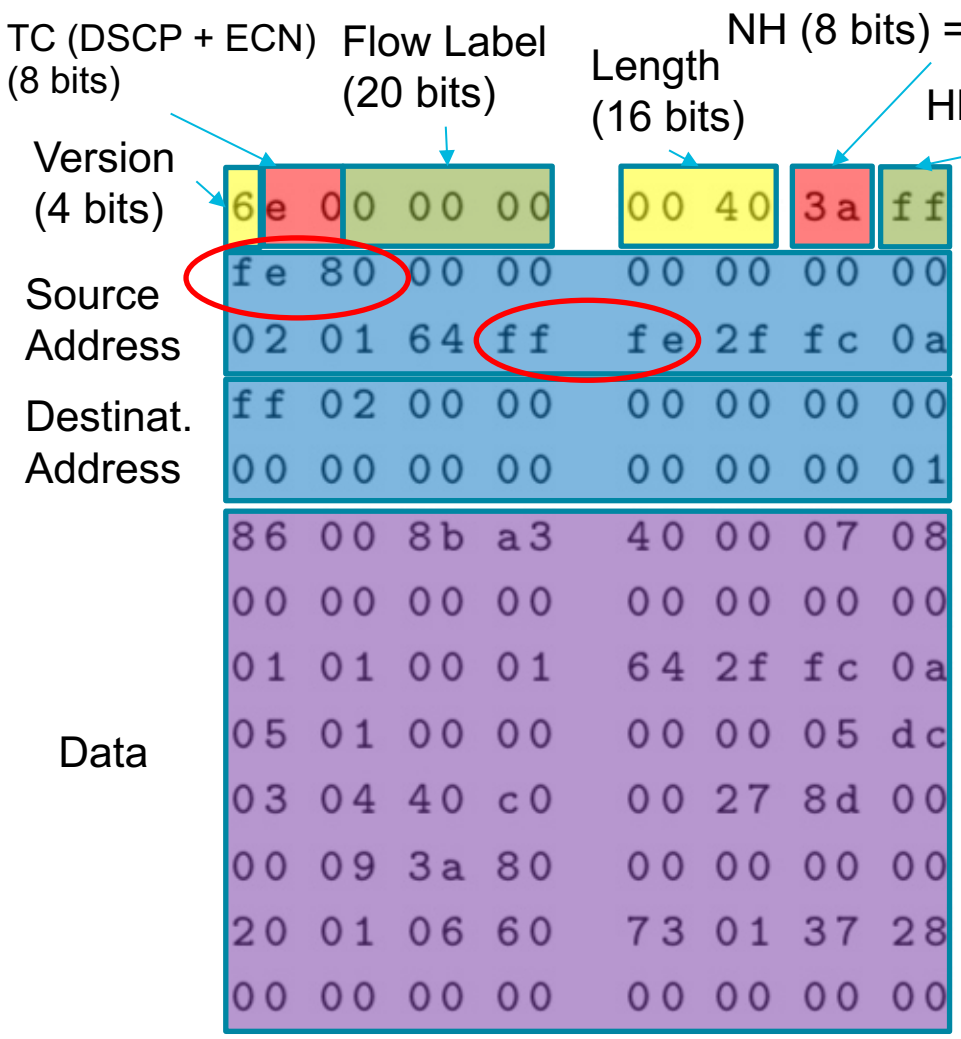
Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

0 0 E0 3A 0 11

The prefix starts with FE80, thus we have link-local IPv6 addresses → CID = 0, SAC = 0.

6LoWPAN : Compression Example



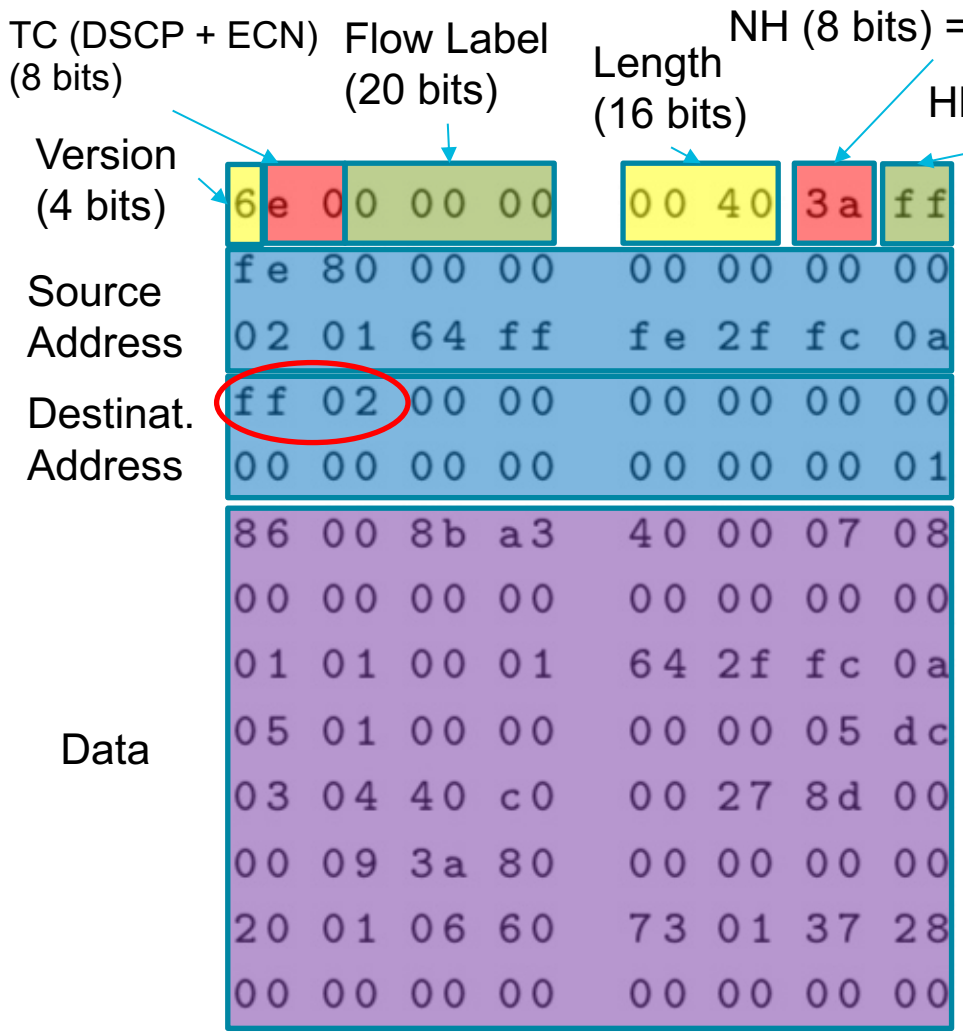
Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

011 10 0 11
0 0 11
E0 3A

- *The prefix starts with FE80 &&*
- *There is "FF FE" in the Interface ID part → IID is taken from L2 source address*
- *As a result, SAM = 11.*

6LoWPAN : Compression Example



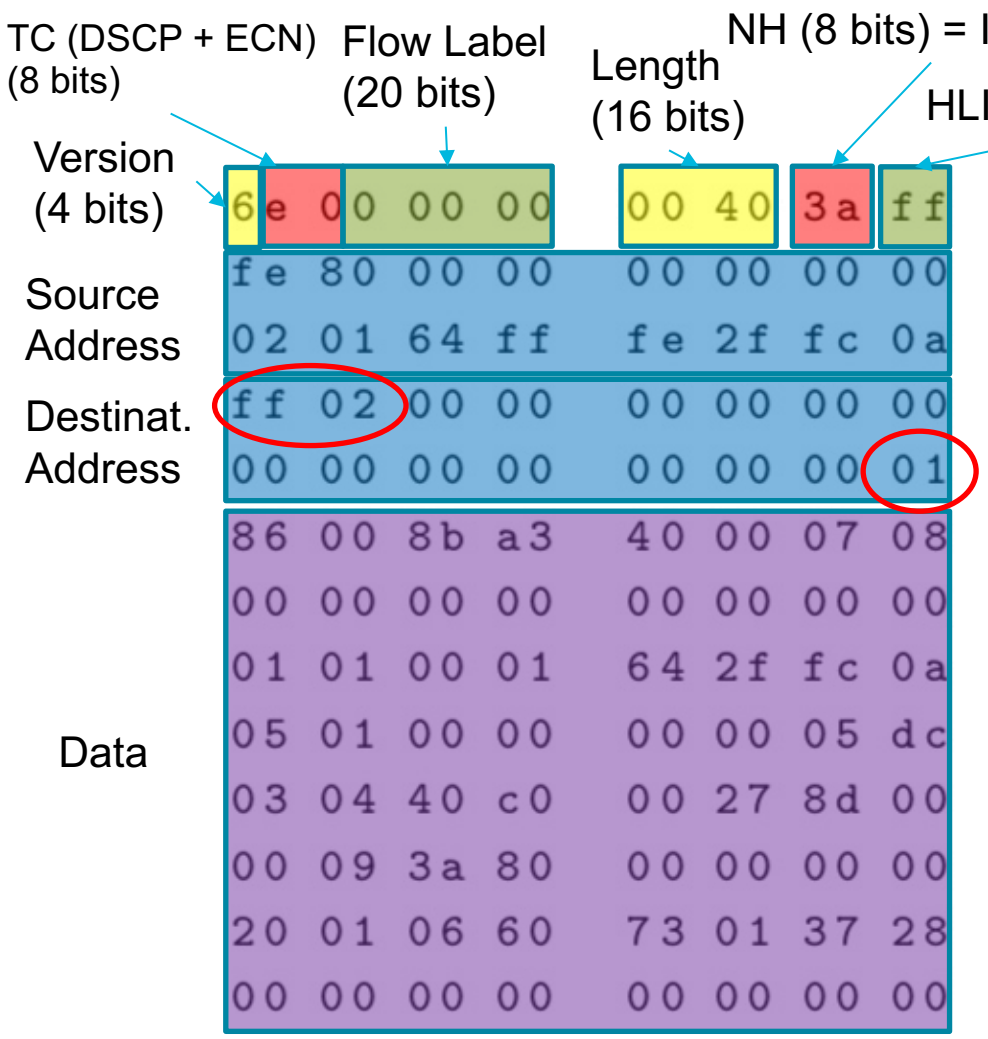
Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

0 0 11 1 0 E0 3A 01

ff02: a typical Multicast Address that has Link-local Scope → DAC = 0.

6LoWPAN : Compression Example



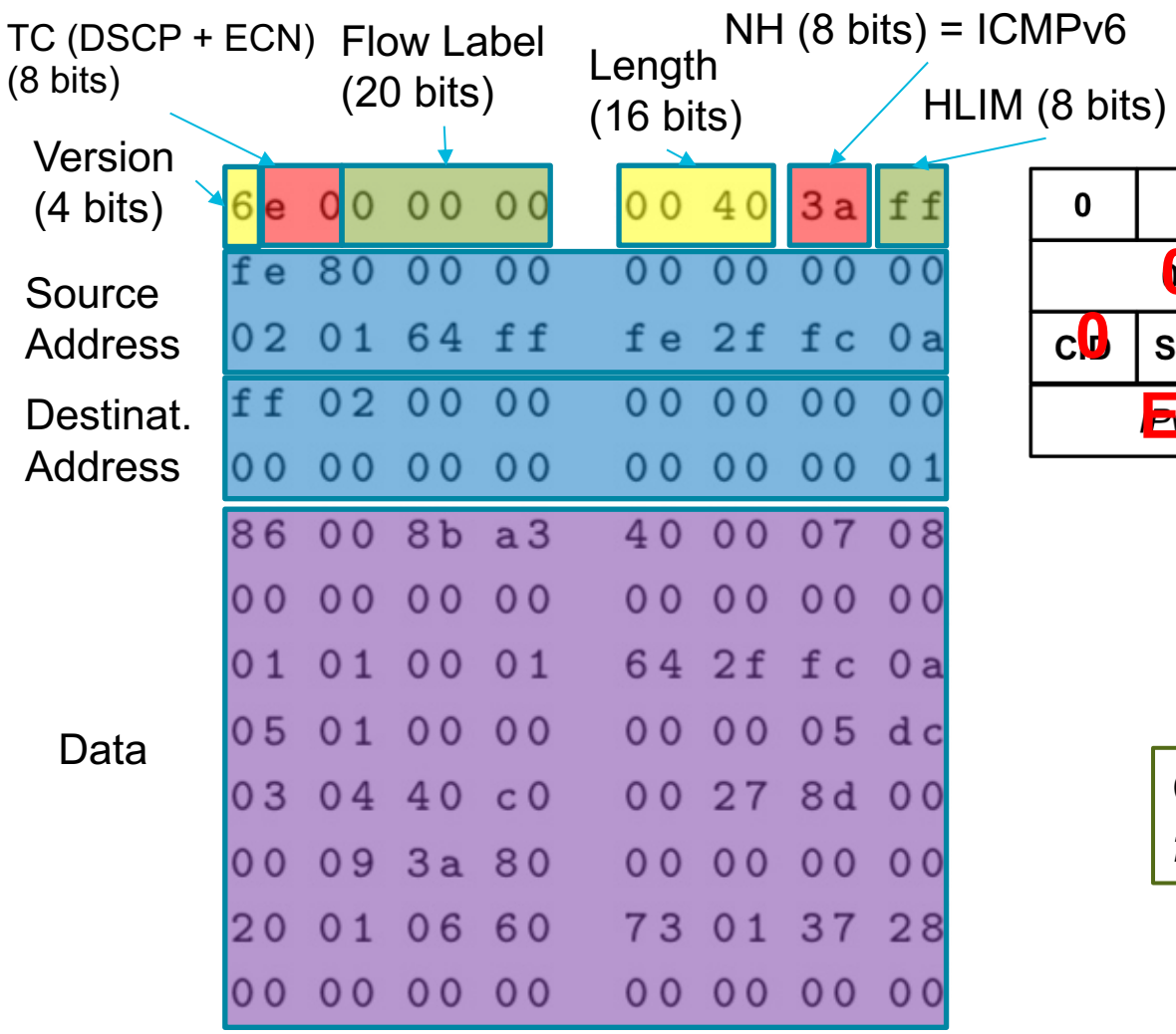
Compressed Header

0	1	2	3	4	5	6	7
011			TF 0		NH 0	HLIM 11	
CID 0	SAC 0	SAM 11		M 1	DAC 0	DAM 11	
E0	3A	01					

IPv6 Header fields ...

It has the following
Multicast Address format: FF02::00XX
Therefore, 8 bits are carried in-line!

6LoWPAN : Compression Example

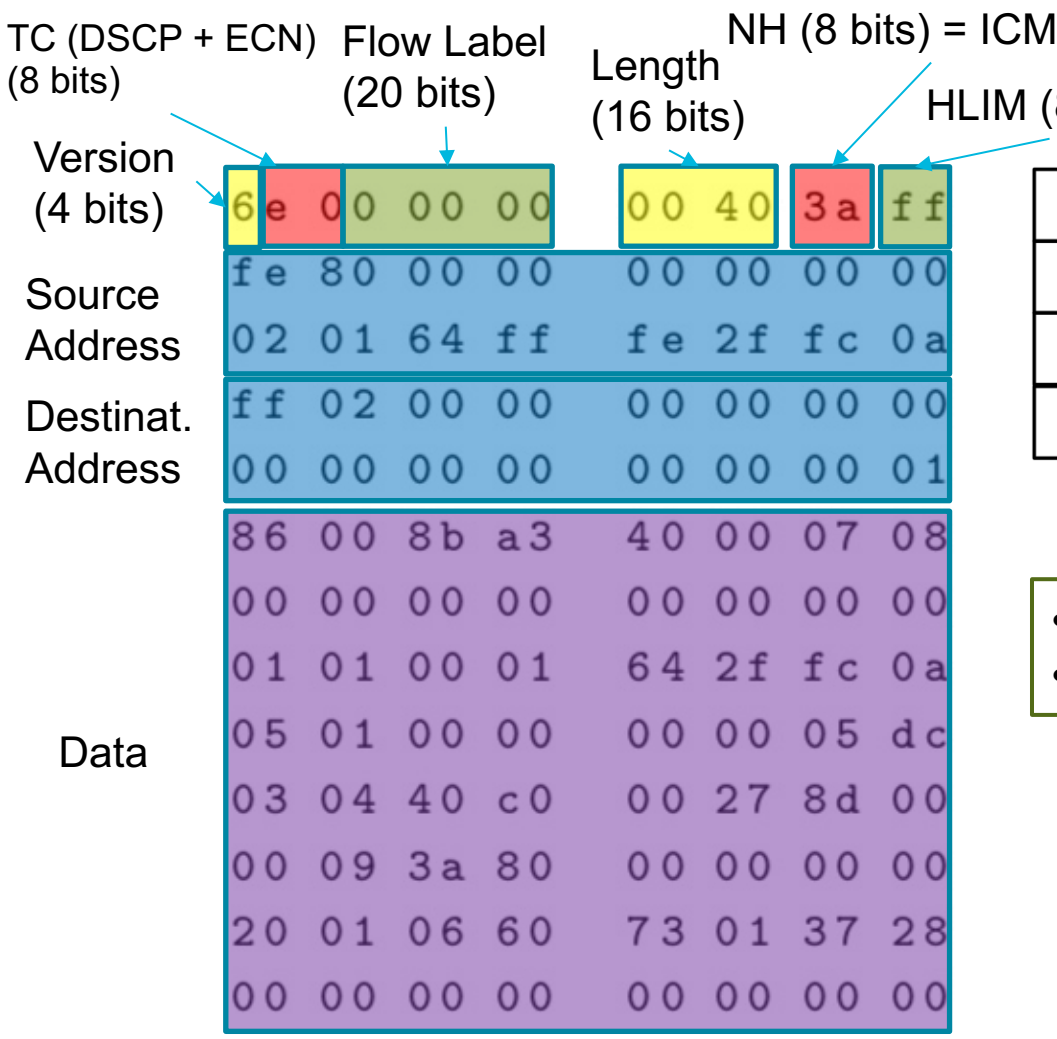


Compressed Header

0	1	2	3	4	5	6	7
011			TF 0		NH 0	HLIM 11	
CID 0	SAC 0	SAM 11		M 1	DAC 0	DAM 11	
IPv6 Header fields ... E0 3A 01							

Compression Result:
from 40 Bytes to 5 Bytes

6LoWPAN : Compression Example



Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
0	0	11		1	0	11	
IPv6 Header fields ... E0 3A 01							

- *Compressed Header = 2 bytes*
- *IPv6 Header fields = 3 bytes*

Compression Result:
from 40 Bytes to 5 Bytes

Example 2
Global Unicast

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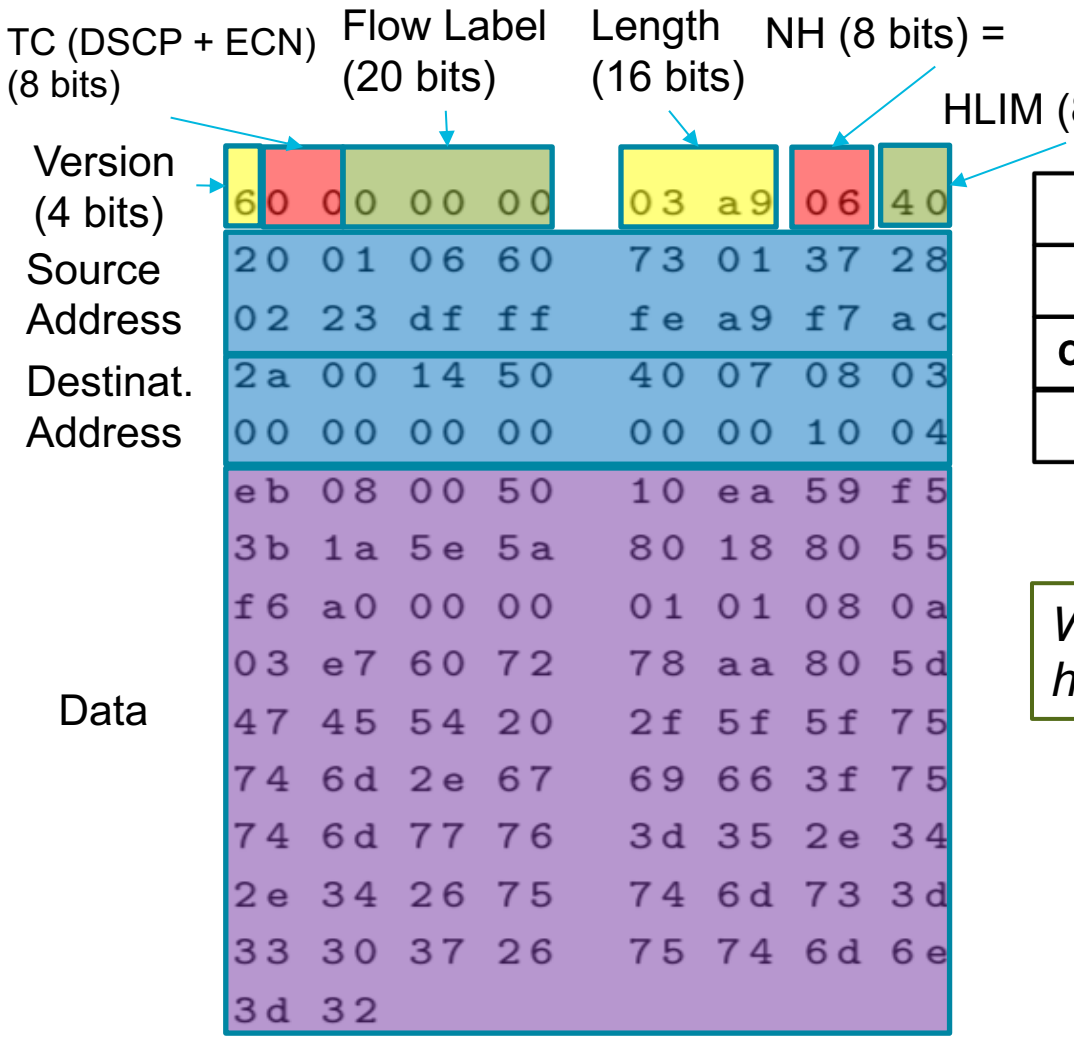
6LoWPAN : Compression Example

```
60 00 00 00   03 a9 06 40
20 01 06 60   73 01 37 28
02 23 df ff   fe a9 f7 ac
2a 00 14 50   40 07 08 03
00 00 00 00   00 00 10 04
eb 08 00 50   10 ea 59 f5
3b 1a 5e 5a   80 18 80 55
f6 a0 00 00   01 01 08 0a
03 e7 60 72   78 aa 80 5d
47 45 54 20   2f 5f 5f 75
74 6d 2e 67   69 66 3f 75
74 6d 77 76   3d 35 2e 34
2e 34 26 75   74 6d 73 3d
33 30 37 26   75 74 6d 6e
3d 32
```

Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

6LoWPAN : Compression Example

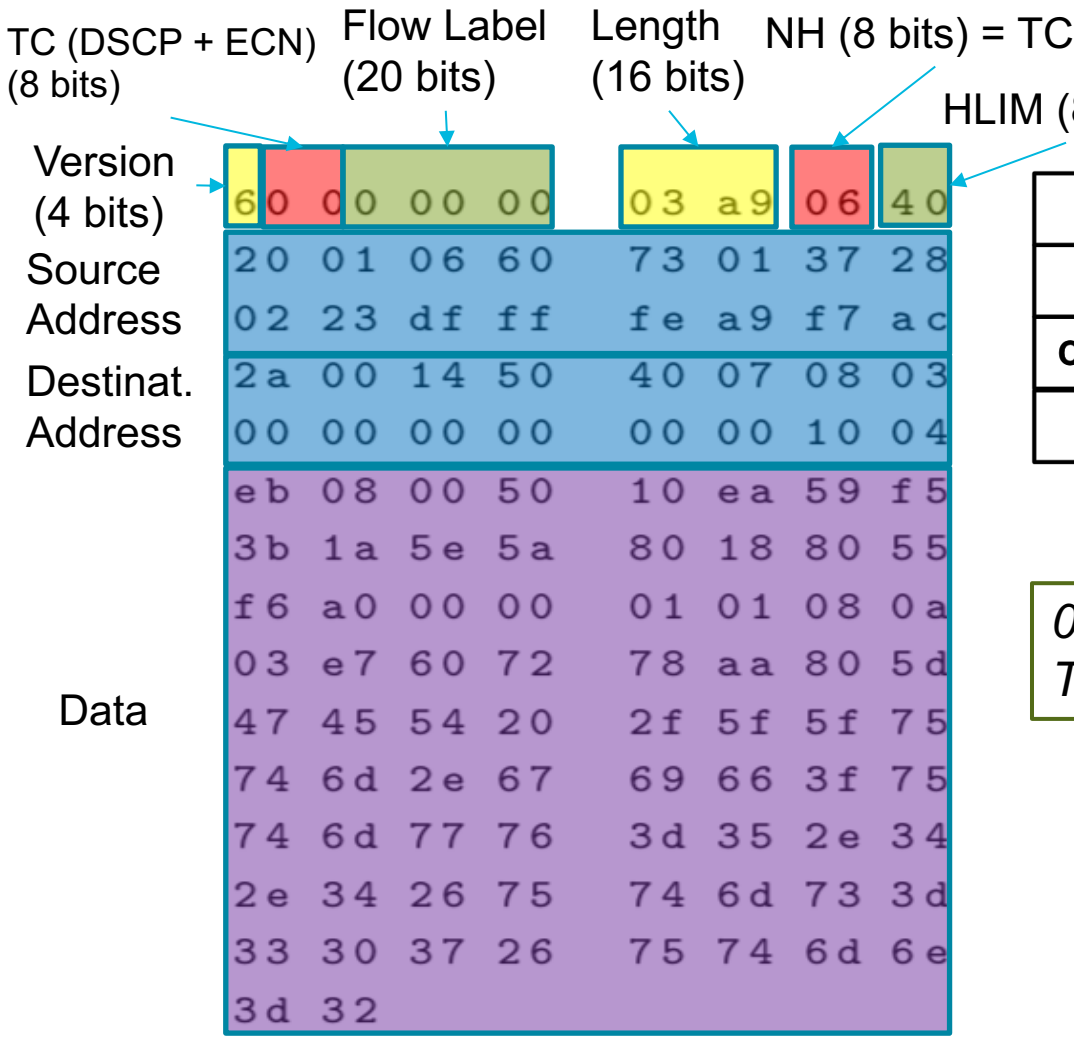


Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

What is the value of the NH field here?

6LoWPAN : Compression Example

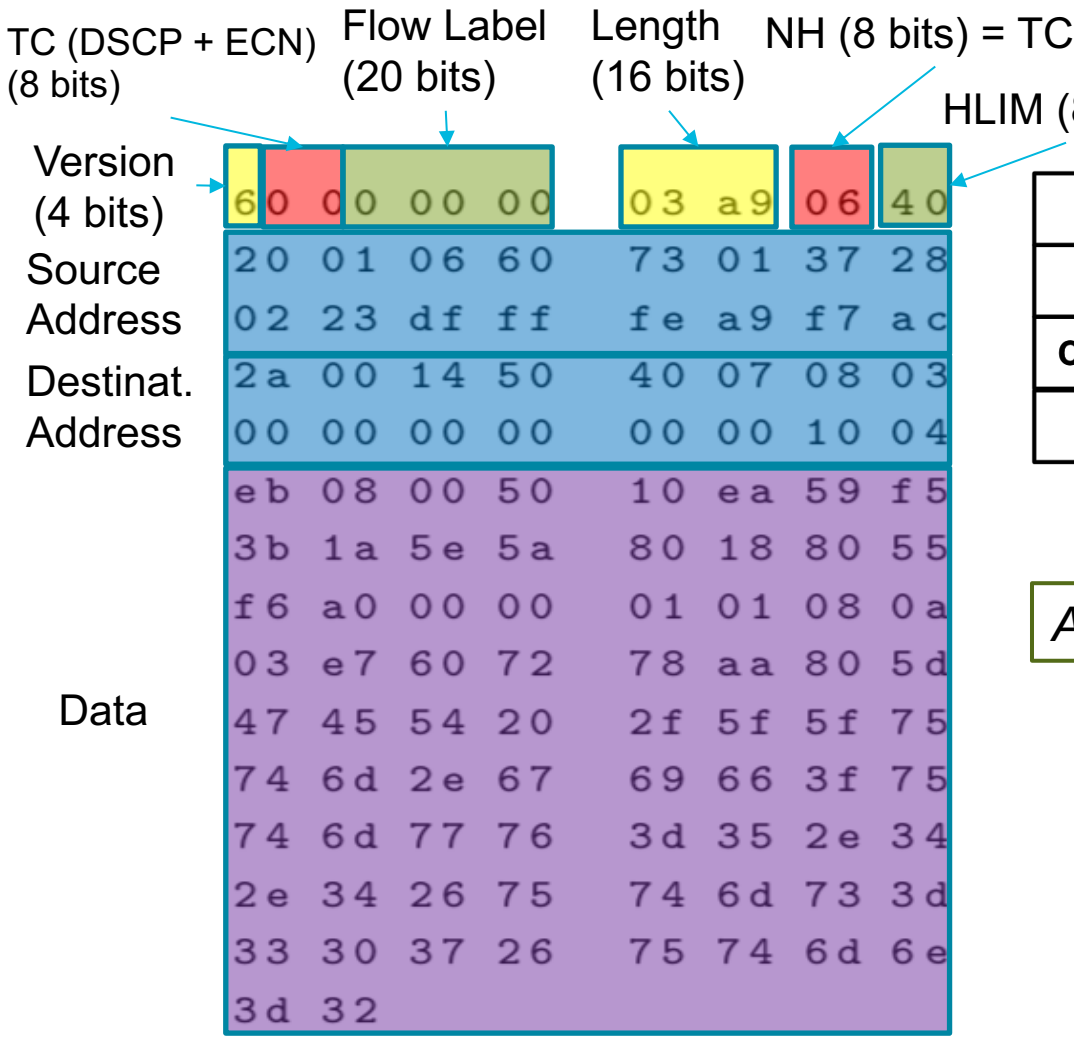


Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

06 hexadecimal is 06 in decimal → TCP

6LoWPAN : Compression Example

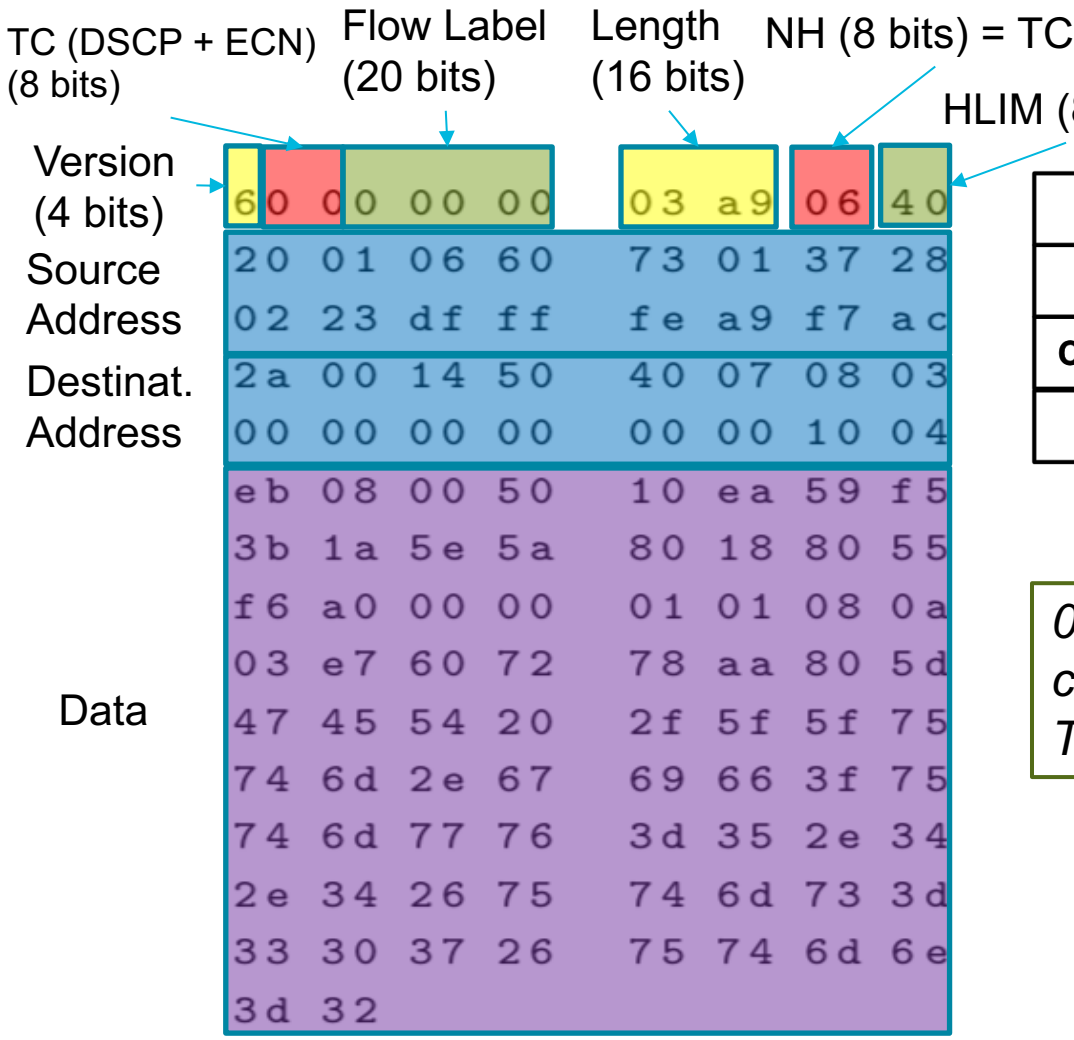


Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

All fields in Traffic Class are zeros!

6LoWPAN : Compression Example

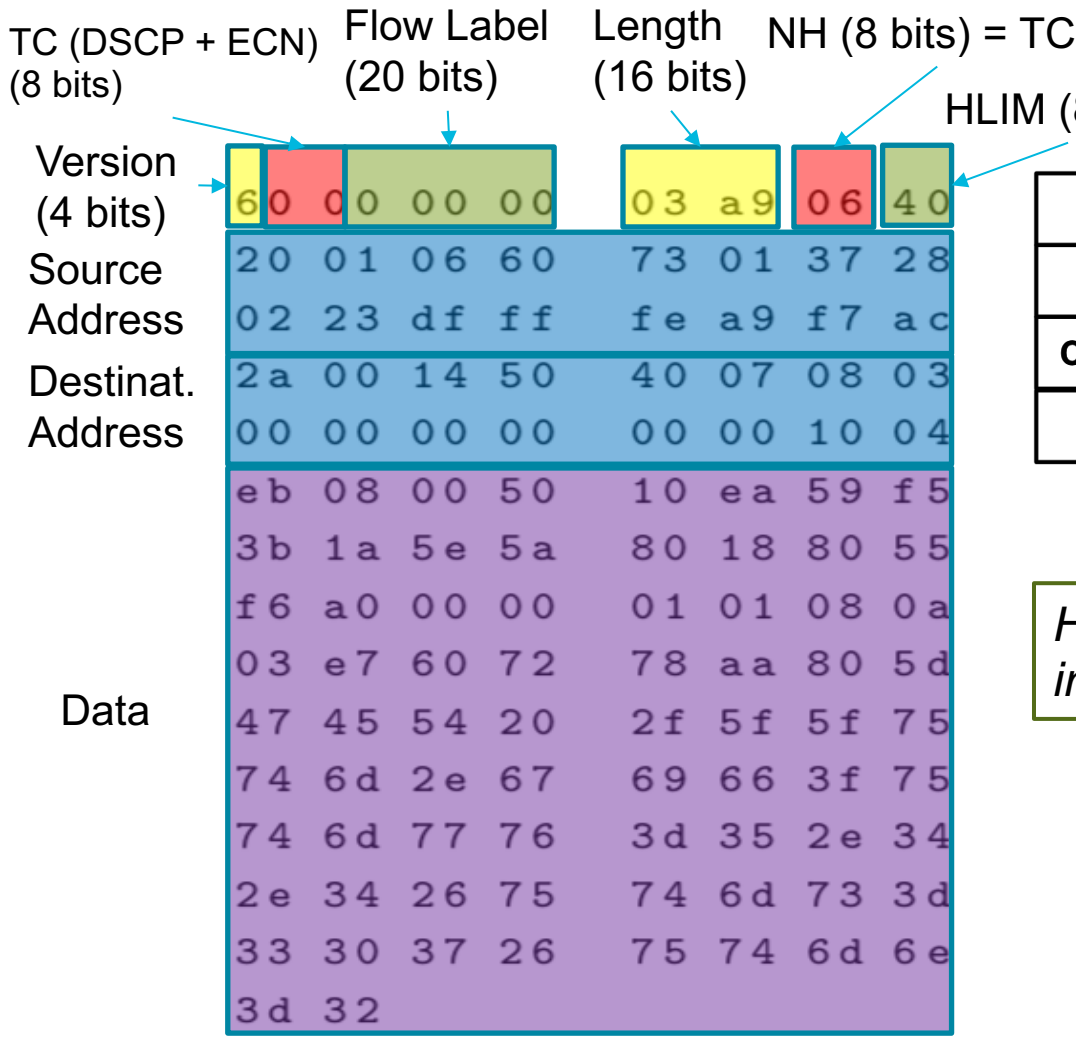


Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
06	*IPv6 Header fields …*						

06 in NH is TCP → there is not a compression mechanism (yet) for TCP protocol.

6LoWPAN : Compression Example

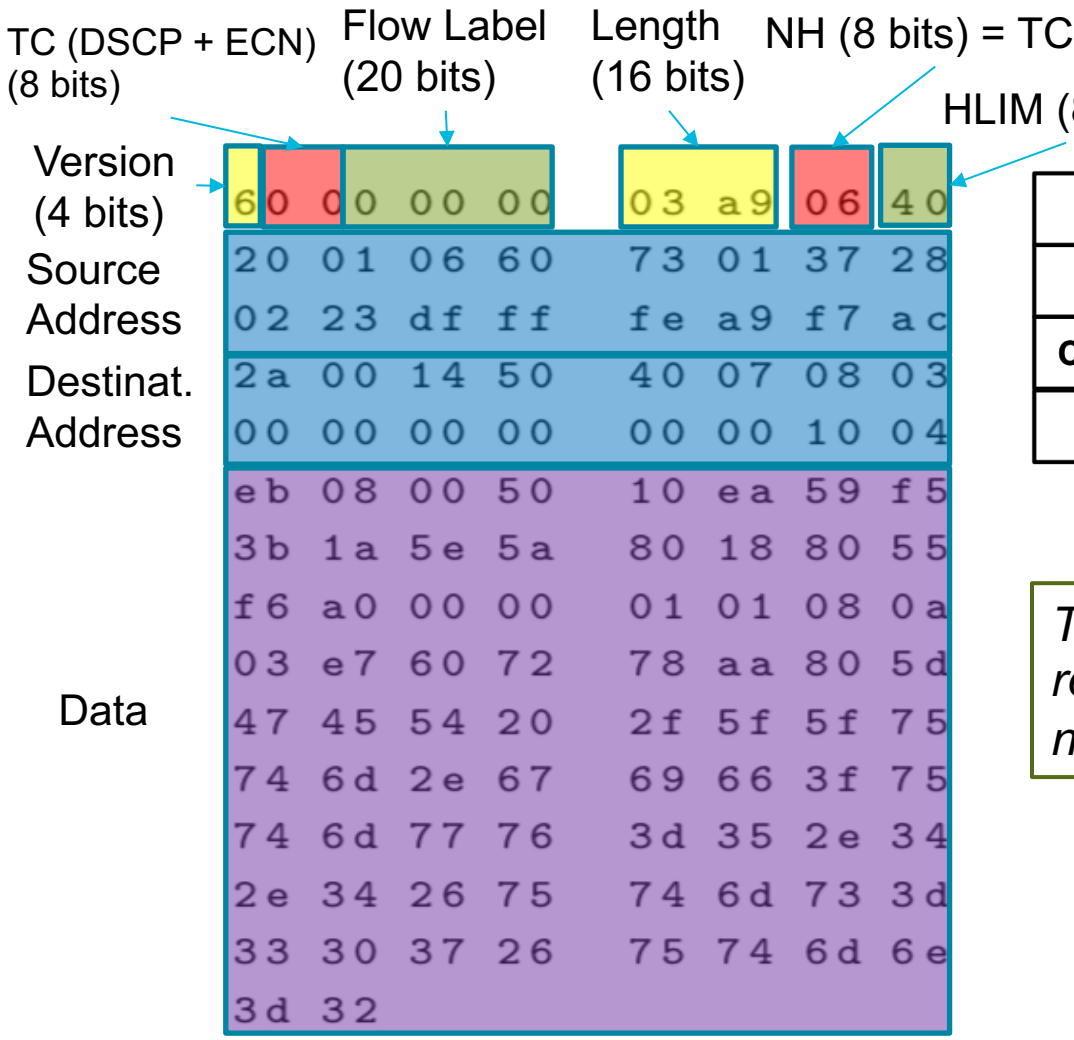


Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIV	
CID	SAC	SAM		M	DAC	DAM	
IPv6 Header fields …							

HLIM value is 40 in hexadecimal is 64 in decimal.

6LoWPAN : Compression Example



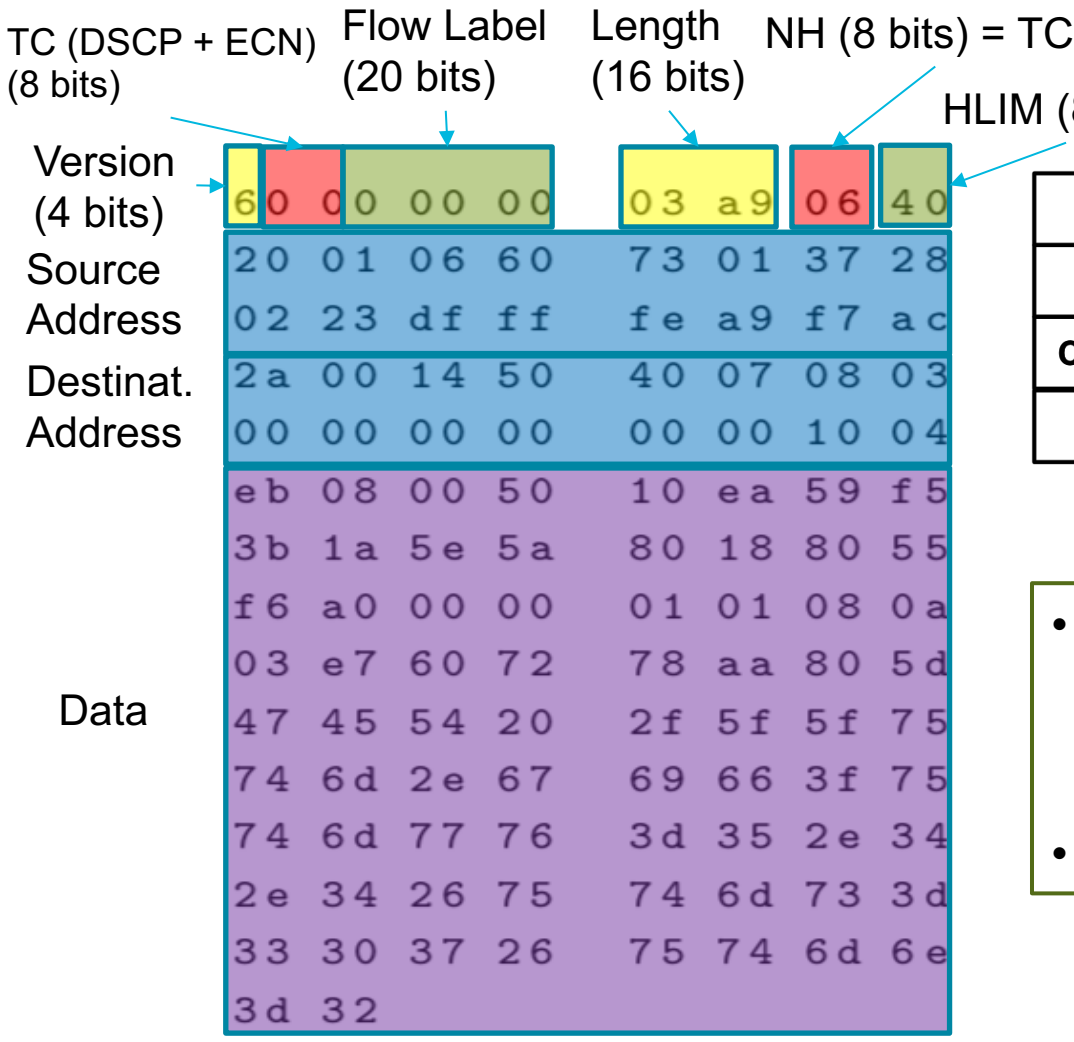
Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
0							
06	*Elided Header fields …*						

10

There is not direct indication regrading the Prefix (if it is given or not by the Context) → CID = 0

6LoWPAN : Compression Example

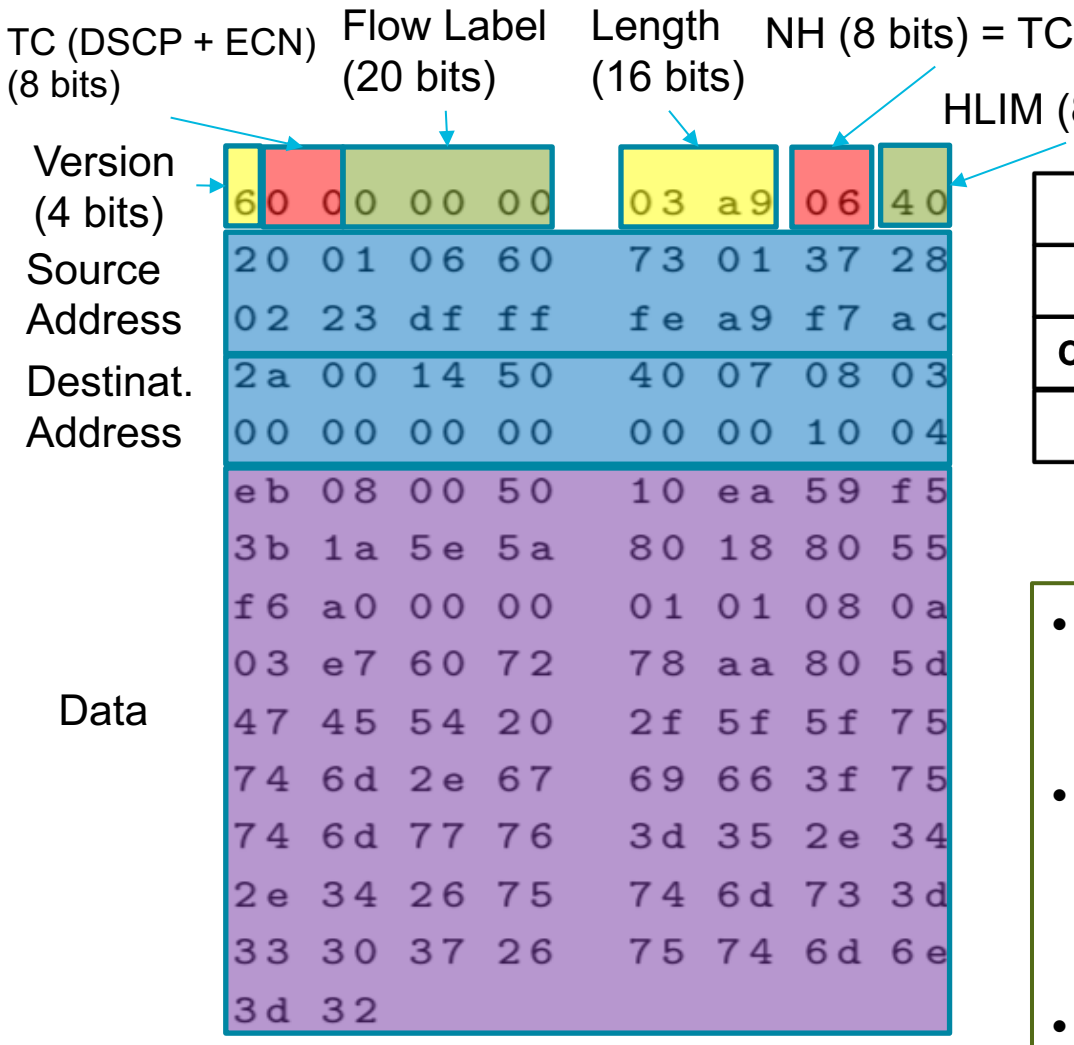


Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIV	
CID	SAC	SAM		M	DAC	DAM	
06	*IPv6 Header fields …*						

- *The Prefix **does not** start with FE80, thus **no** indication for Link Local address*
  → Global Address (SAC = 1)
- *Then, since CID = 0 → SAM = 00.*

6LoWPAN : Compression Example



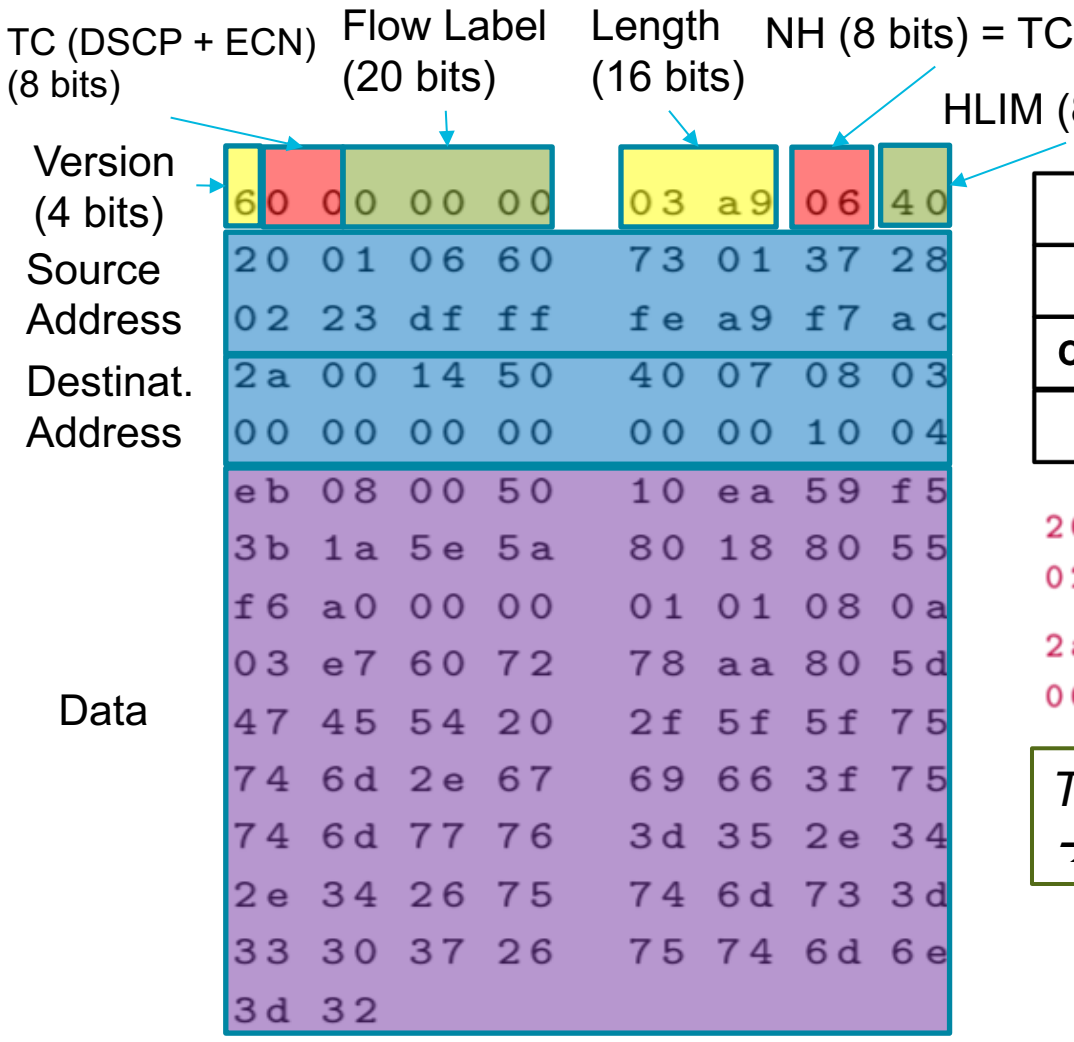
Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
06							

IPv6 Header fields …

- *The destination address **does not** start either with FFXX or FF02 → M = 0.*
- *The Prefix **does not** start with FE80, thus no indication for Link Local address →*
  → Global Address (DAC = 1)
- *Then, since CID = 0 → DAM = 00.*

6LoWPAN : Compression Example



Compressed Header

0	1	2	3	4	5	6	7
011			TF		NH	HLIM	
CID	SAC	SAM		M	DAC	DAM	
06	IPv6 Header fields …						

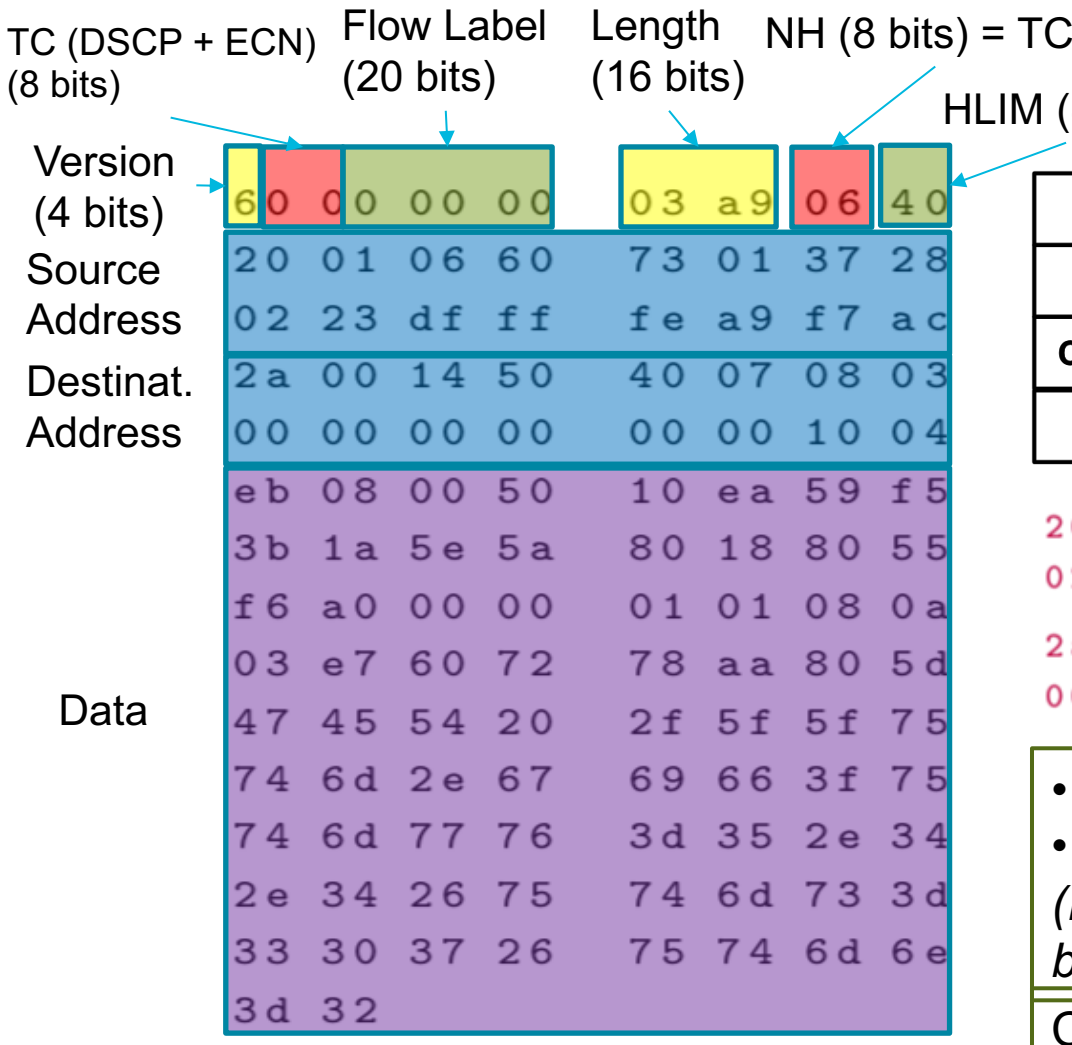
011 1 10 0 1 00 0 00

20 01 06 60 73 01 37 28
02 23 df ff fe a9 f7 ac

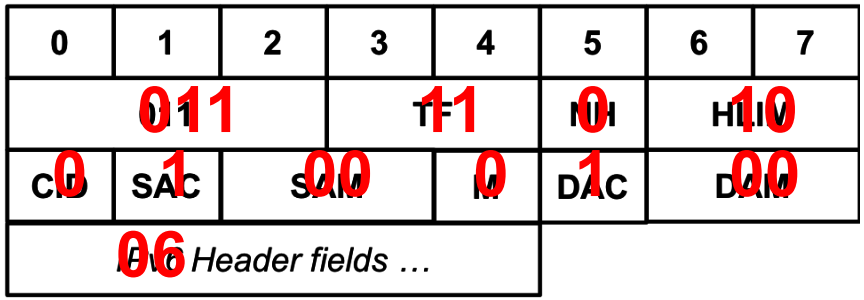
2a 00 14 50 40 07 08 03
00 00 00 00 00 00 10 04

Thus, the IPv6 address must be sent → in the IPv6 Header fields.

6LoWPAN : Compression Example



Compressed Header



20 01 06 60 73 01 37 28
02 23 df ff fe a9 f7 ac

2a 00 14 50 40 07 08 03
00 00 00 00 00 00 10 04

- *Compressed Header = 2 bytes*
- *IPv6 Header fields = 33 bytes →*

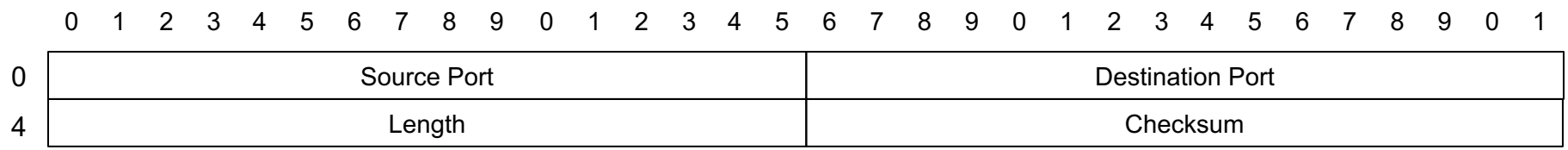
(NH = 1 byte, IPv6 addresses 32 bytes, 16 for source and 16 for dest.)

Compression Result:
from 40 Bytes to 35 Bytes

OUTLINE

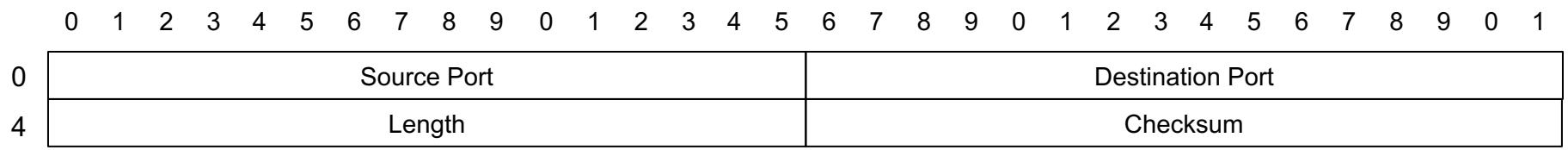
Check the relevant video
"*Tutorial on 6LoWPAN IPv6 and UDP Header Compression*"
on YouTube!

UDP Header Format



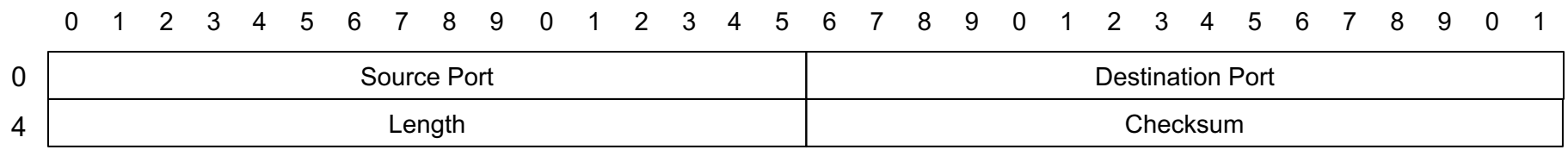
- Source port (16 bits):
  - This field identifies the port of the transmitter, when used, it should be assumed to be the port to reply to. If not used, it should be zero.
- Destination port (16 bits):
  - This field identifies the port of the receiver.
- Length (16 bits):
  - This field specifies the length in bytes of the UDP header and UDP data.
- Checksum (16 bits):
  - It is used for error-checking of the header and data.
  - This field is optional in IPv4, and mandatory (*obligatoire*) in IPv6.
  - The field carries all-zeros if unused.

UDP Header Compression



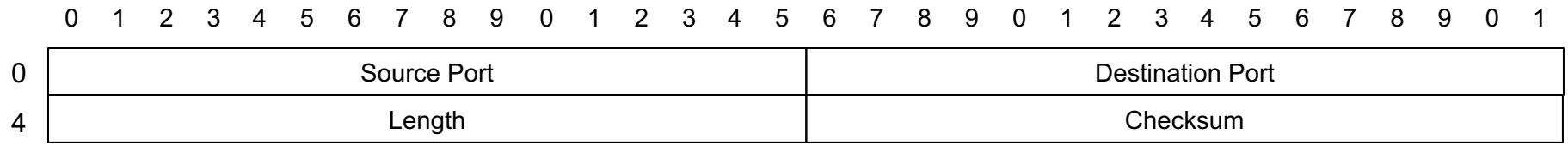
- Assume common values for header fields and define compact forms.
  - Ports within 61616 to 61632 (4 bits).

UDP Header Compression



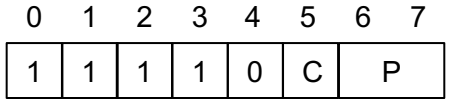
- Assume common values for header fields and define compact forms.
  - Ports within 61616 to 61632 (4 bits).
  - Length can be derived from IPv6 header Length information.
  - Checksum always carried in-line (RFC 4944) or **elided** (RFC 6282).

UDP LOWPAN_NHC Format



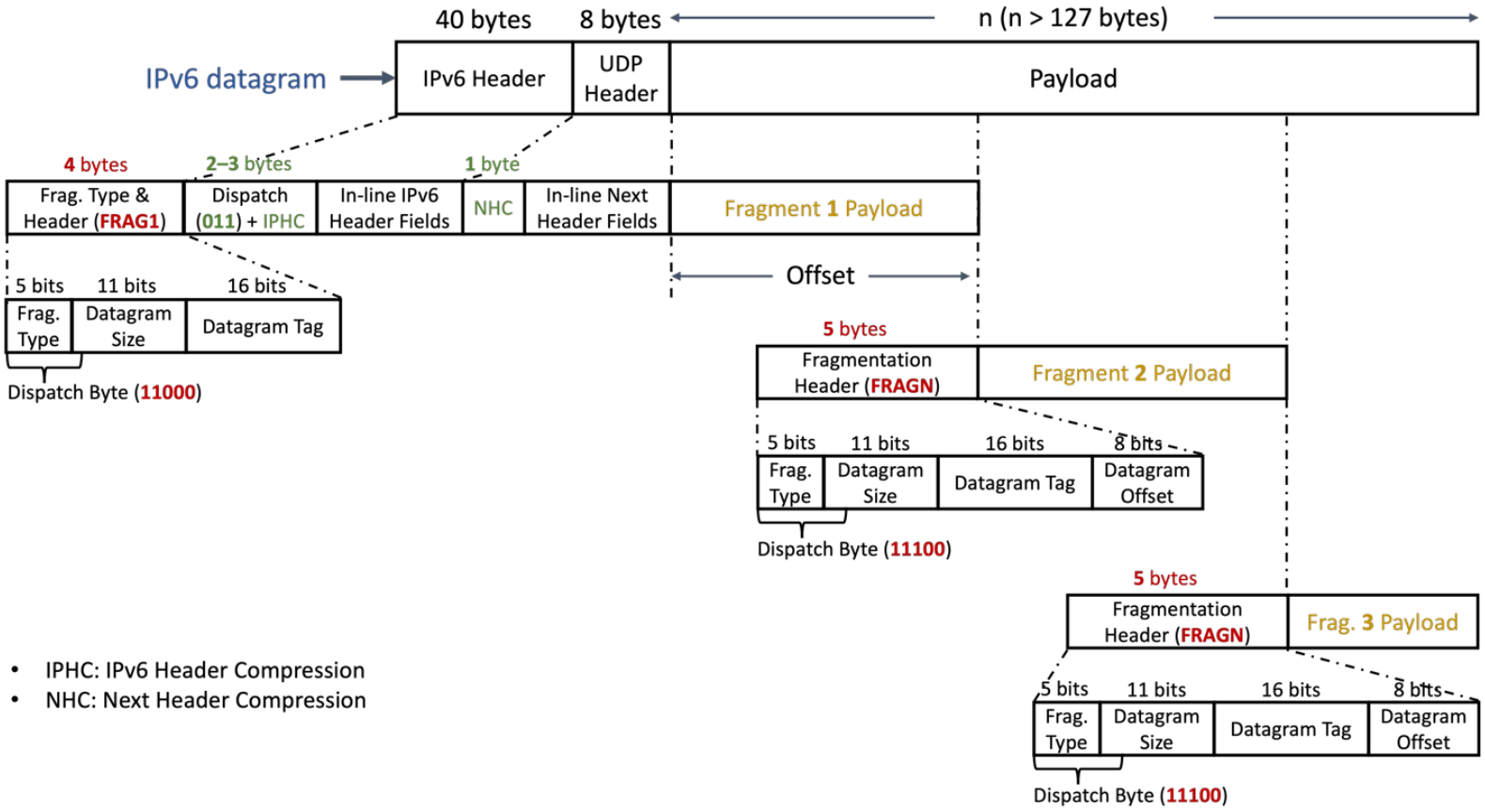
- Assume common values for header fields and define compact forms.
  - Ports within 61616 to 61632 (4 bits).
  - Length can be derived from IPv6 header Length information.
  - Checksum always carried in-line (RFC 4944) or **elided** (RFC 6282).

- C (1 bit), the field represents the Checksum:
  - 0: the Checksum is not compressed, and all its 16 bits are carried in-line.
  - 1: the Checksum is elided.
- P (2 bits), the two bits field represents the Ports:
  - 0 → in-line
  - 1 → elide first 8 bits of Destination Port
  - 2 → elide first 8 bits of Source Port
  - 3 → elide 12 bits of Source and Destination Ports



UDP Header Encoding

Compression and Fragmentation Overview



- IPHC: IPv6 Header Compression
- NHC: Next Header Compression

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6LoWPAN Adaptation Layer:
The Compression Operation

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