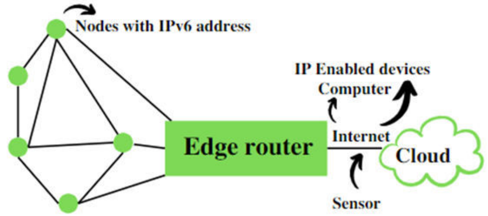
Recent Protocols for IoT

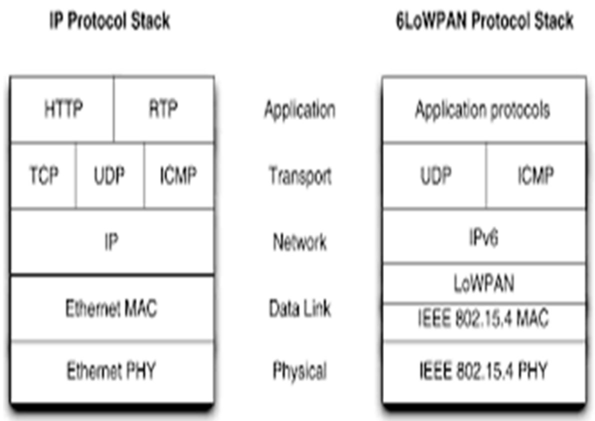
Session	MQTT, SMQTT, CoRE, DDS, AMQP , XMPP, CoAP, IEC, IEEE 1888, …
Network	Encapsulation: **6LowPAN**, 6TiSCH, 6Lo, Thread…
	Routing: **RPL**, CORPL, CARP
Datalink	Wi-Fi, Bluetooth Low Energy, Z-Wave, ZigBee Smart, DECT/ULE, 3G/LTE, NFC, **802.15.4** Weightless, HomePlug GP, 802.11ah, 802.15.4e, G.9959, WirelessHART, DASH7, ANT+, LTE-A, LoRaWAN, ISA100.11a, DigiMesh, WiMAX, …

Security
IEEE 1888.3, TCG, Oath 2.0, SMACK, SASL, EDSA, ace, DTLS, Dice, …

Management
IEEE 1905, IEEE 1451, IEEE 1377, IEEE P1828, IEEE P1856

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





IEEE 802.15.4

- Wireless Personal Area Network (WPAN)
- Allows mesh networking.
  Full function nodes can forward packets to other nodes.
- A PAN coordinator (like Wi-Fi Access Point) allows nodes to join the network.
- Nodes have 64-bit addresses
- Coordinator assigns 16-bit short address for use during the association
- Maximum frame size is 127 bytes

EUI64 Addresses

- **Ethernet addresses**: 48 bit MAC

Unicast Multicast	Universal Local	Organizationally Unique ID (OUI)	Manufacturer Assigned
1b	1b	22b	24b

- **IEEE 802.15.4 Addresses**: 64 bit Extended Unique Id (EUI)

Unicast Multicast	Universal Local	Organizationally Unique ID (OUI)	Manufacturer Assigned
1b	1b	22b	40b

- **Local bit** was incorrectly assigned. L=1 ⇒ Local
  but all-broadcast address = all 1's is not local
  IETF RFC4291 changed the meaning so that L=0 ⇒ Local
  The 2nd bit is now called Universal bit (U-bit)
  ⇒ U-bit formatted EUI64 addresses

- Does the Extended Unique ID function as the MAC address for 802.15.4 devices?

Yes. They do not use the 48-bit IEEE address.

- If the first bit is one and the second is one does it mean U G?

No.

0/1	0/1	
U/M	G/L	
0	0	Unicast, globally unique
0	1	Unicast, Local
1	0	Multicast, Globally unique
1	1	Multicast, Local

MAC Frame Format

Frame Control	Seq. #	Dest. PAN Id	Dest. Addr.	Src PAN Id	Src Addr.	Aux. Security Header	Payload	FCS
16b	8b	0/16b	0/16/64b	0/16b	0/16/64b	0/40/48/80/170b		16b

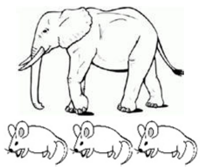
Frame Type	Security enabled	Frame Pending	Ack Reqd	PAN Id Compression	Rsvd	Dest. Addr. Mode	Frame version	Src. Addr. mode
3b	1b	1b	1b	1b	3b	2b	2b	2b

000	Beacon
001	Data
010	Ack
011	MAC Command
Other	Reserved

00	PAN Id and Addr not present
01	Reserved
10	16-bit short address
11	64-bit extended address

6LowPAN

- IPv6 over Low Power Wireless Personal Area Networks
- How to transmit IPv6 datagrams (elephants) over low power IoT devices (mice)?



- **Issues**:

1. **IPv6 address formation**: 128-bit IPv6 from 64-bit EUI64
2. **Maximum Transmission Unit** (MTU): IPv6 at least 1280 bytes vs. IEEE 802.15.4 standard packet size is 127 bytes

802.15.4 Header	Security Option	Payload
25B	21B	81B

3. **Address Resolution**: 128b or 16B IPv6 addresses. 802.15.4 devices use 64 bit or 16 bit addresses
4. **Optional mesh routing in datalink layer**

   $\Rightarrow$ Need destination and intermediate addresses.

Ref: G. Montenegro, et al., "Transmission of IPv6 Packets over IEEE 802.15.4 Networks," RFC 4944, Sep 2007, http://tools.ietf.org/pdf/rfc4944

- In the review question, what problem does 6LowPan address?

See 7 issues in this slide and next.

6LowPAN Adaptation Layer

5. **MAC-level retransmissions versus end-to-end**:
   - Optional hop-by-hop ack feature of 802.15.4 is used but the max number of retransmissions is kept low (to avoid overlapping L2 and L4 retransmissions)
6. **Extension Headers**: 8b $\Rightarrow$ header type

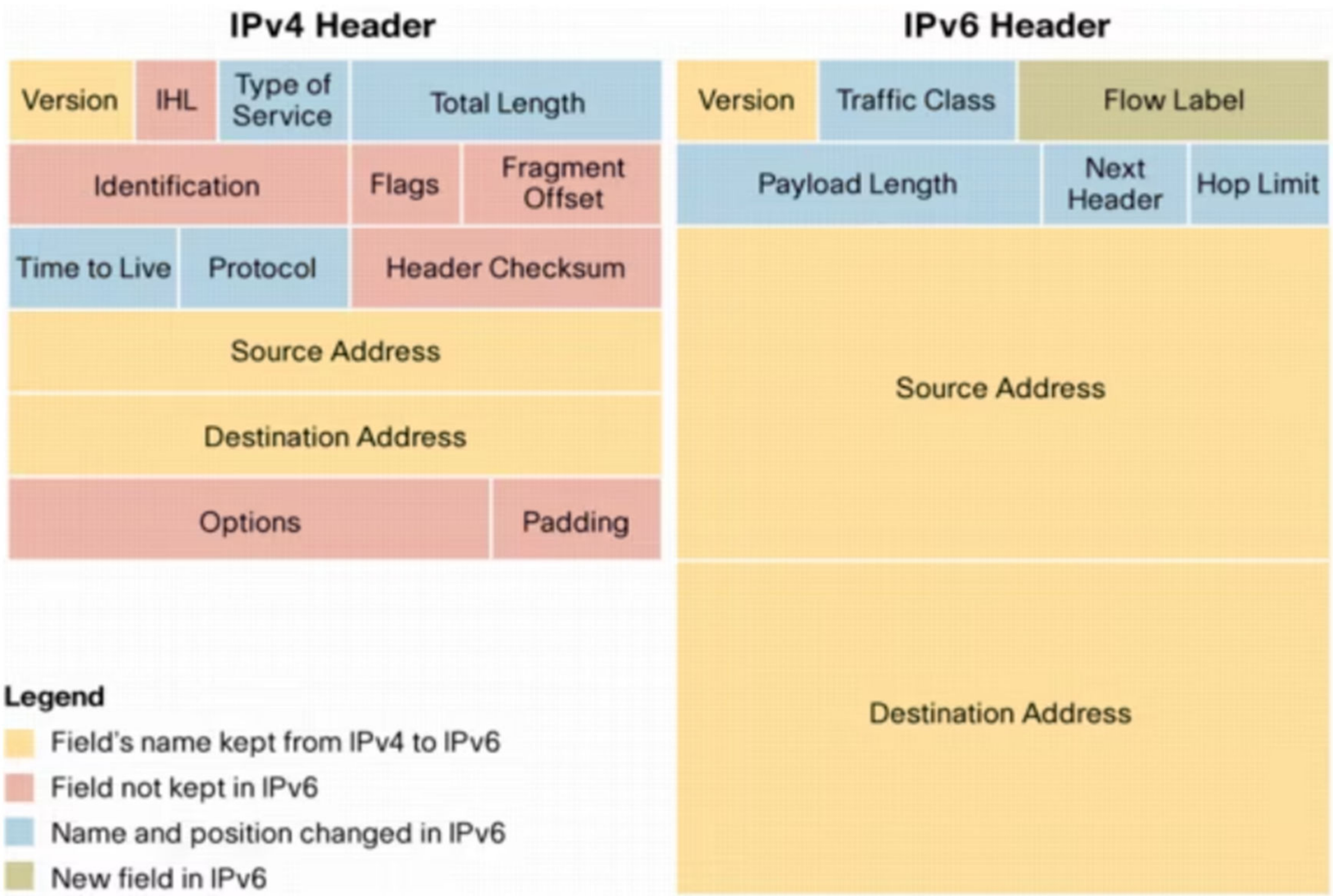
7. **IPv6 and UDP header compression**

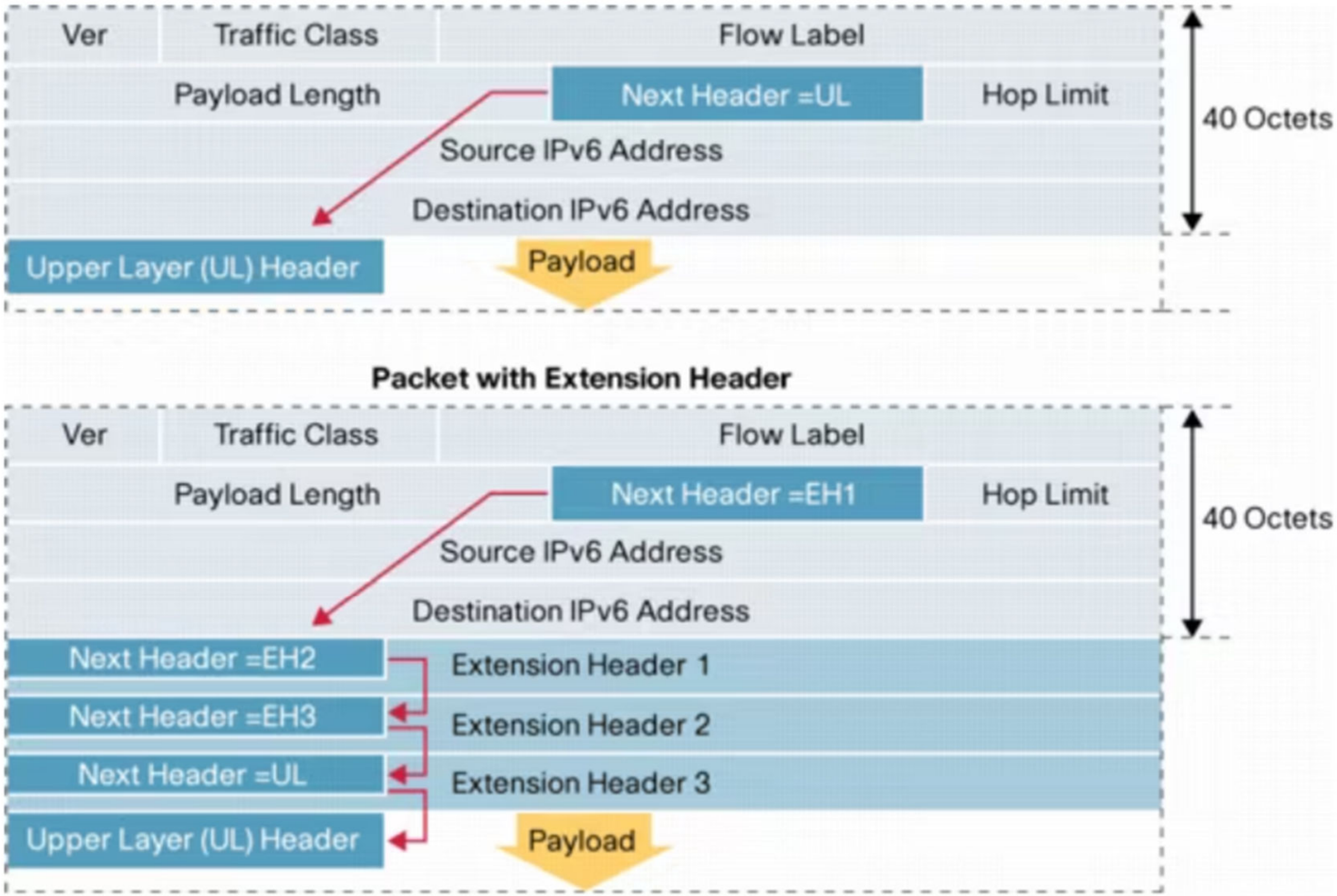
Frame Control	Seq. #	Adrs	[Security]	**Disp bits**	Ext Hdr	Disp bits	Ext Hdr	Disp bits	Ext Hdr	IPv6 Payload
2B	1B	0-20B	0-21B	6LowPAN						

Receiver/Transmitter addresses

6LowPAN

Ref: O. Hersent, et al., “The Internet of Things: Key Applications and Protocols,” Wiley, 2013, 344 pp., ISBN: 9781119994350 (Safari Book)


IPv4 Header
Version
IHL
Type of Service
Total Length
Identification
Flags
Fragment Offset
Time to Live
Protocol
Header Checksum
Source Address
Destination Address
Options
Padding
IPv6 Header
Version
Traffic Class
Flow Label
Payload Length
Next Header
Hop Limit
Source Address
Destination Address
Legend
Field's name kept from IPv4 to IPv6
Field not kept in IPv6
Name and position changed in IPv6
New field in IPv6



Ver
Traffic Class
Flow Label
Payload Length
Next Header =UL
Hop Limit
Source IPv6 Address
Destination IPv6 Address
40 Octets
Upper Layer (UL) Header
Payload
Packet with Extension Header
Ver
Traffic Class
Flow Label
Payload Length
Next Header =EH1
Hop Limit
Source IPv6 Address
Destination IPv6 Address
40 Octets
Next Header =EH2
Extension Header 1
Next Header =EH3
Extension Header 2
Next Header =UL
Extension Header 3
Upper Layer (UL) Header
Payload

RFC2460 defines the extension headers as shown in the following table along with the Next Header values assigne

Table 1. IPv6 Extension Headers and their Recommended Order in a Packet

Order	Header Type	Next Header Code
1	**Basic IPv6 Header**	-
2	**Hop-by-Hop Options**	0
3	**Destination Options (with Routing Options)**	60
4	**Routing Header**	43
5	**Fragment Header**	44
6	**Authentication Header**	51
7	**Encapsulation Security Payload Header**	50
8	**Destination Options**	60
9	**Mobility Header**	135
	No next header	59
Upper Layer	TCP	6
Upper Layer	UDP	17
Upper Layer	ICMPv6	58

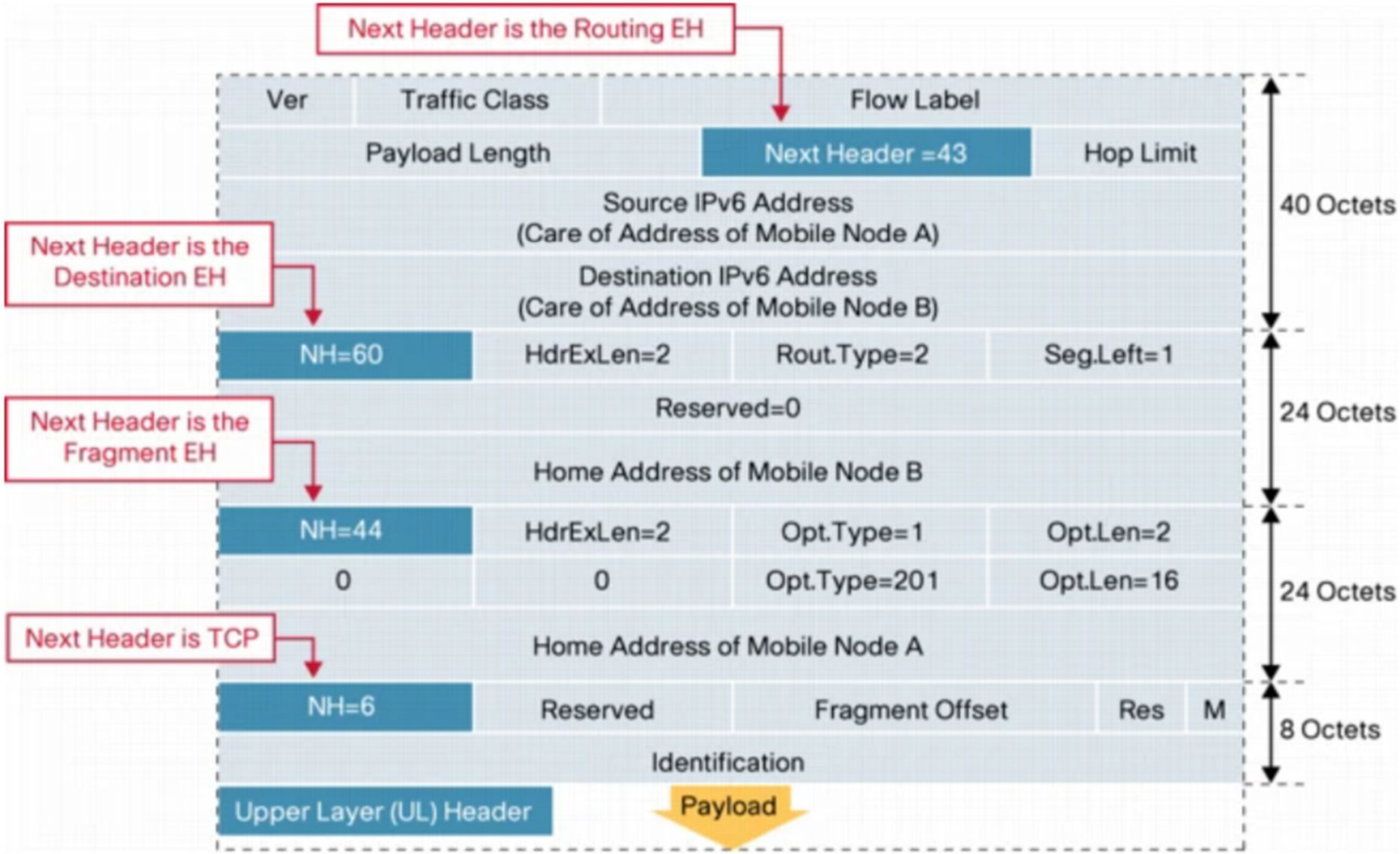
RFC2460 also recommends the order in which they should be chained in an IPv6 packet:

RFC2460 also recommends the order in which they should be chained in an IPv6 packet:

1. **IPv6 main header**
2. **Hop-by-Hop Options header (if present, it MUST be the first one following the main/regular header)**
3. **Destination Options header**
4. **Routing header**
5. **Fragment header**
6. **Authentication header**
7. **Encapsulating Security Payload header**
8. **Destination Options header**
9. **Upper-layer header**

The only **MUST** requirement is that the Hop-by-Hop EH has to be the first one.

Figure 3. Data Traffic Between Two Mobile Nodes over the Route Optimized Path



Frame Control	Seq. #	Adrs	[Security]	**Disp bits**	Ext Hdr	Disp bits	Ext Hdr	Disp bits	Ext Hdr	IPv6 Payload

Types of Dispatch Bits in 6LoWPAN

(A) IPv6 Header Compression Dispatch (IPHC)

•**Disp Bits:** 01

Used for **IPv6 Header Compression** (RFC 6282).

Reduces the **40-byte IPv6 header** to **as small as 2 bytes**.

(B) Mesh Header Dispatch

•**Disp Bits:** 10

Used for **mesh routing in multi-hop networks**.

Helps forward packets in **multi-hop topologies**.

(C) Fragmentation Header Dispatch

•**Disp Bits:** 11

Used when an **IPv6 packet is too large** for a single IEEE 802.15.4 frame.

The packet is split into **multiple fragments**, each with a **fragmentation header**.

(D) LoWPAN Broadcast Dispatch

Disp Bits: 00

Used for **broadcast transmission** to multiple nodes in the network.

Without compression:

IPv6 Header: 40 bytes
UDP Header: 8 bytes
Payload: 10 bytes
Total: 58 bytes

IPv6 Header: 3 bytes
UDP Header: 4 bytes
Payload: 10 bytes
Total: 17 bytes (71% reduction)

The **primary compression algorithm in 6LoWPAN is IPHC (RFC 6282)**, which works alongside **UDP compression** and **fragmentation techniques** to make **IPv6 and UDP headers lightweight**. **ROHC is sometimes used** for further optimization in specific applications like VoIP.

Algorithm	Purpose	Compression Level	Typical Use Case
IPHC	IPv6 Header Compression	High	IoT, Sensor Networks
LOWPAN_UDP	UDP Header Compression	Moderate	CoAP, MQTT, LoRaWAN
LOWPAN_FRAG	Fragmentation	Low	Large IPv6 Packets
ROHC	Full Header Compression	Very High	VoIP, Multimedia

IPv6 Address Formation

- **Link-Local IPv6 address** = FE80::U-bit formatted EUI64
- **Example**:
  - EUI64 Local Address = 40::1 = 0100 0000::0000 0001
  - U-bit formatted EUI64 = 0::1
  - IPv6 Link-local address = FE80::1 = 1111 1110 1000 0000::1
- IEEE 802.15.4 allows nodes to have 16-bit **short addresses** and each PAN has a 16-bit **PAN ID**.
  1st bit of Short address and PAN ID is Unicast/Multicast
  The 2nd bit of Short Address and PAN ID is Local/Universal.
  You can broadcast to all members of a PAN or to all PANs.
- IPv6 Link Local Address = FE80 :: PAN ID : Short Address
  Use 0 if PAN ID is unknown.
  2nd bit of PAN ID should always be zero since it is always local.
  2nd most significant = 6th bit from right)

Student Questions

- In the IPv6 Link Local Address, it says Use 0 if PAN ID is unknown. Does this mean all 128 bits are 0?
- Also can you go over the 2nd most significant bit = 6th bit from the right again?

Homework 14A

- What is the IPv6 Link-Local address for a IEEE 802.15.4 node whose EUI64 address in hex is 0000::0002. Indicate your final answer in hex without using ::
- EUI64 in Binary =
- U-bit EUI64 Binary =
- U-bit EUI64 Hex =
- IPv6 Link Local Address =